## WMT Pre-course Reading Bundle **(revised January 2020)**

Pre-course reading is not required but these papers will prime medics attending WMT course. Laypeople (on Explorer courses) may also find this information useful and accessible. This reading may count towards CPD and be a useful future point of reference.

**Introduction**
Faculty of Prehospital Care, Royal College of Surgeons Edinburgh guidance for medical provision for wilderness medicine

**Mountain Medicine**
Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Acute Altitude Illness: 2019 Update

The 2018 Lake Louise Acute Mountain Sickness Score

Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Frostbite: 2019 update

Retrospective study of 70 cases of severe frostbite lesions: a proposed new classification scheme. Wild Envir Med 12: 248-255

Wilderness Medical Society Clinical Practice Guidelines for the Out-of-Hospital Evaluation and Treatment of Accidental Hypothermia: 2019 Update

**Heat Illness**
Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Heat Illness: 2019 Update

**Drowning**
Wilderness Medical Society Clinical Practice Guidelines for the Treatment and Prevention of Drowning: 2019 Update

**Water Purification**
Wilderness Medical Society Clinical Practice Guidelines for Water Disinfection for Wilderness, International Travel, and Austere Situations

Mellor *et al. Extrem Physiol Med (2015) 4:22*
DOI 10.1186/s13728-015-0041-x

*Extreme Physiology & Medicine*

COMMENTARY

Open Access

# Faculty of Prehospital Care, Royal College of Surgeons Edinburgh guidance for medical provision for wilderness medicine

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**Abstract**

To support leaders and those involved in providing medical care on expeditions in wilderness environments, the Faculty of Pre-Hospital Care (FPHC) of The Royal College of Surgeons of Edinburgh convened an expert panel of leading healthcare professionals and expedition providers. The aims of this panel were to: (1) provide guidance to ensure the best possible medical care for patients within the geographical, logistical and human factor constraints of an expedition environment. (2) Give aspiring and established expedition medics a 'benchmark' of skills they should meet. (3) Facilitate expedition organisers in selecting the most appropriate medical cover and provider for their planned activity. A system of medical planning is suggested to enable expedition leaders to identify the potential medical risks and their mitigation. It was recognised that the scope of practice for wilderness medicine covers elements of primary healthcare, pre-hospital emergency medicine and preventative medicine. Some unique competencies were also identified. Further to this, the panel recommends the use of a matrix and advisory expedition medic competencies relating to the remoteness and medical threat of the expedition. This advice is aimed at all levels of expedition medic, leader and organiser who may be responsible for delivering or managing the delivery of remote medical care for participants. The expedition medic should be someone equipped with the appropriate medical competencies, scope of practice and capabilities in the expedition environment and need not necessarily be a qualified doctor. *In addition to providing guidance regarding the clinical competencies required of the expedition medic*, the document provides generic guidance and signposting to the more pertinent aspects of the role of expedition medic.

**Keywords:** Expedition, Risk assessment, Medical planning, Wilderness medicine, Austere environment

## Background

The Oxford English dictionary defines an expedition as "a journey undertaken by a group of people with a particular purpose". This definition highlights the broad scope of expeditions and de facto, expedition medical planning. Medical care provided in an austere environment is often referred to as "wilderness medicine". This was described by Backer and was defined by its remoteness, physiology, need for improvisation and dependence upon clinical examination and judgement [1]. The scope of this guidance is intended to cover the planning and competencies that facilitate the understanding of the challenges described by Backer and therefore the delivery of good quality clinical care.

The practice of wilderness medicine occurs in many environments and this document is not intended to provide specific advice to specialist expeditions (e.g. deep cave exploration or pioneering extreme new routes in the mountains). The concept of competencies in pre-hospital care has previously been described [2] and *competent individuals are those deemed* to have the "ability to apply knowledge, understanding and skills" to perform to an accepted standard. The competencies discussed consider

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pre-hospital and primary care skills relevant to medical providers on expeditions in remote areas with some consideration of more specialist environments.

Death and serious injury or illness on expeditions is thankfully rare. Aside from extreme sports in the wilderness, the risks faced by participants on a well-planned expedition are equivalent to those faced by an active person living in the UK. For example, road traffic accidents cause approximately 50 % of unexpected deaths on expeditions per annum [3]. Anderson and Johnson [4] reviewed the data from 246 expeditions with 1263 medical problems (gastrointestinal disease 30 %, medical problems 21 %, orthopaedic problems 19 %, environmental problems 14 %) and a 10 % evacuation rate. More recent published data reviewed charity expeditions over a 5-year period provided by one company. Overall 1564 incidents were reported during 42,482 expedition days. 94 % of the incidents reported were minor and 1 % severe giving a risk of a severe injury or condition of 0.47 per 1000 participant days [5]. Even on potentially high threat expeditions to Denali in Alaska, medical incidents were rare with only 3.5 % of 24,079 climbers requesting medical assistance and only 15 % of these requiring evacuation by the National Park Service [6]. It is worth bearing such figures in mind when planning an expedition, and considering the relatively low prevalence of problems, whilst being mindful of the potentially higher impact should they occur. In addition to medical provision the expedition medic will be responsible for the dental health of participants as well as environmental health. Dental problems, in particular, present a potential burden to the expedition with one expedition reporting 50/309 (16.5 %) of expedition members suffering dental symptoms potentially treatable with a simple dental first aid kit [7].

This document not only provides guidance on the clinical competencies required of the expedition medic but also on other pertinent aspects of the role such as medical planning, risk management, human factors, clinical governance and medical kits.

## Methods

An initial meeting was convened by the FPHC. Members were invited based on their contribution to wilderness medicine in terms of research, teaching, military experience or were selected as representatives of UK-based expedition providers. It was identified that the competencies required for wilderness medicine were wide ranging and evidence for what skills and interventions are required was lacking. For this reason, the panel elected to use the existing FPHC competency framework and adapted it (based on expert opinion) for wilderness medicine use. Members of the panel were then selected to undertake literature reviews and to author specific parts of this consensus document.

The key drivers to any medical plan are:

1. The degree of remoteness of the potential incident.
2. The medical threat—the likelihood of a medical incident occurring.

Remoteness was considered as the time taken to *access* advanced medical care defined in varying ways depending on the injury or illness. For the purposes of this document, it is a facility where a doctor, basic diagnostics, pharmacy, etc., are available and the injury or illness can be managed in a timely and definitive manner. It is accepted that this definition is flexible, as definitive care could potentially be delivered within a well-equipped and appropriately staffed expedition setup and is dependent on the presenting condition.

For the purposes of discussing the required medical competencies, three measures of remoteness from advanced medical care were considered:

1. Time 1: less than 4 h away.
2. Time 2: 4–12 h away.
3. Time 3: more than 12 h away.

These timelines were considered alongside the levels of medical threat that take into account the demographics of the group, the location and the planned activity.

1. Low—such as young, fit group trekking in foothills of Atlas Mountains, Morocco.
2. Medium—such as vehicle borne overland expedition across Eastern Africa with diverse middle aged group.
3. High—such as a ski mountaineering in remote area of Greenland or a medically unscreened group doing charity trek up Mt Kilimanjaro.

Using this model, two main assumptions were made, firsty that time is based on typical estimated travelling time, e.g. summer rather than winter and not worse case. However, planning should take into account a range of travel time most likely to be encountered. Secondly, specific competencies will be dictated by environment (cold, high, hot or any unusual endemic diseases identified by the medical plan).

Priorities for care and evacuation, and therefore competencies for each, could then be agreed upon and are summarised as;

- Less than 4 h: emergency field care.
- 4–12 h: commence definitive treatment in the field.
- 12 h plus: prolonged field care.

A suggested level of expedition medic could then be made considering the medical threat and remoteness (Fig. 1). Levels of healthcare provider have previously been established by the FPHC [8].

In summary, these equate to:

- Level D—a non-health care professional with a nationally recognised first aid certificate, caring for patients as a secondary role (such as an expedition leader).
- Level G—a registered healthcare professional working in the expedition environment (such as a junior doctor, nurse or paramedic).
- Level H—an advanced wilderness medicine practitioner (such as a senior doctor with expedition experience).

Once the level of expedition medic has been decided, the competency framework at "Appendix 1" should be used in conjunction with an expedition risk assessment. The competency framework covers most types of expedition—clearly, if the proposed itinerary does not include altitude or diving exposure then those specific competencies will not be required of the expedition medic.

Furthermore, it was recognised by the panel that additional personal skills and attributes may influence who is selected to be the expedition medic. Some of these are discussed within this document.

## Medical planning

The expedition medical plan depends on a fundamental understanding of the risks which are specific to each expedition. Risk assessments are often based on personal experience (or lack of it) and anecdote.

Iserson [9] identified 10 key stages in planning for an extended expedition in a remote location;

1. Optimise workers' fitness.
2. Anticipate treatable problems.
3. Stock appropriate medications.
4. Provide appropriate equipment.
5. Provide adequate logistical support.
6. Provide adequate medical communications.
7. Know the environmental limitations on patient access and evacuation.
8. Use qualified providers.
9. Arrange knowledgeable and timely consultations.
10. Establish and distribute rationale administrative rules.

An additional key planning stage not included in this original list is knowledge of the planned destination and prevention of illness and problems associated with this area, e.g. malaria, snake envenomation.

All this should be put in place before an expedition leaves to mitigate risk. However, there has to be an acceptance that the provision of medical care in a remote location is inherently challenging and likely to be lacking if measured against what would be available in a developed world healthcare setting.

Understanding the expedition population's medical needs is fundamental. The support for an expedition of extremely fit experienced mountaineers will be different to that for a charitable trek following similar terrain. Published data can inform estimates of the frequency of likely illnesses, such as altitude illness [4, 10, 11]. Medication and equipment scales can then be decided upon. Providing adequate equipment for unlikely events but with serious consequences is more difficult. Unfortunately, the reality of medicine in remote areas is that severe illness and injury is often non-survivable. In Snowdonia, North Wales, a retrospective data set of 1100 cases brought to the emergency department concluded "there is little or no scope to save any additional lives from trauma in the mountains of Snowdonia" [11].

Communications, logistical support and evacuation routes are all crucial to medical planning. These factors need to be considered along with the nature of the activity to decide on the medical skills required of the provider. With the improvements in global communications and ability to send images, worldwide expert support for management of conditions such as frostbite can be accessed from remote locations. Such links should be established and tested before an expedition leaves as part of the medical plan where possible.

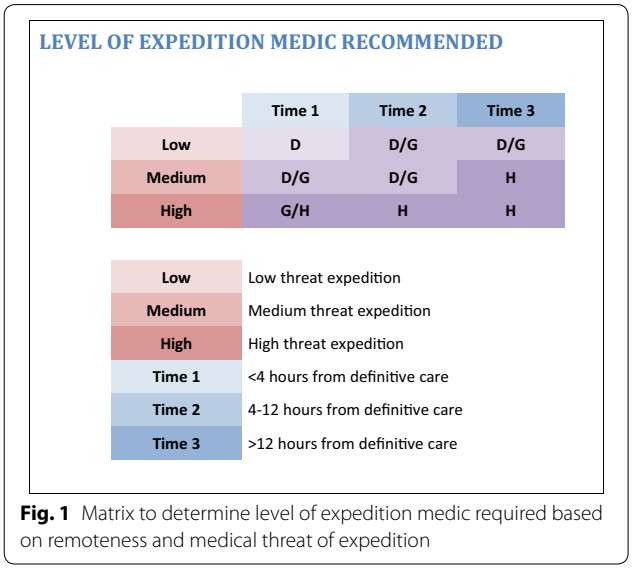


**Fig. 1** Matrix to determine level of expedition medic required based on remoteness and medical threat of expedition

Consideration should be given to medical plans in the absence of the lead expedition medic, i.e. small groups operating from one base location or climbers split across different camps. Diagnostic algorithms for likely conditions such as heat illness or altitude sickness can be placed with medical kits as well as protocols for administration of emergency medication. The lead expedition medic will often be able to communicate emergency medical advice over radio or satellite phone to remote teams, however, algorithms should be robust enough for independent use in emergent situations. The role of expedition medic will include briefing these teams in usage of emergency medical treatments. There is no suggested guidance on the ratio of medics to participants required on an expedition but should be considered on a case-by-case basis in the planning phase.

Medical planning relies on the ability to assess the likelihood of adverse medical events. This is dependent on published data to detect the underlying rate of injury such as discussed above. It is therefore important that, wherever practicable, the incidence of medical problems during expeditions are well recorded and accessible. This is now facilitated by a range of open access journals or online resources.

The purpose of this guideline is to inform best practice and inform expedition planning. It does not seek to provide a mandated framework beyond which none should go. It is accepted that the degree to which the guidelines are implemented may legitimately vary with the nature of the expedition.

## Clinical governance in wilderness medicine

Clinical governance is the framework used to maintain and improve standards of medical care, in which 'organisations are accountable for continuously improving the quality of their services and safeguarding high standards of care…' [12].

There are several domains to clinical governance that all have a part to play in an expedition setting:

- Risk management.
- Continuing professional development.
- Evidence based and effective clinical care.
- Audit.
- Patient satisfaction.

These features remain applicable during the pre-expedition, expedition, and post-expedition phases and should not be viewed as optional simply because a practitioner is working outside the health system of the UK. Participants in an expedition should have care provided by someone working within an appropriate scope of practice.

Responsibility for clinical governance rests with both the expedition medic and the expedition organisers. For instance, the organisation must ensure that it carefully selects the expedition medic, that it provides them with timely and accurate information about the participants and the nature of the expedition and that it encourages a culture of openness through the sharing of [medical] risk assessments and post-expedition [medical] reports. The expedition medic is responsible for maintaining their own personal and medical competencies, for precise and robust documentation and for the safe usage and maintenance of medical kit and equipment. Both are responsible for reporting identified problems of any nature and recording these in such a way that incidents can be learned from and mitigated against in the future. Clinical audit should be encouraged.

It is good practice to have a contract between the expedition medic and organisation. An example of such is the UIAA's Model Contract for Health Care on Trekking and Expeditions [13].

Other factors that the expedition medic and expedition organisers should agree on are listed:

- Provision of medical kit and supply/resupply.
- Work place and distant supervision of expedition medics.
- Responsibility for arranging the provision of specialist medical advice.
- Security and ownership of confidential medical information.
- Responsibility for development and use of Medical Standard Operating Procedures.
- Standardised medical record keeping.

*The liability for providing adequate medical care for all expedition members ultimately lies with the expedition organisers.* In addition, all Level G and H practitioners should discuss any proposed expedition with their professional indemnifiers.

## Risk management

Pre-emptive risk management is essential for managing safety while on expeditions. An understanding of the terms used in risk management is needed to manage risk appropriately.

A threat is something that can cause harm. This may be harm to an individual, to property or to the expedition itself. For example malaria may constitute a threat to an individual, theft is a risk to property and a hurricane may represent a threat to all three. The result of the threat is the consequence of that occurrence.

Likelihood: This is the chance of a threat occurring. For example, acute mountain sickness (AMS) is a threat to

which climbers in Scotland will not be exposed. However, for the Himalayan mountaineer, AMS is a threat to which he or she is vulnerable.

The likelihood multiplied by the consequences gives an index of the threat [14]. The assessment of the threat must take place within the context of the expedition. With this context comes the important concept of residual risk. Residual risk describes the risks that remain despite mitigation attempts. For example, while driving a car, a driver may mitigate the risks of crashing by ensuring the car is roadworthy, not driving at night and not exceeding the speed limit. However, the threat of error by another driver causing an accident is difficult to mitigate. This is known as a residual risk.

Once a threat has been assessed and is deemed to be above the threshold of risk for an expedition steps may be taken to reduce the impact of the threat. There are three main ways to mitigate risk:

1. Remove or diminish the threat.
2. Reduce the exposure to the threat.
3. Take measures to reduce the impact of the threat.

For example, an expedition to the Honduran jungle may consider the threat of envenomation by snakebite. The threat may be diminished by ensuring everyone on the expedition wears boots. The exposure to the threat can be reduced by running a teaching session about the snake habitat and how to avoid coming into contact with snakes. The impact could be reduced by ensuring timely evacuation is available to a facility where appropriate care is available. These measures may change an unacceptable risk into a risk accepted by the expedition.

Risk assessment should be carried out at three levels; generic risk assessment for the activity, a daily risk assessment documented for the activity and local conditions and then dynamic risk assessment during the course of the activity.

Incidents that cause harm should be documented, as should 'near misses'. This will aid future expeditions in building an evidence base of hazards and mitigation strategies. Expedition providers have a legal responsibility for the safety of both paying clients (under Package Travel Regulations 1992) and staff, including any locally employed *staff* (Employer's Liability). Thorough risk assessment is key to providing both physical and legal protection for both staff and clients.

## Medical threats and mitigation

Expeditions to remote areas are, by their very nature, complex and normal medical risk assumptions and mitigation may not apply.

The experiential evidence backed up by limited published evidence suggest serious incidents on expeditions are unusual [3–6]. Most medical conditions or injuries seen during expeditions can be managed by a competent expedition medic with basic skills. However, incidents in the wilderness environment are compounded by a number of factors;

- The incident occurs in a different location to the expedition medic.
- The casualty may be travelling alone (e.g. between camps in a jungle or on a mountain).
- The casualty may not have the means, capacity or capability to identify their location.
- The casualty may not have the means, capacity or capability to communicate and request help.
- Bad weather/night/visibility/poor communications may hinder the realisation that someone is missing, that a medical incident has occurred and therefore delay any response.

Good medical screening can reduce, but not eliminate, the medical risks to an expedition and should be an essential part of any medical planning. Consideration should be given to who has access to this medically confidential information and whether a certificate and disclosure from the participants' medical practitioner may be required. In addition to screening, education as to the likely hazards is a key part of reducing the medical risks on an expedition. It should be borne in mind that participants often fail to disclose key medical information and this only comes to light once the expedition starts. Participants should be medically risk assessed again if new information becomes available.

On many expeditions it may be impossible, impractical or unreasonable (as it would fundamentally change the character of the expedition) to provide the highest level of medical care and participants should be sufficiently well informed to accept this risk. Suitable planning and development of guidelines and protocols for management of likely hazards is an important part of medical planning and may remove the need for a medical professional on an expedition.

## Human factors

Human factors refer to the non-clinical aspects of wilderness medicine. It is important to recognise that the role of the expedition medic goes beyond the simple provision of medical care. They often form part of the leadership team, with all the associated responsibilities that this entails.

In the best case, the expedition medic is an independent experienced professional who puts the health and

safety of the participants above the objectives of the expedition. For every trip, the expectations and requirements of the expedition medic, from the participants, expedition leaders and the organisers will be subtly different. On occasions, they may even be a source of conflict.

Therefore, the expedition medic does not merely require appropriate clinical skills to deliver care in a wilderness setting but should have the personal skills to work within a team and the technical skills to be able to live comfortably in that environment. A deficiency in any part of the clinical–personal–technical triad will render the expedition medic less effective.

#### Personal skills

Personal/interpersonal skills do not always come naturally yet are a vital part of being a functioning, respected team member. The manner in which one employs these 'soft' skills will vary depending on the expedition. For example, interaction with a group of ultra-marathon athletes will differ considerably from an inexperienced charity clientele group. The following areas should be considered:

- Communication skills and self-awareness.
- Teamwork.
- Leadership.
- Decision making.
- Coping with fatigue and stress.

The ability to communicate and interact successfully with a team whilst living alongside them is incredibly important, particularly when fostering therapeutic relationships. The expedition medic must be aware of subtle differences in 'sense of humour', the need for compassion even with the trivial and regularly reflect on the need to adapt. Instructions or advice should be clear and unambiguous for those to whom they are directed. The expedition medic will often spend the majority of their time as an equal team colleague and friend. It is important to ensure boundaries are well defined and it is clear to participants when there is a swap to the "medic role".

Leadership styles vary greatly. The expedition medic should be capable of adapting their leadership skills to the needs and requirements of the group. Clear demarcation of roles, responsibilities and decision-making frameworks should be clarified before departure thus minimising the potential for conflict during times of increased stress. Both expedition leader and medic require clarity of jurisdiction, not only during a medical incident/s, but also in a situation where failure to intervene pre-emptively may result in harm.

Decision making on expedition carries with it far more responsibility than purely arriving at a treatable diagnosis. The decisions made will have consequences varying from temporary cessation of activities to permanent casualty evacuation, with all the associated logistical, financial and emotional implications.

The demands placed on the expedition medic have the potential to exceed any other expedition participant. Expedition medics should be prepared to carry out a full day's expedition activities and then face the possibility of providing the full range of expedition healthcare, irrespective of the time of day or night, including a complex casualty evacuation. Mental resilience and physical fitness are important, as stressors on expedition are many and varied. They include clinical pressures associated with independent/autonomous decision making, stressors of living in a close-knit community or the difficulties of just living and surviving in uncomfortable surroundings with reduced communication with home.

#### Expedition skills

The expedition medic will need a range of skills specific to the expedition objectives. These skills are beyond the scope of this document.

Real-life examples of the impact of personal or expedition skill deficiencies can be found at "Appendix 2".

### Medical kit

Designing and gathering a fit-for-purpose medical kit is frequently overlooked by expedition planners but it is a multifaceted and time-consuming job. It must be clear whose responsibility it will be to provide and pay for medical kit and it must be checked regularly for acceptable quality, including for damage, stock level and out-of-date contents. Meticulous labelling, organisation of the kit and a contents spreadsheet are of paramount importance.

The expedition medic must have knowledge of the indications and side effects of each medication carried, this will depend on the level of medical provider, but any provider must be competent dispensing or administering those medications and be familiar with the identification and timely treatment of any complications occurring. All expedition medics should have access to reference material in this regard. For example, the British National Formulary (BNF) is available electronically as an App.

Medical kits should be bespoke to the expedition in question. Their composition will vary based on team composition, demographics and number of participants as well as destination and the duration of the trip. Kits should reflect the likely illness and injury patterns of the planned activities and to some extent, the level and skills of the expedition medic. Published surveys suggest that first responder medical kits tend to be well equipped to support trauma but less well equipped for medical

emergencies [15]. It should also be remembered that the majority of medical presentations on expeditions are not high-level trauma or medical emergencies and medical kits should reflect this by including medications and equipment for treating simple illness and injuries.

Comprehensive advice on provision of medical kits is beyond the scope of this publication. Broad areas for consideration are listed below.

1. A medical kit should be dictated by the medical plan and wilderness environment.
2. Medications (unlike dressings) cannot be improvised and expeditions need to have adequate supplies of trustworthy medications.
3. Import and export restrictions for medications vary between countries.
4. Medications that have a variety of uses should be taken.
5. Practitioners should be aware of expedition members with drug allergies or on regular medications and be aware of any interactions these may have.
6. Group medical kits should be appropriately and securely stored.
7. Ensure adequate means of diluting and administering drugs are available.
8. Individuals should have a personal first aid kit on their person at all times.
9. If travelling in areas with high incidence of HIV or hepatitis consider carrying sterile needles, etc.

These points are expanded in "Appendix 3".

## Cardiopulmonary resuscitation in the wilderness environment

The decision whether to attempt resuscitation or not in the event of cardio-respiratory arrest in the wilderness is a complex one and requires a pragmatic and realistic decision-making process. Resuscitation efforts and extrication may take place in hazardous terrain and in extreme meteorological conditions. Additionally, resources may be very limited, and there may be multiple casualties amongst who these resources must be shared. Multiple casualty emergencies may fit the definition criteria for a major incident and appropriate Major Incident Medical Management systems may need to be applied in a wilderness setting to effectively utilise available resources.

In 2012, Paal et al. [16] published a position paper to establish scientifically supported guidelines under which cardiopulmonary resuscitation (CPR) could be terminated during mountain rescue. This guidance was subsequently adopted as a formal recommendation by the International Commission for Alpine Rescue (ICAR/CISA) and it is applicable both to medical and non-medical personnel.

As the same principles apply both to organised rescue in the mountains and to wilderness expeditions in terms of decision-making algorithms. The aim of these guidelines is to reduce unnecessary CPR, diminish risk to expedition members or rescuers, apportion limited human and material resources effectively and to identify special circumstances where extended CPR may be indicated.

These circumstances permit the termination of CPR in a patient with unwitnessed loss of vital signs in the wilderness:

1. No return of spontaneous circulation during 20 min of CPR.

AND

2. No special circumstance (see below) warranting extended CPR.

AND

3. When professional medical support is available, either that no shock is advised by an Automated External Defibrillator (AED) at any time, or that only asystole is observed by electrocardiogram (ECG) monitoring.

Special circumstances are hypothermia, lightning strike and submersion (drowning). With these, prolonged CPR may be associated with a good neurological outcome and functional recovery.

## Conclusion

The role of an expedition medic can fall to either medically qualified professionals or to others providing medical care in addition to their primary duty. It is important to recognise that the role of expedition medic is multifaceted and requires an extensive skill set in addition to suitable underpinning medical knowledge and skills. Expedition medical planning should enable all these aspects to be considered so that appropriate personnel are selected and medical threats recognised and mitigated against.

## Additional file

**Additional file 1.** Expedition medic competencies.

**Abbreviations**
AED: automated external defibrillator; AMS: acute mountain sickness; BNF: British National Formulary; CPR: cardiopulmonary resuscitation; ECG: electrocardiogram; FPHC: Faculty of prehospital care of the Royal College of Surgeons of Edinburgh; ICAR: International Commission for Alpine Rescue; UIAA: International Climbing and Mountaineering Federation (Union International des Associations d'Alpinisme).

**Authors' contributions**
All authors contributed to the FPHC working group in expedition medical capability and contributed to the manuscript. JH chaired the working group, ND collated authors' initial drafts, AM and HP drafted the final manuscript and AM, HP, JH, ND edited the final version of the manuscript. RJ, MW, TH-W, JR drafted the human factors, threats and medical planning sections, NH and DL drafted the personal skills section, BL contributed to the dental and medical kit sections, ND, JH, SD, DH, EH, SH, DL and NH drafted the competency matrix, PD drafted the section on CPR. All listed authors reviewed and revised the final version of the manuscript. All authors read and approved the final manuscript.

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**Competing interests**
A number of the authors have affiliations to commercial medical training providers but none view this as a conflict of interest in contributing to these guidelines.

## Appendix 1

The FPHC competencies are available as an additional file please see Additional file 1.

## Appendix 2

This appendix includes examples of where the expedition medic without the appropriate personal or expedition skills could potentially put themselves and others at risk. These examples are based on the real-life experiences of those on the panel.

1. The expedition medic has never been to altitude and therefore has a lack of environmental experience. As a result is unable to cope with working at altitude and is less effective in providing medical care. Eventually falls prey to altitude illness and has to be evacuated to definitive medical care. The group is left without the originally intended medical care.
2. Expedition medic is required to independently arrive at a casualty in a remote environment. The expedition medic is not competent in navigating and fails to arrive at the casualty. The expedition medic potentially becomes a lost person and requires additional resources to mount a search and rescue effort.
3. Expedition medic lacks situational awareness and as a result becomes targeted by assailants at a market place in a foreign country. They are attacked and robbed of possessions. The expedition medic is psychologically affected for the duration of the expedition and is less effective in providing care with potential long-term health implications.
4. Expedition medic does not have experience in camp craft and lacks necessary personal admin skills. The expedition medic is late each morning in properly organising own equipment. As a result is not ready when the rest of group is ready and either the expedition is delayed or the group is left without the intended medical care until later.
5. A commercial television production taking expedition naive individuals to a hostile environment and filming the outcome. Production aims are to stress individuals physically, socially and mentally whilst filming results. Production company staff have limited understanding of both risk and consequence of harm in the expedition environment and as such encourage risky activities. Intervention by the expedition medic to mitigate risk is frowned upon as this reduces 'story potential'. These issues will be predicted by experienced expedition medics and mitigated for.
6. Expedition medic is required to treat a casualty on more technical terrain. Expedition medic does not have sufficient technical skills such as appropriate rope work to move competently over technical terrain. They become stranded as a result and require rescuing.
7. A production company wish to film a sequence where a presenter is attempting to recover a vehicle trapped in soft sand. Expedition porters are placing rocks and sand ladders in front of spinning wheels whilst the presenter is positioned behind the vehicle at great risk of being hit by flying debris. An astute and experienced medic with identify a significant risk of injury to the presenter and intervene promptly.

The above examples can happen to anyone even with sound non-medical skills and experience in the wilderness environment. However, expedition medics that have the required operational capability reduce any risk.

## Appendix 3

This annex composes some of the lessons identified from the experience of the panel with regard to preparing an expedition medical kit.

1. Know your environment and adapt the team medical kit accordingly. For example, for tropical environments where the risk of infection is high, take broad spectrum antibiotics, a malarial detection kit (with high sensitivity) and stand-by treatment. For high altitude environments, include medications following the most recent guidance in the treatment of acute mountain sickness, high altitude pulmonary and cerebral oedema.
2. You cannot improvise medications. Dressings and splints can be improvised whereas medications cannot be. You cannot guarantee the quality of medications bought in many countries so whilst they may be easily available, they may not be as efficacious.
3. Know the import and export restrictions for countries. Know the Medicines Health and Regulatory Agency (MHRA) scheduling of different drugs and the restrictions that this imposes. Be aware of the restrictions imposed by other countries; for example, drugs such as codeine are robustly regulated in the Middle Eastern countries. The FCO website is a useful resource for more details of restrictions for individual countries.
4. Take medications with more than one use. For example, codeine has analgesic, antitussive and anti diarrhoeal properties so is extremely versatile. Antibiotics such as co-amoxiclav and azithromycin have broad spectrums of cover so can be used to treat a wide range of infection.
5. Beware of interactions between medicines in the medical kit. For example, ciprofloxacin and ibuprofen in combination can reduce the seizure threshold so make epileptics more prone to seize. Be aware what regular medications are being taken by group members and compile the group medical kit accordingly.
6. Choose the most appropriate container for the medical kit. Be aware that in a tropical environment, the medical kit will need to be stored in a damp proof, sealable container.
7. Ensure that all participants have their own personal medical kits containing basic medical supplies such as blister prevention and treatment, simple analgesia, dressings and a plentiful supply of their own regular medication.
8. Be aware that certain medications used for intramuscular injection have specific diluents. For example, ceftriaxone for intramuscular injection uses 1 % lignocaine for reconstitution and injection. This is particularly important for groups where the medic is not confident or unable to achieve intravenous cannulation.
9. If travelling to regions of the world with a high incidence of HIV, consider taking a set of sterile needles and cannulae in the event that a participant requires local hospital admission.
10. Remember that other issues not normally associated with developed world medicine will fall to the expedition medic. For example, issues with contact lenses and hearing aids. Contact lenses can be problematic on expedition. The risk of keratitis is greater in contact lens wearers. Ensure all participants that plan to wear contact lenses take their glasses in addition. Ensure that anyone with a hearing aid takes spare batteries and that you and they know how to change them. If participants travel with specific pieces of equipment to manage their condition, consider asking for a demonstration on usage before the trip, for example, an insulin pump. A plan for dealing with failure of equipment (e.g. insulin pump) should be in place.

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**References**

1. Backer H. What is wilderness medicine? Wilderness Env Med. 1995;6:3–10.
2. Clements R, Mackenzie R. Competence in prehospital care: evolving concepts. Emerg Med J. 2005;22:516–9.
3. Johnson C, Anderson S, Dallimore J, Winser S, Warrell D. Oxford handbook of expedition and wilderness medicine. 2nd ed. Oxford: Oxford Univeristy Press; 2008.
4. Anderson SR, Johnson CJ. Expedition health and safety: a risk assessment. J R Soc Med. 2000;93(11):557–62.
5. Lyon R, Wiggins C. Expedition medicine—risk of illness and injury. Wilderness Env Med. 2010;21:318–24.
6. McIntosh SE, Campbell A, Weber D, Dow J, Joy E, Grissom CK. Mountaineering medical events and trauma on Denali, 1992–2011. High Alt Med Biol. 2012;13(4):275–80.
7. Kupper T, Hettlich M, Horz HP, Lechner K, Scharfenberg C, Conrads G, et al. Dental problems and emergencies of trekkers—epidemiology and prevention. Results of the ADEMED Expedition 2008. High Alt Med Biol. 2014;15(1):39–45.
8. Faculty of Pre-Hospital Care, The Royal College of Surgeons Edinburgh, PHEM Skills Framework. http://www.fphc.co.uk/content/LatestNews/PHEMSkillsFramework.aspx. Accessed 7 Sept 2015.
9. Iserson KV. Medical planning for extended remote expeditions. Wilderness Environ Med. 2013;24(4):366–77.
10. Barry PW, Pollard AJ. Altitude illness. BMJ. 2003;326(7395):915–9.

11. Bangor Mountain Medicine Project, Ysbyty Gwynedd Mountain Medicine database. http://www.mountainmedicine.co.uk/Mountain_Medicine_Bangor/Mountain_Medicine.html. Accessed 29 August 2015.
12. Scally G, Donaldson LJ. The NHS's 50 anniversary. Clinical governance and the drive for quality improvement in the new NHS in England. BMJ. 1998;317(7150):61–5.
13. Küpper T, Nies I, Hillebrandt D, Milledge J, Basnayt B. Model contract for health care on trekking and expeditions for doctors. Intended for doctors, interested non-medical persons and trekking or expedition operators. UIAA. 2008. http://theuiaa.org/medical_advice.html. Accessed 29 August 2015.
14. Woodruff JM. Consequence and likelihood in risk estimation: a matter of balance in UK health and safety risk assessment practice. Saf Sci. 2005;43:345–53.
15. Elsensohn F, Soteras I, Resiten O, Ellerton J, Brugger H, Paal P. Equipment of medical backpacks in mountain rescue. High Alt Med Biol. 2011;12(4):343–7.
16. Paal P, Milani M, Brown D, Boyd J, Ellerton J. Termination of cardiopulmonary resuscitation in mountain rescue. High Alt Med Biol. 2012;13(3):200–8.

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WILDERNESS MEDICAL SOCIETY PRACTICE GUIDELINES

# Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Acute Altitude Illness: 2019 Update

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To provide guidance to clinicians about best preventive and therapeutic practices, the Wilderness Medical Society (WMS) convened an expert panel to develop evidence-based guidelines for prevention and treatment of acute mountain sickness, high altitude cerebral edema, and high altitude pulmonary edema. Recommendations are graded based on the quality of supporting evidence and the balance between the benefits and risks/burdens according to criteria put forth by the American College of Chest Physicians. The guidelines also provide suggested approaches to prevention and management of each form of acute altitude illness that incorporate these recommendations. This is an updated version of the original WMS Consensus Guidelines for the Prevention and Treatment of Acute Altitude Illness published in 2010 and subsequently updated as the WMS Practice Guidelines for the Prevention and Treatment of Acute Altitude Illness in 2014.

*Keywords:* high altitude, acute mountain sickness, high altitude pulmonary edema, high altitude cerebral edema, acetazolamide, dexamethasone, nifedipine

## Introduction

Travel to elevations above 2500 m is associated with risk of developing 1 or more forms of acute altitude illness: acute mountain sickness (AMS), high altitude cerebral edema (HACE), and high altitude pulmonary edema (HAPE). Because large numbers of people travel to such elevations, many clinicians are faced with questions from patients about the best means to prevent these disorders. In addition, clinicians working at facilities in high altitude regions or as members of expeditions traveling to such areas can expect to see persons who are experiencing these illnesses and must be familiar with prophylactic regimens and proper treatment protocols.

To provide guidance to clinicians and disseminate knowledge about best practices, the Wilderness Medical Society (WMS) convened an expert panel to develop evidence-based guidelines for prevention and treatment of acute altitude illness. Preventive and therapeutic modalities are presented and recommendations made for each form of acute altitude illness. Recommendations are graded based on the quality of supporting evidence and consideration of benefits and risks/burdens associated with each modality. These recommendations are intended to apply to all travelers to high altitude, whether they are traveling to high altitude for work, recreation, or various activities including hiking, skiing, trekking, and mountaineering.

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## Methods

The original expert panel was convened at the 2009 annual meeting of the WMS in Snowmass, Colorado. Members were selected by the WMS based on their clinical and/or research experience. Relevant articles were identified through the MEDLINE database by keyword search using the terms acute mountain sickness, high altitude pulmonary edema, high altitude cerebral edema, treatment, prevention, acetazolamide, dexamethasone, ibuprofen, nifedipine, tadalafil, sildenafil, and salmeterol. English-language, peer-reviewed studies including adults and/or children that were related to prevention and treatment of acute altitude illnesses, including randomized controlled trials, observational studies, and case series, were reviewed, and the level of evidence supporting various preventive and treatment modalities was assessed. Animal studies and abstract-only studies were not included. Conclusions from review articles were not considered in the formulation of recommendations but are cited to provide background information on the acute altitude illnesses and their management. The panel used a consensus approach to develop recommendations and graded each recommendation according to criteria stipulated in the American College of Chest Physicians statement on grading recommendations and strength of evidence in clinical guidelines (online Supplementary Table 1).[1]

This set of guidelines is an updated version of the original Wilderness Medical Society Consensus Guidelines for the Prevention and Treatment of Acute Altitude Illness published in 2010[2] and the update as the Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Acute Altitude Illness published in 2014.[3] As for the 2014 update, the panel used the approach described to identify relevant studies, adding additional search terms to reflect updates in the literature. The new search terms for the current version included budesonide, acetaminophen, continuous positive airway pressure (CPAP), and hypoxic tents.

## Defining the threshold for "high altitude" and when to apply these guidelines

Unacclimatized individuals are at risk of high altitude illness when ascending to altitudes above 2500 m. Prior studies and extensive clinical experience, however, suggest that susceptible individuals can develop AMS, and potentially HAPE, at elevations as low as 2000 m.[4–6] HACE is typically encountered at higher elevations but has also been reported at around 2500 m in patients with concurrent HAPE.[7] Part of the difficulty in defining a specific threshold at which altitude illness can develop is the fact that the symptoms and signs of AMS, the most common form of altitude illness, are nonspecific, as demonstrated in several studies in which participants met criteria for the diagnosis of AMS despite no gain in altitude.[8–10] As a result, studies assessing AMS incidence at modest elevations may label individuals as having altitude illness when, in fact, symptoms are related to some other process, thereby falsely elevating the reported incidence of AMS at that elevation.

Recognizing the difficulty in defining a clear threshold, the expert panel recommends an approach to preventing and treating acute altitude illness that does not depend strictly on the altitude to which an individual is traveling. Preventive measures should be considered based on the altitude to which the individual is traveling and also account for factors such as history of performance at high altitude, rate of ascent, and availability of acclimatization days (described in greater detail later). Diagnoses of AMS, HAPE, or HACE should not be excluded based on the fact that an ill individual is below 2500 m. These diagnoses should be strongly considered in the presence of compatible clinical features, with careful attempts to exclude other entities such as severe dehydration, hyponatremia, pneumonia, carbon monoxide poisoning, and hypoglycemia.

## Acute mountain sickness and high altitude cerebral edema

Information on the epidemiology, clinical presentation, and pathophysiology of AMS and HACE is provided in several extensive reviews.[11–14] From a clinical standpoint, HACE represents an extremely severe form of AMS; therefore, preventive and treatment measures for the 2 disorders can be addressed simultaneously.

### PREVENTION

Measures considered for prevention of AMS and HACE include the following.

#### *Gradual ascent*

Controlling the rate of ascent, in terms of the number of meters gained per day, is a highly effective means of preventing acute altitude illness; however, aside from 2 recent prospective studies,[15,16] this strategy has largely been evaluated retrospectively.[17] In planning the rate of ascent, the altitude at which someone sleeps is considered more important than the altitude reached during waking hours.

***Recommendation.*** Gradual ascent, defined as a slow increase in sleeping elevation, is recommended for AMS and HACE prevention. A specific approach is described further later in the text. Recommendation Grade: 1B

### *Acetazolamide*

Multiple trials have established a role for acetazolamide in prevention of AMS.[18–21]

Acetazolamide contains a sulfa moiety but carries an extremely low risk of inciting an allergic reaction in persons with sulfonamide allergy. As a result, persons with known allergy to sulfonamide medications can consider a supervised trial of acetazolamide before the trip, particularly if planning travel to a location remote from medical resources.[22] Prior anaphylaxis to a sulfonamide medication or a history of Stevens-Johnson syndrome should be considered a contraindication to acetazolamide.

Some studies suggest that acetazolamide may have an adverse effect on maximum exercise capacity,[23] perceived dyspnea during maximal exercise tests,[24] and respiratory muscle function at high levels of work.[25] The small observed changes, however, are unlikely to affect overall exercise performance for the majority of activities in which high altitude travelers engage (hiking, skiing) or the chance of summit success for climbers at moderate and even extreme elevations. These changes should not be viewed as a reason to avoid acetazolamide.

The recommended adult dose for prophylaxis is 125 mg every 12 h (Table 1). Although doses up to 750 mg daily are effective at preventing AMS compared to placebo, they are associated with more frequent and/or pronounced side effects, do not convey greater efficacy, and are not recommended for prevention. A recent, small study suggested that 62.5 mg every 12 h was noninferior to 125 mg every 12 h,[26] but further research with greater numbers of participants in different high altitude settings should be completed before a change in dose can be recommended. The pediatric dose of acetazolamide is 2.5 $mg \cdot kg^{-1} \cdot dose^{-1}$ (maximum 125 $mg \cdot dose^{-1}$) every 12 h.[27]

***Recommendation.*** Acetazolamide should be strongly considered in travelers at moderate or high risk of AMS with ascent to high altitude. Recommendation Grade: 1A.

***Recommendation.*** Acetazolamide can be used in children for prevention of AMS. Recommendation Grade: 1C.

### *Dexamethasone*

Although dexamethasone does not facilitate acclimatization like acetazolamide, prospective trials have established a benefit for dexamethasone in AMS prevention.[28,29] The recommended adult doses are 2 mg every 6 h or 4 mg every 12 h. Very high doses (4 mg every 6 h) may be considered in very high-risk situations, such as military or search and rescue personnel being airlifted to altitudes >3500 m with

**Table 1.** Recommended dosages for medications used in the prevention and treatment of altitude illness

| *Medication* | *Indication* | *Route* | *Dosage* |
|---|---|---|---|
| Acetazolamide | AMS, HACE prevention | Oral | 125 mg every 12 h[a]<br>Pediatrics: 2.5 $mg \cdot kg^{-1}$ every 12 h |
| | AMS treatment[b] | Oral | 250 mg every 12 h<br>Pediatrics: 2.5 $mg \cdot kg^{-1}$ every 12 h (maximum: 125 mg per dose) |
| Dexamethasone | AMS, HACE prevention | Oral | 2 mg every 6 h or 4 mg every 12 h[a]<br>Pediatrics: Should not be used for prophylaxis |
| | AMS, HACE treatment | Oral, IV, IM | AMS: 4 mg every 6 h<br>HACE: 8 mg once, then 4 mg every 6 h<br>Pediatrics: 0.15 $mg \cdot kg^{-1} \cdot dose^{-1}$ every 6 h (Maximum: 4 mg per dose) |
| Ibuprofen | AMS prevention | Oral | 600 mg every 8 h |
| Nifedipine | HAPE prevention | Oral | 30 mg ER version, every 12 h or 20 mg ER version every 8 h[c] |
| | HAPE treatment | Oral | 30 mg ER version, every 12 h or 20 mg ER version every 8 h |
| Tadalafil | HAPE prevention | Oral | 10 mg every 12 h[c] |
| Sildenafil | HAPE prevention | Oral | 50 mg every 8 h[c] |

AMS, acute mountain sickness; HACE, high altitude cerebral edema; IM, intramuscularly; ER, extended release; HAPE, high altitude pulmonary edema.

[a] For individuals ascending to and remaining at a given elevation, after arrival at the target elevation, the medication should be continued for 2 d in individuals adhering to the recommended ascent rate and 2 to 4 d in individuals ascending faster than recommended rates. Individuals who ascend to a target elevation and immediately descend can stop the medication once descent is initiated.

[b] Acetazolamide can also be used at this dose as an *adjunct* to dexamethasone in HACE treatment, but dexamethasone remains the primary treatment for HACE.

[c] For individuals ascending to and remaining at a given elevation, after arrival at the target elevation, the medication should be continued for 4 d in individuals adhering to the recommended ascent rate and 4 to 7 d in individuals ascending faster than recommended rates. Individuals who ascend to a target elevation and immediately descend can stop the medication once descent is initiated.

immediate performance of physical activity, but should not be used except in these limited circumstances. Prolonged use carries a risk of adrenal suppression. Although some resources state that use of less than 2-wk duration does not require a taper,[30] in remote mountain environments a more conservative approach is warranted. If used for longer than 10 d, the medication should be tapered over a 1-wk period rather than stopped abruptly. Given the absence of data on the use of dexamethasone for AMS prevention in children and the availability of other safe alternatives—specifically, graded ascent and acetazolamide—dexamethasone is not recommended for AMS prevention in children.

***Recommendation.*** Dexamethasone can be used as an alternative to acetazolamide for adult travelers at moderate or high risk of AMS. Recommendation Grade: 1A.

### *Inhaled budesonide*

Two studies indicated that inhaled budesonide 200 micrograms twice daily was effective at preventing AMS when compared to placebo.[31,32] These studies were limited by methodological issues such as timing of the assessment for AMS[31] and number of participants in each study arm.[32] A clear mechanism of action was not apparent in these studies, but small improvements in spirometry and oxygen saturation—both of little clinical significance—were suggested as evidence that the benefit might derive from a direct lung effect. More recent, well-designed randomized controlled trials failed to replicate these results.[33,34]

***Recommendation.*** Inhaled budesonide should not be used for altitude illness prophylaxis. Recommendation Grade: 1C

### *Ginkgo biloba*

Although 2 trials demonstrated a benefit of *Ginkgo* in AMS prevention,[35,36] 2 other negative trials have also been published.[37,38] This discrepancy may result from differences in the source and composition of the *Ginkgo* products.[39] *Ginkgo* should be avoided in pregnant women[40] and used with caution in people taking anticoagulants.[41] Acetazolamide is considered far superior for AMS prevention.

***Recommendation.*** *Ginkgo biloba* should not be used for AMS prevention. Recommendation Grade: 1C

### *Ibuprofen*

Two trials demonstrated that ibuprofen (600 mg 3 times daily) is more effective than placebo at preventing AMS,[42,43] while a third, smaller study showed no benefit.[44] Another study claimed to show benefit, but the trial did not include a placebo arm and instead compared the incidence of AMS with ibuprofen with historically reported rates from the region in which the study was conducted.[45] Although no studies have compared ibuprofen with dexamethasone, 2 studies have compared ibuprofen with acetazolamide. The first found an equal incidence of high altitude headache and AMS in the acetazolamide and ibuprofen groups, with both showing significant protection compared to placebo.[46] A more recent trial failed to show that ibuprofen was noninferior to acetazolamide (ie, ibuprofen is inferior to acetazolamide for AMS prophylaxis).[47] The aforementioned trials all used the medication for a short duration (~24−48 h). As a result, efficacy and safety (eg, the risk of gastrointestinal bleeding or renal dysfunction) over longer periods of use at high altitude remain unclear. For these reasons, as well as more extensive clinical experience with acetazolamide and dexamethasone, ibuprofen cannot be recommended over these medications for AMS prevention for rapid ascent.

***Recommendation.*** Ibuprofen can be used for AMS prevention in persons who do not wish to take acetazolamide or dexamethasone or have allergies or intolerance to these medications. Recommendation Grade: 2B.

### *Acetaminophen*

A single study demonstrated that acetaminophen 1000 mg 3 times daily was as effective as ibuprofen at preventing AMS in trekkers travelling between 4370 and 4940 m in elevation.[45] Rather than including a placebo arm, the study attempted to establish the benefit of acetaminophen by comparing the incidence rates in the study with those of untreated trekkers from prior studies that used the same ascent profile. Based on these data, acetaminophen is not recommended for use as a preventive agent over acetazolamide or dexamethasone.

***Recommendation.*** Acetaminophen should not be used for AMS prevention. Recommendation Grade: 1C

### *Staged ascent and preacclimatization*

Two studies showed that spending 6 to 7 d at moderate altitude (~2200−3000 m) before proceeding to higher altitude (referred to as "staged ascent") decreases the risk of AMS, improves ventilation and oxygenation, and blunts the pulmonary artery pressure response after subsequent ascent to 4300 m.[16,48] Many travelers to high altitude visit mountain resorts at more moderate elevations between 2500 and 3000 m. The value of short stays at intermediate elevations of ~1500 m for decreasing the risk of AMS during such ascents makes sense from a physiologic standpoint. However, this approach has not been studied in a randomized fashion, aside from 1 cross-sectional study finding a decreased risk of AMS in travelers who spent 1 night at 1600 m before ascent to resort communities between 1920 and 2950 m.[5]

A larger number of studies examining the effects of repeated exposures to hypobaric or normobaric hypoxia in the days and week preceding high altitude travel (referred to as "preacclimatization") showed mixed results, with some studies finding benefit in terms of decreased AMS incidence or severity[49–51] and others showing no effect.[52–55] A significant challenge in interpreting the literature on preacclimatization is the variability among the hypoxic exposure protocols used, as well as the fact that not all studies include evidence that their protocols induced physiologic responses consistent with acclimatization.

Implementation of either staged ascent or preacclimatization may be logistically difficult for many high altitude travelers. In general, short-term exposures (eg, 15−60 min of exposure to hypoxia, or a few hours of hypoxia a few times before ascent) are unlikely to aid acclimatization, whereas longer exposures (eg, >8 h daily for >7 d) are more likely to yield benefit. Hypobaric hypoxia is more effective than normobaric hypoxia in facilitating preacclimatization and preventing AMS.[56] Because the optimal methods for preacclimatization and staged ascent have not been fully determined, the panel recommends consideration of these approaches but does not endorse a particular protocol.

***Recommendation.*** When feasible, staged ascent and preacclimatization can be considered as a means for AMS prevention. Recommendation Grade: 1C

### *Hypoxic tents*

Commercial products are available that allow individuals to sleep or exercise in hypoxic conditions for the purpose of facilitating acclimatization before a trip to high altitude. Only 1 placebo-controlled study has examined their utility.[57] Although this study demonstrated a lower incidence of AMS in persons who slept in simulated high altitude conditions compared to normoxia, technical difficulties with the system resulted in a substantial number of study participants not receiving the intended hypoxic dose. Although the systems are marketed to be of benefit and anecdotal reports suggest they are widely used by climbers and other athletes competing at high altitude, there are no data indicating increased likelihood of summit success or improved physical performance. As with the preacclimatization approaches previously described, any benefit that may accrue from these systems is more likely with long hypoxic exposures (>8 h per day) for at least several weeks before planned high altitude travel. Short and/or infrequent exposures, including exercise training, are likely of no benefit. In addition to the cost of the systems and power needed to run them, individuals face the risk of poor sleep, which over a long period of time could have deleterious effects on performance during an expedition.

***Recommendation.*** Hypoxic tents can be used for facilitating acclimatization and preventing AMS, provided sufficiently long exposures can be undertaken regularly over an appropriate number of weeks and other factors, such as sleep quality, are not compromised. Recommendation Grade: 2B

### *Other options*

Chewed coca leaves, coca tea, and other coca-derived products are commonly recommended for travelers in the Andes mountains for AMS prevention. Their utility in prevention of altitude illness has not been properly studied, so they should not be substituted for other established preventive measures described in these guidelines. Multiple studies have sought to determine whether other agents, including antioxidants,[58] iron,[59] dietary nitrates,[60] leukotriene receptor blockers,[61,62] phosphodiesterase inhibitors,[63] salicylic acid,[64] spironolactone,[65] and sumatriptan[66] can prevent AMS, but the current state of evidence does not support their use. "Forced" or "over" hydration has never been found to prevent altitude illness and might increase the risk of hyponatremia; however, maintenance of adequate hydration is important because symptoms of dehydration can mimic those of AMS. Nocturnal expiratory positive airway pressure (EPAP) administered via a single-use nasal strip during sleep is not effective for AMS prophylaxis,[67] nor is a regimen of remote ischemic preconditioning.[68]

No studies have examined short-term oxygen use in the form of either visits to oxygen bars or over-the-counter oxygen delivery systems by which individuals inhale oxygen-enriched gas from a small prefilled canister. Due to the small volume of gas (2−10 L/canister) and short duration of administration, these interventions are unlikely to be of benefit and, as a result, have no role in AMS/HACE prevention. Other over-the-counter products, such as powdered drink mixes, also lack any evidence of benefit.

## SUGGESTED APPROACH TO AMS/HACE PREVENTION

Because the rates of acclimatization and physiologic responses to high altitude vary considerably between individuals, clinicians must recognize that the recommendations that follow, although generally effective, do not guarantee successful prevention in all high altitude travelers.

The approach to prevention of AMS and HACE should be a function of the risk profile of the individual traveling to high altitude (Table 2). The first priority should be ensuring gradual ascent to the target elevation. Travelers can lower their risk by sleeping 1 night at an intermediate altitude. For example, sea-level residents traveling to Colorado resort areas over 2800 m can spend

**Table 2.** Risk categories for acute mountain sickness

| *Risk category* | *Description* |
|---|---|
| Low | • Individuals with no history of altitude illness and ascending to ≤2800 m<br>• Individuals taking ≥2 d to arrive at 2500−3000 m with subsequent increases in sleeping elevation <500 m·d$^{-1}$and an extra day for acclimatization every 1000 m |
| Moderate | • Individuals with history of AMS and ascending to 2500−2800 m in 1 d<br>• No history of AMS and ascending to >2800 m in 1 d<br>• All individuals ascending >500 m·d$^{-1}$ (increase in sleeping elevation) at altitudes above 3000 m but with an extra day for acclimatization every 1000 m |
| High | • Individuals with a history of AMS and ascending to >2800 m in 1 d<br>• All individuals with a history of HACE or HAPE<br>• All individuals ascending to >3500 m in 1 d<br>• All individuals ascending >500 m·d$^{-1}$ (increase in sleeping elevation) above >3000 m without extra days for acclimatization<br>• Very rapid ascents (eg, <7 d ascents of Mt. Kilimanjaro) |

AMS, acute mountain sickness; HACE, high altitude cerebral edema; HAPE, high altitude pulmonary edema.

Altitudes listed in the table refer to the altitude at which the person sleeps.

Ascent is assumed to start from elevations <1200 m.

The risk categories described pertain to unacclimatized individuals.

1 night in Denver (1600 m). It should be recognized that a large number of people will travel directly by car or plane to commonly visited mountain high altitude locations, often located between 2500 and 3000 m, and may be unable to ascend gradually because of various logistical factors. In such situations, pharmacologic prophylaxis can be considered. Such individuals should also take care to slow the rate of further ascent beyond the altitude achieved at the start of their visit.

With travel above 3000 m, individuals should not increase their sleeping elevation by more than 500 m·d$^{-1}$ and should include a rest day (ie, no ascent to higher sleeping elevation) every 3 to 4 d. The increase in sleeping elevation should be less than 500 m for any given day of a trip. In many areas, terrain and other logistical factors prevent strict adherence to this approach and mandate larger gains in sleeping elevation over a single day. In such cases, acclimatization days should be strongly considered before and/or after these large gains in elevation and elsewhere in the itinerary to ensure—at the very least and as an approximation of properly controlled ascent—that the overall ascent rate averaged over the entire trip (ie, total elevation gain divided by the number of days of ascent during the trip) is below the 500 m·d$^{-1}$threshold.

Prophylactic medications are not necessary in low-risk situations but should be considered in addition to gradual ascent for use in moderate- to high-risk situations (Table 2). Acetazolamide is the preferred medication; dexamethasone may be used as an alternative in individuals with a history of intolerance of or allergic reaction to acetazolamide. In rare circumstances (eg, military or rescue teams that must ascend rapidly to and perform physical work at >3500 m), consideration can be given to concurrent use of acetazolamide and dexamethasone. This strategy should be avoided except in these particular or other emergency circumstances that mandate very rapid ascent.

Acetazolamide and dexamethasone should be started the day before ascent but still have beneficial effects if started on the day of ascent. For individuals ascending to and staying at the same elevation for more than several days, prophylaxis may be stopped after 2 d at the highest altitude. Individuals ascending faster than the recommended ascent rates may consider continuing preventive medication for 2 to 4 d after arrival at the target altitude, but there are no data to support this approach. For individuals ascending to a high point and then descending toward the trailhead (eg, descending from the summit of Mt. Kilimanjaro), in the absence of AMS/HACE symptoms, preventive medications should be stopped when descent is initiated.

## TREATMENT

Potential therapeutic options for AMS and HACE include the following.

### *Descent*

Descent remains the single best treatment for AMS and HACE, but it is not necessary in all circumstances (discussed further later in the text). Individuals should descend until symptoms resolve unless terrain, weather, or injuries make descent impossible. Symptoms typically resolve after descent of 300 to 1000 m, but the required decrease in altitude varies among individuals. Individuals should not descend alone, particularly if they are experiencing HACE.

***Recommendation.*** Descent is effective for any degree of AMS/HACE and is indicated for individuals with severe AMS, AMS that fails to resolve with other measures, or HACE. Recommendation Grade: 1A

### Supplemental oxygen

Oxygen delivered by nasal cannula or mask at flow rates sufficient to relieve symptoms provides a suitable alternative to descent. A peripheral capillary oxygen saturation ($S_pO_2$) >90% is usually adequate. Use of oxygen is not required in all circumstances and is generally reserved for mountain clinics and hospitals where supply is abundant. It should also be used when descent is recommended but not feasible or during descent in severely ill individuals. The inspired oxygen fraction will vary significantly between oxygen delivery systems, including nasal cannula, simple facemasks, Venturi masks, or non-rebreather masks. In addition, because of interindividual variability in inspiratory flow rates and minute ventilation, the inspired fractional concentration of oxygen ($F_IO_2$) can vary significantly between patients for any given common oxygen delivery system, with the exception of high flow systems. For this reason, supplemental oxygen should be administered to target an $S_pO_2$ of >90% rather than a specific $F_IO_2$. Oxygen supply may be limited at remote high altitude clinics or on expeditions, necessitating judicious use. Short-term oxygen use in the form of visits to oxygen bars or use of over-the-counter oxygen canisters has not been studied for AMS treatment and should not be relied on for this purpose.

***Recommendation.*** When available, ongoing supplemental oxygen sufficient to raise $S_pO_2$ to >90% or to relieve symptoms can be used while waiting to initiate descent or when descent is not practical. Recommendation Grade: 1A

### Portable hyperbaric chambers

Portable hyperbaric chambers are effective for treating severe altitude illness[69,70] but require constant tending by care providers and are difficult to use with claustrophobic or vomiting patients. Symptoms may recur when individuals are removed from the chamber,[71] but this should not preclude use of the chamber when indicated. In many cases, ill individuals may improve sufficiently to enable them to assist in their evacuation and descend once symptoms improve. Use of a portable hyperbaric chamber should not delay descent in situations where descent is required.

***Recommendation.*** When available, portable hyperbaric chambers should be used for patients with severe AMS or HACE when descent is infeasible or delayed and supplemental oxygen is not available. Recommendation Grade: 1B

### Acetazolamide

Only 1 study has examined acetazolamide for AMS treatment. The dose studied was 250 mg every 12 h; whether a lower dose might suffice is unknown.[72] No studies have assessed AMS treatment with acetazolamide in pediatric patients, but anecdotal reports suggest it has utility. The pediatric treatment dose is 2.5 $mg \cdot kg^{-1} \cdot dose^{-1}$ every 12 h up to a maximum of 250 $mg \cdot dose^{-1}$.

***Recommendation.*** Acetazolamide should be considered for treatment of AMS. Recommendation Grade: 1C

### Dexamethasone

Dexamethasone is very effective for treating AMS.[73–75] The medication does not facilitate acclimatization, so further ascent should be delayed until the patient is asymptomatic while off the medication. Although systematic studies have not been conducted, extensive clinical experience supports using dexamethasone in patients with HACE. It is administered as an 8 mg dose (intramuscularly, IV, or orally) followed by 4 mg every 6 h until symptoms resolve. The pediatric dose is 0.15 $mg \cdot kg^{-1} \cdot dose^{-1}$ every 6 h.[27]

***Recommendation.*** Dexamethasone should be considered for treatment of AMS. Recommendation Grade 1B.

***Recommendation.*** Dexamethasone should be administered to patients with HACE. Recommendation Grade: 1B

### Acetaminophen

Acetaminophen has been found to relieve headache at high altitude[76] but has not been found to improve the full spectrum of AMS symptoms or effectively treat HACE.

***Recommendation.*** Acetaminophen can be used to treat headache at high altitude. Recommendation Grade: 1C.

### Ibuprofen

Ibuprofen has been found to relieve headache at high altitude[76] but has not been shown to improve the full spectrum of AMS symptoms or effectively treat HACE.

***Recommendation.*** Ibuprofen can be used to treat headache at high altitude. Recommendation Grade: 1C.

### Continuous positive airway pressure

Rather than affecting barometric pressure, CPAP works by increasing transmural pressure across alveolar walls, thereby increasing alveolar volume and improving ventilation-perfusion matching and gas exchange. Two reports have demonstrated the feasibility of administering CPAP to treat AMS,[77,78] but this has not been studied in a systematic manner. Logistical challenges to use in field settings include access to power and the weight and bulk of these systems.

***Recommendation.*** Because of lack of data, no recommendation can be made regarding use of CPAP for AMS treatment.

## SUGGESTED APPROACH TO AMS/HACE TREATMENT

Care should be taken to exclude disorders whose symptoms and signs resemble those seen with AMS and HACE, such as carbon monoxide poisoning, dehydration, exhaustion, hypoglycemia, hypothermia, and hyponatremia. Persons with AMS of any severity or HACE should cease ascending and may need to consider descent, depending on the severity of illness and the circumstances (Table 3).[11] Patients with AMS can remain at their current altitude and use nonopioid analgesics for headache and antiemetics for nausea and vomiting. These individuals should be closely observed for signs of progression of altitude illness. Descent should be initiated for AMS if symptoms worsen or fail to improve after 1 to 2 d of appropriate interventions.

Although acetazolamide facilitates acclimatization and is somewhat effective for treating mild illness, it is likely better for prevention than for treatment. Dexamethasone is considered to be a more reliable treatment for moderate to severe AMS, which often also requires descent. Individuals with AMS may resume ascending once symptoms resolve. Further ascent or reascent to a previously attained altitude should never be undertaken if there are ongoing symptoms. After resolution of AMS, taking acetazolamide at preventive doses during reascent is prudent.

HACE is differentiated from severe AMS by neurological signs such as ataxia, confusion, or altered mental status in the setting of acute ascent to high altitude and may follow AMS or occur concurrently with HAPE. Individuals developing HACE in locations with access to hospitals or specialized clinics should be started on dexamethasone and supplemental oxygen sufficient to achieve an $S_pO_2$ >90%. In remote areas away from medical resources, descent should be initiated in any suspected cases of HACE or if symptoms of AMS are worsening despite treatment with acetazolamide or dexamethasone. If descent is not feasible, supplemental oxygen or a portable hyperbaric chamber should be used. Persons with HACE should also be started on dexamethasone. There are no systematic data or case reports about reascent during the same trip or expedition after resolution of HACE. The prudent course is to avoid reascent in this situation, but if it is to be attempted, at a minimum the individual should be asymptomatic and no longer taking dexamethasone for at least 2 to 3 d before reascent.

### High altitude pulmonary edema

Information on the epidemiology, clinical presentation, and pathophysiology of HAPE, the majority of which comes from studies in adults, is provided in extensive reviews.[13,14,79,80] Although some of the prophylactic and therapeutic modalities are the same for HAPE as for AMS and HACE, important differences in the underlying pathophysiology mandate certain alternative prevention and treatment approaches.

## PREVENTION

Potential preventive measures for HAPE include the following.

### *Gradual ascent*

No studies have prospectively assessed whether limiting the rate of increase in sleeping elevation prevents HAPE; however, there is a clear relationship between rate of ascent and disease incidence.[17,81,82]

***Recommendation.*** Gradual ascent is recommended to prevent HAPE. Recommendation Grade: 1B

**Table 3.** Acute mountain sickness classification

| *Category* | *Mild AMS* | *Moderate–Severe AMS* | *High altitude cerebral edema (HACE)* |
|---|---|---|---|
| Symptoms | Headache plus 1 or more other symptoms (nausea/vomiting, fatigue, lassitude, dizziness) | Headache plus 1 or more other symptoms (nausea/vomiting, fatigue, lassitude, dizziness) | Worsening of symptoms seen in moderate to severe AMS |
| | All symptoms of mild intensity | All symptoms of moderate–severe intensity | |
| Signs | None | None | Ataxia, severe lassitude, altered mental status, encephalopathy |
| Lake Louise AMS Score[a] | 3–5 | 6–12 | Not applicable |

AMS, acute mountain sickness.
[a] Self-report AMS score. Roach et al.[103]

### *Nifedipine*

A single, randomized, placebo-controlled study[83] and extensive clinical experience have established a role for nifedipine in HAPE prevention in susceptible individuals. The recommended dose is 30 mg of the extended-release preparation administered every 12 h. Hypotension was not noted in the study[83] and is generally not a concern with the extended-release version of the medication but may occur in a limited number of individuals.

***Recommendation.*** Nifedipine is recommended for HAPE prevention in HAPE-susceptible people. Recommendation Grade: 1B

### *Salmeterol*

In a single randomized, placebo-controlled study, the long-acting inhaled beta-agonist salmeterol decreased the incidence of HAPE by 50% in susceptible individuals.[84] Very high doses (125 micrograms twice daily) that are often associated with side effects, including tremor and tachycardia, were used in the study. Clinical experience with salmeterol at high altitude is limited.

***Recommendation.*** Salmeterol is not recommended for HAPE prevention. Recommendation Grade: 2B.

### *Tadalafil*

In a single, randomized placebo-controlled trial, 10 mg of tadalafil every 12 h was effective in preventing HAPE in susceptible individuals.[85] The number of individuals in the study was small, and 2 developed incapacitating AMS. Clinical experience with tadalafil is lacking compared to nifedipine. As a result, further data are necessary before tadalafil can be recommended over nifedipine.

***Recommendation.*** Tadalafil can be used for HAPE prevention in known susceptible individuals who are not candidates for nifedipine. Recommendation Grade: 1C

### *Dexamethasone*

In the same study that assessed the role of tadalafil in HAPE prevention, dexamethasone (8 mg every 12 h) was also found to prevent HAPE in susceptible individuals.[85] The mechanism for this effect is not clear, and there is very little clinical experience in using dexamethasone for this purpose. Further data are necessary before it can be recommended for HAPE prevention.

***Recommendation.*** Dexamethasone can be used for HAPE prevention in known susceptible individuals who are not candidates for nifedipine and tadalafil. Recommendation Grade: 1C

### *Acetazolamide*

Because acetazolamide hastens acclimatization, it should be effective at preventing all forms of acute altitude illness. It has also been shown to blunt hypoxic pulmonary vasoconstriction, a key factor in HAPE pathophysiology, in animal models[86–88] and in a single study in humans,[89] but there are no data specifically supporting a role in HAPE prevention. Clinical observations suggest acetazolamide may prevent reentry HAPE,[90] a disorder seen in individuals who reside at high altitude, travel to lower elevation, and then develop HAPE upon rapid return to their residence.

***Recommendation.*** Because of lack of data, no recommendation can be made regarding use of acetazolamide for HAPE prevention.

***Recommendation.*** Acetazolamide can be considered for prevention of reentry HAPE in people with a history of the disorder. Recommendation Grade: 1C

### *Preacclimatization and staged ascent*

No study has examined whether preacclimatization strategies are useful for HAPE prevention. Staged ascent, with 7 d of residence at moderate altitude (~2200 m), has been found to blunt the hypoxia-induced increase in pulmonary artery pressure.[48] However, uncertainty remains as to the magnitude and duration of moderate altitude exposure necessary to yield benefit, and no study has specifically investigated whether the strategy is of benefit in HAPE-susceptible individuals. Although the risks of preacclimatization and staged ascent are likely low, feasibility is a concern for many high altitude travelers. Because the optimal methods for preacclimatization and staged ascent have not been fully determined, the panel recommends consideration of these approaches but cannot endorse a particular protocol for implementation.

***Recommendation.*** When feasible, staged ascent and preacclimatization can be considered as a means for HAPE prevention. Recommendation Grade: 1C

## SUGGESTED APPROACH TO HAPE PREVENTION

As noted earlier, because the rates of acclimatization and physiologic responses to high altitude vary considerably among individuals, the recommendations that follow, although generally effective, do not guarantee prevention in all high altitude travelers. A gradual ascent profile is the primary method for preventing HAPE; the recommendations provided for AMS and HACE prevention also apply to HAPE prevention. Pharmacologic prophylaxis should only be considered for individuals with a history of HAPE, especially multiple episodes. Nifedipine is the preferred drug in such situations; it should be started the day before

ascent and continued either until descent is initiated or the individual has spent 4 d at the highest elevation, perhaps up to 7 d if the individual's rate of ascent was faster than recommended. Note that these durations are longer than use of acetazolamide for AMS prevention. For individuals ascending to a high point and then descending toward the trailhead (eg, descending from the summit of Kilimanjaro), prophylactic medications should be stopped when descent is initiated. Further research is needed before tadalafil or dexamethasone can be recommended over nifedipine for prevention. Acetazolamide facilitates acclimatization in general but should not be relied upon as the sole preventive agent in known HAPE-susceptible individuals.

## TREATMENT

Therapeutic options for HAPE include the following.

### *Descent*

As with AMS and HACE, descent remains the single best treatment for HAPE. Individuals should try to descend at least 1000 m or until symptoms resolve. They should exert themselves as little as possible while descending (eg, travel without a pack or via motor vehicle, helicopter, or animal transportation) because exertion can further increase pulmonary artery pressure and exacerbate edema formation.

***Recommendation.*** Descent is indicated for individuals with HAPE. Recommendation Grade: 1A

### *Supplemental oxygen*

Oxygen delivered by nasal cannula or mask at flow rates sufficient to achieve an $S_pO_2$ >90% provides a suitable alternative to descent, particularly when patients can access healthcare facilities and be closely monitored.[91–93] As noted earlier in the section on AMS/HACE treatment, providers should target an $S_pO_2$ of >90% rather than a particular $F_IO_2$. Short-term use in the form of visits to oxygen bars or use of over-the-counter oxygen canisters has no role in HAPE treatment.

***Recommendation.*** When available, supplemental oxygen sufficient achieve an $S_pO_2$ of >90% or to relieve symptoms should be used while waiting to initiate descent when descent is infeasible and during descent in severely ill patients. Recommendation Grade: 1A

### *Portable hyperbaric chambers*

As for AMS and HACE, portable hyperbaric chambers can be used for HAPE treatment. They have not been systematically studied for this purpose, but their use for HAPE has been reported in the literature.[94] Use of a portable hyperbaric chamber should not delay descent in situations where descent is feasible.

***Recommendation.*** When descent is infeasible or delayed or supplemental oxygen is unavailable, a portable hyperbaric chamber may be used to treat HAPE. Recommendation Grade: 1C

### *Nifedipine*

A single, nonrandomized, unblinded study demonstrated utility of nifedipine (10 mg of the short-acting version followed by 20 mg slow-release every 6 h) for HAPE treatment when oxygen or descent was not available.[95] Although participants in this study received a loading dose of the short-acting version of the medication, this initial dose is no longer employed because of concerns about provoking systemic hypotension. Although hypotension is less common with the extended-release preparation, it may develop when nifedipine is given to patients with intravascular volume depletion. A prospective, cross-sectional study of individuals with HAPE demonstrated that addition of nifedipine (30 mg sustained release every 12 h) to descent, oxygen, and rest offered no additional benefit in terms of time to resolution of hypoxemia and radiographic opacities or hospital length of stay.[96]

***Recommendation.*** Nifedipine should be used for HAPE treatment when descent is impossible or delayed and reliable access to supplemental oxygen or portable hyperbaric therapy is unavailable. Recommendation Grade: 1C

### *Beta-agonists*

Although there are reports of beta-agonist use in HAPE treatment[97] and the risks of use are likely low, no data support a benefit from salmeterol or albuterol in patients experiencing HAPE.

***Recommendation.*** No recommendation can be made regarding beta-agonists for HAPE treatment due to lack of data.

### *Phosphodiesterase inhibitors*

By virtue of their ability to cause pulmonary vasodilation and decrease pulmonary artery pressure, there is a strong physiologic rationale for using phosphodiesterase inhibitors in HAPE treatment. Although reports document their use for this purpose,[97,98] no systematic study has examined the role of tadalafil or sildenafil in HAPE treatment as either mono- or adjunctive therapy. Combined use of nifedipine and sildenafil or tadalafil should be avoided because of risk of hypotension.

***Recommendation.*** Tadalafil or sildenafil can be used for HAPE treatment when descent is impossible or delayed, access to supplemental oxygen or portable hyperbaric therapy is impossible, and nifedipine is unavailable. Recommendation Grade: 2C

*Continuous positive airway pressure*

As noted earlier, positive airway pressure works by increasing transmural pressure across alveolar walls, thereby increasing alveolar volume and improving ventilation-perfusion matching and, as a result, gas exchange. A small study demonstrated that EPAP, in which a mask system is used to increase airway pressure during exhalation only, improved gas exchange in patients with HAPE.[99] However, although several reports document use of CPAP for management of HAPE in hospital and field settings,[6,78] there is no systematic evidence that CPAP or EPAP improves patient outcomes compared to oxygen alone or in conjunction with medications. Given the low risks associated with the therapy, CPAP can be considered an adjunct to oxygen administration in a medical facility, provided the patient has normal mental status and can tolerate the mask. Although lithium battery−powered devices and decreased size and weight of CPAP machines have increased feasibility of field use, logistical challenges remain and currently limit overall utility in this setting.

***Recommendation.*** CPAP or EPAP may be considered for treatment of HAPE when supplemental oxygen or pulmonary vasodilators are not available or as adjunctive therapy in patients not responding to supplemental oxygen alone. Recommendation Grade: 2C

*Diuretics*

Although their use is documented in older reports,[100] diuretics have no role in HAPE treatment, particularly because many patients with HAPE have intravascular volume depletion.

***Recommendation.*** Diuretics should not be used for treatment of HAPE. Recommendation Grade: 1C.

*Acetazolamide*

Although clinical reports document use of acetazolamide for treatment of HAPE,[97,98] there are no systematic studies examining its role in HAPE treatment. The diuretic effect might provoke hypotension in the intravascularly depleted patient, and the added stimulus to ventilation might worsen dyspnea.

***Recommendation.*** Acetazolamide should not be used for treatment of HAPE. Recommendation Grade: 1C

*Dexamethasone*

Considering its potential role in HAPE prevention noted earlier and studies demonstrating effects on maximum exercise capacity,[101] pulmonary inflammation, and ion transporter function in hypoxia,[102] dexamethasone may have a role in HAPE treatment. Although reports document clinical use in this regard,[98] no study has established whether it is effective for this purpose.

***Recommendation.*** Because of insufficient evidence, no recommendation can be made regarding dexamethasone for HAPE treatment.

## SUGGESTED APPROACH TO HAPE TREATMENT

Before initiating treatment, consideration should be given to other causes of respiratory symptoms at high altitude, such as asthma, bronchospasm, mucous plugging, pneumonia, pneumothorax, pulmonary embolism, viral upper respiratory tract infection, or myocardial infarction. If HAPE is suspected or diagnosed, oxygen should be started if available, and descent to lower elevation should be initiated. If descent is infeasible or delayed, supplemental oxygen should be continued or the individual should be placed in a portable hyperbaric chamber. Patients who have access to supplemental oxygen and can be adequately monitored in a medical setting (eg, urgent care clinic or emergency department) may not need to descend to lower elevation and can be treated with oxygen alone at the current elevation. Descent should be initiated, however, if oxygenation fails to improve with supplemental oxygen and/or CPAP, if the patient's condition deteriorates despite achieving an oxygen saturation >90%, or if the patient fails to show signs of improvement with appropriate interventions for HAPE. In more remote settings, early descent should be considered.

Addition of nifedipine may not yield additional benefit in well-monitored settings.[93,96] In the field setting, where resources are limited, nifedipine can be used as an adjunct to descent, supplemental oxygen, or portable hyperbaric therapy. It should only be used as primary therapy if none of these other measures is available. A phosphodiesterase inhibitor may be used if nifedipine is not available, but concurrent use of multiple pulmonary vasodilators is not recommended. In the hospital setting, CPAP can be considered as an adjunct to supplemental oxygen and nifedipine can be added if the patient fails to respond to oxygen therapy alone. There is no established role for beta-agonists, diuretics, acetazolamide, or dexamethasone in the treatment of HAPE, although, as noted below, dexamethasone should be considered when concern is raised for concurrent HACE.

Selected patients (able to achieve an oxygen saturation >90%, with adequate support from family or friends, with adequate housing or lodging arrangements) may be discharged from direct medical care if they can continue using supplemental oxygen rather than being admitted to a healthcare facility. Individuals treated in this manner should be admitted to the hospital if they develop worsening symptoms and/or oxygen saturation while on supplemental oxygen. Descent to lower elevation should be pursued if oxygenation or other aspects of their condition worsen despite appropriate interventions for HAPE, as

this suggests they may have alternative pathology that requires further evaluation and management.

Individuals who develop HAPE may consider further ascent to higher altitude or reascent only when symptoms of HAPE have completely resolved and they maintain stable oxygenation at rest and with mild exercise while off supplemental oxygen and/or vasodilator therapy. Consideration may be given to using nifedipine or another pulmonary vasodilator upon resuming ascent.

## SUGGESTED APPROACH FOR PATIENTS WITH CONCURRENT HAPE AND HACE

Dexamethasone should be added to the treatment regimen of patients with concurrent HAPE and HACE at the doses described earlier for patients with HACE. Some patients with HAPE may have neurologic dysfunction caused by hypoxic encephalopathy rather than caused by HACE, but making the distinction between hypoxic encephalopathy and HACE in the field can be difficult. Therefore, dexamethasone should be added to the treatment regimen for patients with HAPE with neurologic dysfunction that does not resolve rapidly with administration of supplemental oxygen and improvement in oxygen saturation. If supplemental oxygen is not available, dexamethasone should be started in addition to the medications for HAPE in patients with altered mental status and/or suspected concurrent HACE. Nifedipine or other pulmonary vasodilators may be used in patients with concurrent HAPE and HACE, with care to avoid lowering mean arterial pressure, as this may decrease cerebral perfusion pressure and thus increase the risk for cerebral ischemia.

## Conclusions

We have provided evidence-based guidelines for prevention and treatment of acute altitude illnesses, including the main prophylactic and therapeutic modalities for AMS, HACE, and HAPE, and recommendations regarding their role in disease management. Although these guidelines cover many of the important issues related to prevention and treatment of altitude illness, several important questions remain to be addressed and should serve as a focus for future research. Such research includes determining the optimal rate of ascent to prevent altitude illness, the role of acetazolamide in HAPE prevention and treatment, proper dosing regimens for prevention and treatment of altitude illness in the pediatric population, and the role of staged ascent, preacclimatization, and hypoxic tents in altitude illness prevention.

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## Supplementary materials

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## References

1. Guyatt G, Gutterman D, Baumann MH, Addrizzo-Harris D, Hylek EM, Phillips B, et al. Grading strength of recommendations and quality of evidence in clinical guidelines: report from an American College of Chest Physicians task force. *Chest*. 2006;129(1):174–81.
2. Luks AM, McIntosh SE, Grissom CK, Auerbach PS, Rodway GW, Schoene RB, et al. Wilderness Medical Society consensus guidelines for the prevention and treatment of acute altitude illness. *Wilderness Environ Med*. 2010;21(2):146–55.
3. Luks AM, McIntosh SE, Grissom CK, Auerbach PS, Rodway GW, Schoene RB, et al. Wilderness Medical Society Practice Guidelines for the prevention and treatment of acute altitude illness: 2014 update. *Wilderness Environ Med*. 2014;25(4S):S4–14.
4. Montgomery AB, Mills J, Luce JM. Incidence of acute mountain sickness at intermediate altitude. *JAMA*. 1989;261(5):732–4.
5. Honigman B, Theis MK, Koziol-McLain J, Roach R, Yip R, Houston C, et al. Acute mountain sickness in a general tourist population at moderate altitudes. *Ann Intern Med*. 1993;118(8):587–92.
6. Gabry AL, Ledoux X, Mozziconacci M, Martin C. High-altitude pulmonary edema at moderate altitude (< 2,400 m; 7,870 feet): a series of 52 patients. *Chest*. 2003;123(1):49–53.
7. Hackett PH, Yarnell PR, Weiland DA, Reynard KB. Acute and evolving MRI of high-altitude cerebral edema: microbleeds, edema, and pathophysiology. *AJNR Am J Neuroradiol*. 2019;40(3):464–9.
8. Southard A, Niermeyer S, Yaron M. Language used in Lake Louise Scoring System underestimates symptoms of acute mountain sickness in 4- to 11-year-old children. *High Alt Med Biol*. 2007;8(2):124–30.
9. Muhm JM, Rock PB, McMullin DL, Jones SP, Lu IL, Eilers KD, et al. Effect of aircraft-cabin altitude on passenger discomfort. *N Engl J Med*. 2007;357(1):18–27.
10. Theis MK, Honigman B, Yip R, McBride D, Houston CS, Moore LG. Acute mountain sickness in children at 2835 meters. *Am J Dis Child*. 1993;147(2):143–5.
11. Hackett PH, Roach RC. High-altitude illness. *N Engl J Med*. 2001;345(2):107–14.
12. Hackett PH, Roach RC. High altitude cerebral edema. *High Alt Med Biol*. 2004;5(2):136–46.
13. Bartsch P, Swenson ER. Clinical practice: acute high-altitude illnesses. *N Engl J Med*. 2013;368(24):2294–302.

14. Hackett PH, Luks AM, Lawley JS, Roach RC. High altitude medicine and pathophysiology. In: Auerbach PS, ed. *Auerbach's Wilderness Medicine*. Philadelphia: Elsevier; 2017.
15. Bloch KE, Turk AJ, Maggiorini M, Hess T, Merz T, Bosch MM, et al. Effect of ascent protocol on acute mountain sickness and success at Muztagh Ata, 7546 m. *High Alt Med Biol*. 2009;10(1):25–32.
16. Beidleman BA, Fulco CS, Muza SR, Rock PB, Staab JE, Forte VA, et al. Effect of six days of staging on physiologic adjustments and acute mountain sickness during ascent to 4300 meters. *High Alt Med Biol*. 2009;10(3):253–60.
17. Hackett PH, Rennie D, Levine HD. The incidence, importance, and prophylaxis of acute mountain sickness. *Lancet*. 1976;2(7996):1149–55.
18. Forwand SA, Landowne M, Follansbee JN, Hansen JE. Effect of acetazolamide on acute mountain sickness. *N Engl J Med*. 1968;279(16):839–45.
19. Basnyat B, Gertsch JH, Holck PS, Johnson EW, Luks AM, Donham BP, et al. Acetazolamide 125 mg BD is not significantly different from 375 mg BD in the prevention of acute mountain sickness: the prophylactic acetazolamide dosage comparison for efficacy (PACE) trial. *High Alt Med Biol*. 2006;7(1):17–27.
20. van Patot MC, Leadbetter 3rd G, Keyes LE, Maakestad KM, Olson S, Hackett PH. Prophylactic low-dose acetazolamide reduces the incidence and severity of acute mountain sickness. *High Alt Med Biol*. 2008;9(4):289–93.
21. Low EV, Avery AJ, Gupta V, Schedlbauer A, Grocott MP. Identifying the lowest effective dose of acetazolamide for the prophylaxis of acute mountain sickness: systematic review and meta-analysis. *BMJ*. 2012;345:e6779.
22. Luks AM, Swenson ER. Medication and dosage considerations in the prophylaxis and treatment of high-altitude illness. *Chest*. 2008;133(3):744–55.
23. Elisabeth E, Hannes G, Johannes B, Martin F, Elena P, Martin B. Effects of low-dose acetazolamide on exercise performance in simulated altitude. *Int J Physiol Pathophysiol Pharmacol*. 2017;9(2):28–34.
24. Bradwell AR, Myers SD, Beazley M, Ashdown K, Harris NG, Bradwell SB, et al. Exercise limitation of acetazolamide at altitude (3459 m). *Wilderness Environ Med*. 2014;25(3):272–7.
25. Gonzales JU, Scheuermann BW. Effect of acetazolamide on respiratory muscle fatigue in humans. *Respir Physiol Neurobiol*. 2013;185(2):386–92.
26. McIntosh SE, Hemphill M, McDevitt MC, Gurung TY, Ghale M, Knott JR, et al. Reduced acetazolamide dosing in countering altitude illness: a comparison of 62.5 vs 125 mg (the RADICAL Trial). *Wilderness Environ Med*. 2019;30(1):12–21.
27. Pollard AJ, Niermeyer S, Barry P, Bartsch P, Berghold F, Bishop RA, et al. Children at high altitude: an international consensus statement by an ad hoc committee of the International Society for Mountain Medicine, March 12, 2001. *High Alt Med Biol*. 2001;2(3):389–403.
28. Ellsworth AJ, Larson EB, Strickland D. A randomized trial of dexamethasone and acetazolamide for acute mountain sickness prophylaxis. *Am J Med*. 1987;83(6):1024–30.
29. Ellsworth AJ, Meyer EF, Larson EB. Acetazolamide or dexamethasone use versus placebo to prevent acute mountain sickness on Mount Rainier. *West J Med*. 1991;154(3):289–93.
30. Chrousos G, Pavlaki AN, Magiakou MA, et al. Glucocorticoid therapy and adrenal suppression. In: De Groot LJ, Chrousos G, Dungan K, eds. *Endotext*. South Dartmouth, MA: MDText.com; 2011.
31. Zheng CR, Chen GZ, Yu J, Qin J, Song P, Bian SZ, et al. Inhaled budesonide and oral dexamethasone prevent acute mountain sickness. *Am J Med*. 2014;127(10):1001–9. e2.
32. Chen GZ, Zheng CR, Qin J, Yu J, Wang H, Zhang JH, et al. Inhaled budesonide prevents acute mountain sickness in young Chinese men. *J Emerg Med*. 2015;48(2):197–206.
33. Berger MM, Macholz F, Sareban M, Schmidt P, Fried S, Dankl D, et al. Inhaled budesonide does not prevent acute mountain sickness after rapid ascent to 4559 m. *Eur Respir J*. 2017;50(3).
34. Lipman GS, Pomeranz D, Burns P, Phillips C, Cheffers M, Evans K, et al. Budesonide versus acetazolamide for prevention of acute mountain sickness. *Am J Med*. 2018;131(2):e9–16.
35. Roncin JP, Schwartz F, D'Arbigny P. EGb 761 in control of acute mountain sickness and vascular reactivity to cold exposure. *Aviat Space Environ Med*. 1996;67(5):445–52.
36. Moraga FA, Flores A, Serra J, Esnaola C, Barriento C. *Ginkgo biloba* decreases acute mountain sickness in people ascending to high altitude at Ollague (3696 m) in northern Chile. *Wilderness Environ Med*. 2007;18(4):251–7.
37. Gertsch JH, Basnyat B, Johnson EW, Onopa J, Holck PS. Randomised, double blind, placebo controlled comparison of *Ginkgo biloba* and acetazolamide for prevention of acute mountain sickness among Himalayan trekkers: the prevention of high altitude illness trial (PHAIT). *BMJ*. 2004;328(7443):797.
38. Chow T, Browne V, Heileson HL, Wallace D, Anholm J, Green SM. *Ginkgo biloba* and acetazolamide prophylaxis for acute mountain sickness: a randomized, placebo-controlled trial. *Arch Intern Med*. 2005;165(3):296–301.
39. Leadbetter G, Keyes LE, Maakestad KM, Olson S, Tissot van Patot MC, Hackett PH. *Ginkgo biloba* does—and does not—prevent acute mountain sickness. *Wilderness Environ Med*. 2009;20(1):66–71.
40. Dugoua JJ, Mills E, Perri D, Koren G. Safety and efficacy of ginkgo (*Ginkgo biloba*) during pregnancy and lactation. *Can J Clin Pharmacol*. 2006;13(3):e277–84.
41. Stoddard GJ, Archer M, Shane-McWhorter L, Bray BE, Redd DF, Proulx J, et al. *Ginkgo* and warfarin interaction in a large veterans administration population. *AMIA Annu Symp Proc*. 2015;2015:1174–83.
42. Gertsch JH, Corbett B, Holck PS, Mulcahy A, Watts M, Stillwagon NT, et al. Altitude Sickness in Climbers and Efficacy of NSAIDs Trial (ASCENT): randomized, controlled

trial of ibuprofen versus placebo for prevention of altitude illness. *Wilderness Environ Med*. 2012;23(4):307–15.
43. Lipman GS, Kanaan NC, Holck PS, Constance BB, Gertsch JH. Ibuprofen prevents altitude illness: a randomized controlled trial for prevention of altitude illness with nonsteroidal anti-inflammatories. *Ann Emerg Med*. 2012; 59(6):484–90.
44. Lundeberg J, Feiner JR, Schober A, Sall JW, Eilers H, Bickler PE. Increased cytokines at high altitude: lack of effect of ibuprofen on acute mountain sickness, physiological variables, or cytokine levels. *High Alt Med Biol*. 2018;19(3):249–58.
45. Kanaan NC, Peterson AL, Pun M, Holck PS, Starling J, Basyal B, et al. Prophylactic acetaminophen or ibuprofen results in equivalent acute mountain sickness incidence at high altitude: a prospective randomized trial. *Wilderness Environ Med*. 2017;28(2):72–8.
46. Gertsch JH, Lipman GS, Holck PS, Merritt A, Mulcahy A, Fisher RS, et al. Prospective, double-blind, randomized, placebo-controlled comparison of acetazolamide versus ibuprofen for prophylaxis against high altitude headache: the Headache Evaluation at Altitude Trial (HEAT). *Wilderness Environ Med*. 2010;21(3):236–43.
47. Burns P, Lipman GS, Warner K, Jurkiewicz C, Phillips C, Sanders L, et al. Altitude sickness prevention with ibuprofen relative to acetazolamide. *Am J Med*. 2019;132 (2):247–51.
48. Baggish AL, Fulco CS, Muza S, Rock PB, Beidleman B, Cymerman A, et al. The impact of moderate-altitude staging on pulmonary arterial hemodynamics after ascent to high altitude. *High Alt Med Biol*. 2010;11(2):139–45.
49. Lyons TP, Muza SR, Rock PB, Cymerman A. The effect of altitude pre-acclimatization on acute mountain sickness during reexposure. *Aviat Space Environ Med*. 1995;66 (10):957–62.
50. Beidleman BA, Muza SR, Fulco CS, Cymerman A, Ditzler D, Stulz D, et al. Intermittent altitude exposures reduce acute mountain sickness at 4300 m. *Clin Sci (Lond)*. 2004;106(3):321–8.
51. Wille M, Gatterer H, Mairer K, Philippe M, Schwarzenbacher H, Faulhaber M, et al. Short-term intermittent hypoxia reduces the severity of acute mountain sickness. *Scand J Med Sci Sports*. 2012;22(5):e79–85.
52. Burse RL, Forte Jr VA. Acute mountain sickness at 4500 m is not altered by repeated eight-hour exposures to 3200−3550 m normobaric hypoxic equivalent. *Aviat Space Environ Med*. 1988;59(10):942–9.
53. Schommer K, Wiesegart N, Menold E, Haas U, Lahr K, Buhl H, et al. Training in normobaric hypoxia and its effects on acute mountain sickness after rapid ascent to 4559 m. *High Alt Med Biol*. 2010;11(1):19–25.
54. Fulco CS, Muza SR, Beidleman BA, Demes R, Staab JE, Jones JE, et al. Effect of repeated normobaric hypoxia exposures during sleep on acute mountain sickness, exercise performance, and sleep during exposure to terrestrial altitude. *Am J Physiol Regul Integr Comp Physiol*. 2011; 300(2):R428–36.
55. Faulhaber M, Pocecco E, Gatterer H, Niedermeier M, Huth M, Dunnwald T, et al. Seven passive 1-h hypoxia exposures do not prevent AMS in susceptible individuals. *Med Sci Sports Exerc*. 2016;48(12):2563–70.
56. Fulco CS, Beidleman BA, Muza SR. Effectiveness of preacclimatization strategies for high-altitude exposure. *Exerc Sport Sci Rev*. 2013;41(1):55–63.
57. Dehnert C, Bohm A, Grigoriev I, Menold E, Bartsch P. Sleeping in moderate hypoxia at home for prevention of acute mountain sickness (AMS): a placebo-controlled, randomized double-blind study. *Wilderness Environ Med*. 2014;25(3):263–71.
58. Baillie JK, Thompson AA, Irving JB, Bates MG, Sutherland AI, Macnee W, et al. Oral antioxidant supplementation does not prevent acute mountain sickness: double blind, randomized placebo-controlled trial. *QJM*. 2009;102(5):341–8.
59. Talbot NP, Smith TG, Privat C, Nickol AH, Rivera-Ch M, Leon-Velarde F, et al. Intravenous iron supplementation may protect against acute mountain sickness: a randomized, double-blinded, placebo-controlled trial. *High Alt Med Biol*. 2011;12(3):265–9.
60. Rossetti GMK, Macdonald JH, Wylie LJ, Little SJ, Newton V, Wood B, et al. Dietary nitrate supplementation increases acute mountain sickness severity and sense of effort during hypoxic exercise. *J Appl Physiol (1985)*. 2017;123(4):983–92.
61. Grissom CK, Richer LD, Elstad MR. The effects of a 5-lipoxygenase inhibitor on acute mountain sickness and urinary leukotriene e4 after ascent to high altitude. *Chest*. 2005;127(2):565–70.
62. Luks AM, Henderson WR, Swenson ER. Leukotriene receptor blockade does not prevent acute mountain sickness induced by normobaric hypoxia. *High Alt Med Biol*. 2007;8(2):131–8.
63. Bates MG, Thompson AA, Baillie JK, Sutherland AI, Irving JB, Hirani N, et al. Sildenafil citrate for the prevention of high altitude hypoxic pulmonary hypertension: double blind, randomized, placebo-controlled trial. *High Alt Med Biol*. 2011;12(3):207–14.
64. Kayser B, Hulsebosch R, Bosch F. Low-dose acetylsalicylic acid analog and acetazolamide for prevention of acute mountain sickness. *High Alt Med Biol*. 2008;9 (1):15–23.
65. Basnyat B, Holck PS, Pun M, Halverson S, Szawarski P, Gertsch J, et al. Spironolactone does not prevent acute mountain sickness: a prospective, double-blind, randomized, placebo-controlled trial by SPACE Trial Group (spironolactone and acetazolamide trial in the prevention of acute mountain sickness group). *Wilderness Environ Med*. 2011;22(1):15–22.
66. Jafarian S, Gorouhi F, Salimi S, Lotfi J. Sumatriptan for prevention of acute mountain sickness: randomized clinical trial. *Ann Neurol*. 2007;62(3):273–7.
67. Lipman GS, Kanaan NC, Phillips C, Pomeranz D, Cain P, Fontes K, et al. Study Looking at End Expiratory Pressure for Altitude Illness Decrease (SLEEP-AID). *High Alt Med Biol*. 2015;16(2):154–61.

68. Berger MM, Macholz F, Lehmann L, Dankl D, Hochreiter M, Bacher B, et al. Remote ischemic preconditioning does not prevent acute mountain sickness after rapid ascent to 3,450 m. *J Appl Physiol (1985)*. 2017;123 (5):1228–34.
69. Bartsch P, Merki B, Hofstetter D, Maggiorini M, Kayser B, Oelz O. Treatment of acute mountain sickness by simulated descent: a randomised controlled trial. *BMJ*. 1993;306 (6885):1098–101.
70. Keller HR, Maggiorini M, Bartsch P, Oelz O. Simulated descent v dexamethasone in treatment of acute mountain sickness: a randomised trial. *BMJ*. 1995;310(6989): 1232–5.
71. Taber RL. Protocols for the use of portable hyperbaric chambers for the treatment of high altitude disorders. *J Wild Med*. 1990;1:181–92.
72. Grissom CK, Roach RC, Sarnquist FH, Hackett PH. Acetazolamide in the treatment of acute mountain sickness: clinical efficacy and effect on gas exchange. *Ann Intern Med*. 1992;116(6):461–5.
73. Ferrazzini G, Maggiorini M, Kriemler S, Bartsch P, Oelz O. Successful treatment of acute mountain sickness with dexamethasone. *Br Med J (Clin Res Ed)*. 1987;294 (6584):1380–2.
74. Hackett PH, Roach RC, Wood RA, Foutch RG, Meehan RT, Rennie D, et al. Dexamethasone for prevention and treatment of acute mountain sickness. *Aviat Space Environ Med*. 1988;59(10):950–4.
75. Levine BD, Yoshimura K, Kobayashi T, Fukushima M, Shibamoto T, Ueda G. Dexamethasone in the treatment of acute mountain sickness. *N Engl J Med*. 1989;321 (25):1707–13.
76. Harris NS, Wenzel RP, Thomas SH. High altitude headache: efficacy of acetaminophen vs. ibuprofen in a randomized, controlled trial. *J Emerg Med*. 2003;24(4):383–7.
77. Johnson PL, Johnson CC, Poudyal P, Regmi N, Walmsley MA, Basnyat B. Continuous positive airway pressure treatment for acute mountain sickness at 4240 m in the Nepal Himalaya. *High Alt Med Biol*. 2013;14(3):230–3.
78. Walmsley M. Continuous positive airway pressure as adjunct treatment of acute altitude illness. *High Alt Med Biol*. 2013;14(4):405–7.
79. Stream JO, Grissom CK. Update on high-altitude pulmonary edema: pathogenesis, prevention, and treatment. *Wilderness Environ Med*. 2008;19(4):293–303.
80. Bartsch P, Mairbaurl H, Maggiorini M, Swenson ER. Physiological aspects of high-altitude pulmonary edema. *J Appl Physiol*. 2005;98(3):1101–10.
81. Bartsch P, Maggiorini M, Mairbaurl H, Vock P, Swenson ER. Pulmonary extravascular fluid accumulation in climbers. *Lancet*. 2002;360(9332):571; author reply −2.
82. Singh I, Kapila CC, Khanna PK, Nanda RB, Rao BD. High-altitude pulmonary oedema. *Lancet*. 1965;191:229–34.
83. Bartsch P, Maggiorini M, Ritter M, Noti C, Vock P, Oelz O. Prevention of high-altitude pulmonary edema by nifedipine. *N Engl J Med*. 1991;325(18):1284–9.
84. Sartori C, Allemann Y, Duplain H, Lepori M, Egli M, Lipp E, et al. Salmeterol for the prevention of high-altitude pulmonary edema. *N Engl J Med*. 2002;346(21):1631–6.
85. Maggiorini M, Brunner-La Rocca HP, Peth S, Fischler M, Bohm T, Bernheim A, et al. Both tadalafil and dexamethasone may reduce the incidence of high-altitude pulmonary edema: a randomized trial. *Ann Intern Med*. 2006; 145(7):497–506.
86. Hohne C, Krebs MO, Seiferheld M, Boemke W, Kaczmarczyk G, Swenson ER. Acetazolamide prevents hypoxic pulmonary vasoconstriction in conscious dogs. *J Appl Physiol*. 2004;97(2):515–21.
87. Shimoda LA, Luke T, Sylvester JT, Shih HW, Jain A, Swenson ER. Inhibition of hypoxia-induced calcium responses in pulmonary arterial smooth muscle by acetazolamide is independent of carbonic anhydrase inhibition. *Am J Physiol Lung Cell Mol Physiol*. 2007;292(4): L1002–12.
88. Pickerodt PA, Francis RC, Hohne C, Neubert F, Telalbasic S, Boemke W, et al. Pulmonary vasodilation by acetazolamide during hypoxia: impact of methyl-group substitutions and administration route in conscious, spontaneously breathing dogs. *J Appl Physiol (1985)*. 2014; 116(7):715–23.
89. Teppema LJ, Balanos GM, Steinback CD, Brown AD, Foster GE, Duff HJ, et al. Effects of acetazolamide on ventilatory, cerebrovascular, and pulmonary vascular responses to hypoxia. *Am J Respir Crit Care Med*. 2007; 175(3):277–81.
90. Liptzin DR, Abman SH, Giesenhagen A, Ivy DD. An approach to children with pulmonary edema at high altitude. *High Alt Med Biol*. 2018;19(1):91–8.
91. Marticorena E, Hultgren HN. Evaluation of therapeutic methods in high altitude pulmonary edema. *Am J Cardiol*. 1979;43(2):307–12.
92. Zafren K, Reeves JT, Schoene R. Treatment of high-altitude pulmonary edema by bed rest and supplemental oxygen. *Wilderness Environ Med*. 1996;7(2):127–32.
93. Yanamandra U, Nair V, Singh S, Gupta A, Mulajkar D, Yanamandra S, et al. Managing high-altitude pulmonary edema with oxygen alone: results of a randomized controlled trial. *High Alt Med Biol*. 2016;17(4):294–9.
94. Freeman K, Shalit M, Stroh G. Use of the Gamow Bag by EMT-basic park rangers for treatment of high-altitude pulmonary edema and high-altitude cerebral edema. *Wilderness Environ Med*. 2004;15(3):198–201.
95. Oelz O, Maggiorini M, Ritter M, Waber U, Jenni R, Vock P, et al. Nifedipine for high altitude pulmonary oedema. *Lancet*. 1989;2(8674):1241–4.
96. Deshwal R, Iqbal M, Basnet S. Nifedipine for the treatment of high altitude pulmonary edema. *Wilderness Environ Med*. 2012;23(1):7–10.
97. Fagenholz PJ, Gutman JA, Murray AF, Harris NS. Treatment of high altitude pulmonary edema at 4240 m in Nepal. *High Alt Med Biol*. 2007;8(2):139–46.
98. Jones BE, Stokes S, McKenzie S, Nilles E, Stoddard GJ. Management of high altitude pulmonary edema in the

Himalaya: a review of 56 cases presenting at Pheriche medical aid post (4240 m). *Wilderness Environ Med*. 2013;24(1):32–6.

99. Schoene RB, Roach RC, Hackett PH, Harrison G, Mills Jr WJ. High altitude pulmonary edema and exercise at 4,400 meters on Mount McKinley. Effect of expiratory positive airway pressure. *Chest*. 1985;87(3):330–3.
100. Singh I, Lal M, Khanna PK, Mathew NT. Augmentation of frusemide diuresis by morphine in high altitude pulmonary oedema. *Br Heart J*. 1967;29(5):709–13.
101. Siebenmann C, Bloch KE, Lundby C, Nussbamer-Ochsner Y, Schoeb M, Maggiorini M. Dexamethasone improves maximal exercise capacity of individuals susceptible to high altitude pulmonary edema at 4559 m. *High Alt Med Biol*. 2011;12(2):169–77.
102. Urner M, Herrmann IK, Booy C, Z'Graggen BR, Maggiorini M, Beck-Schimmer B. Effect of hypoxia and dexamethasone on inflammation and ion transporter function in pulmonary cells. *Clin Exp Immunol*. 2012; 169(2):119–28.
103. Roach RC, Hackett PH, Oelz O, Bartsch P, Luks AM, MacInnis MJ, et al. The 2018 Lake Louise Acute Mountain Sickness Score. *High Alt Med Biol*. 2018;19(1): 4–6.

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# The 2018 Lake Louise Acute Mountain Sickness Score

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**Abstract**

Roach, Robert C., Peter H. Hackett, Oswald Oelz, Peter Bärtsch, Andrew M. Luks, Martin J. MacInnis, J. Kenneth Baillie, and The Lake Louise AMS Score Consensus Committee. The 2018 Lake Louise Acute Mountain Sickness Score. *High Alt Med Biol*. 19:4–6, 2018.— The Lake Louise Acute Mountain Sickness (AMS) scoring system has been a useful research tool since first published in 1991. Recent studies have shown that disturbed sleep at altitude, one of the five symptoms scored for AMS, is more likely due to altitude hypoxia per se, and is not closely related to AMS. To address this issue, and also to evaluate the Lake Louise AMS score in light of decades of experience, experts in high altitude research undertook to revise the score. We here present an international consensus statement resulting from online discussions and meetings at the International Society of Mountain Medicine World Congress in Bolzano, Italy, in May 2014 and at the International Hypoxia Symposium in Lake Louise, Canada, in February 2015. The consensus group has revised the score to eliminate disturbed sleep as a questionnaire item, and has updated instructions for use of the score.

**Keywords:** AMS; high altitude illness; history; Lake Louise; symptom scores

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## Introduction

Acute mountain sickness (AMS) is the most common form of acute altitude illness and typically occurs in unacclimatized persons ascending to altitudes >2500 m, although it can develop at lower altitudes in highly susceptible individuals. Established risk factors include rate of ascent, altitude reached, and individual predisposition. With 25 years of use in hundreds of publications, the Lake Louise AMS score has provided a robust and practical tool for researchers to diagnose and to score the severity of AMS. Recent opinion (Milledge, 2014) and research (MacInnis et al., 2013; Hall et al., 2014) have suggested that updating the Lake Louise AMS score is in order. This article outlines the brief historical background, reviews diagnostic criteria, describes modifications to the score, and offers suggested experimental procedures that may improve the use of the score in future studies.

## Background

At the 1991 International Hypoxia Symposium, the participants executed a consensus process chaired by Peter Hackett and Oswald Oelz (Hackett et al., 1992; supplementary reprint of original article is available online at www.liebertpub.com/ham) to define and quantify the various altitude illnesses. Subsequently at the 1993 conference, all delegates were given the opportunity to have input into the preparation of the document. The score for AMS consisted of the five symptoms (headache, gastrointestinal upset, fatigue/weakness, dizziness/light-headedness, and sleep disturbance), rated on a scale of severity from 0 to 3. The double-worded terms were to facilitate understanding as well as translation into many languages (Roach et al., 1993; supplementary reprint of original article is available online at www.liebertpub.com/ham). A total score ≥3, in the presence of a headache, was considered diagnostic for AMS.

## Methods

This effort is the result of online discussions and meetings at the International Society of Mountain Medicine World Congress in Bolzano, Italy, in May 2014 and at the International Hypoxia Symposium in Lake Louise, Canada, in February 2015. Members of the consensus committee are those who have participated in the online or in-person discussions and are listed in alphabetical order in the box.

## Rationale for Revising the Lake Louise AMS Score

Although use of the scoring system has helped standardize the diagnosis and severity of AMS across research studies, debate has persisted since its inception regarding whether sleep should be included in the diagnostic criteria. Recently this discussion has intensified. Two independent reports in 2013 provided empirical evidence that sleep disturbance is discordant from other symptoms of AMS (MacInnis et al., 2013; Hall et al., 2014). Hall et al. (2014) used network analysis of data from 292 research volunteers exposed to altitudes from 3650 to 5200 m to demonstrate that sleep disturbance correlated poorly with other symptoms of AMS. Importantly, sleep disturbance was absent in 40% of cases with severe headache, long considered a hallmark of AMS. MacInnis et al. (2013) applied factor analysis to Lake Louise AMS scores of 491 Nepalese pilgrims at 4390 m and revealed that sleep had only a weak relationship with the other four symptoms in the score. Milledge also expressed doubt as to whether sleep disturbance was a symptom of AMS, or rather an effect of hypoxia *per se*, based on his own experience with AMS studies (Milledge, 2014). Another problem recognized over time is that many studies of AMS have used only daytime exposures, making the sleep component irrelevant. Without a score for sleep in these studies, comparison with overnight studies is difficult. Based on these concerns, the consensus committee recommends that the sleep component be removed from the Lake Louise AMS score.

## Diagnostic Criteria and Assessment of AMS

AMS is defined as a Lake Louise AMS score total of three or more points from the four rated symptoms, including at least one point from headache in the setting of a recent ascent or gain in altitude (Roach et al., 2011; West, 2011) (Table 1). Some authors have suggested a higher cutoff for diagnosing AMS (Maggiorini et al., 1998; Bärtsch et al., 2004), but the consensus committee believes that by eliminating the sleep question, more people with true AMS will be identified at the threshold of three points, including headache. Sufficient research is lacking to divide the score into severity rankings. For those who wish to do so, we suggest mild AMS as 3–5 points, moderate AMS as 6–9 points, and severe AMS as 10–12 points. Although symptoms can develop within 6 hours of gain in altitude, we recommend assessing AMS score only after 6 hours, to avoid confusing AMS with confounding symptoms from travel or responses to acute hypoxia (e.g., vagal responses). If investigators wish to assess the impact of AMS symptoms on overall function at high altitude, the ''AMS Clinical Functional Score'' is available (Table 1).

Table 1. 2018 Lake Louise Acute Mountain Sickness Score

| |
|---|
| Headache |
| 0—None at all |
| 1—A mild headache |
| 2—Moderate headache |
| 3—Severe headache, incapacitating |
| Gastrointestinal symptoms |
| 0—Good appetite |
| 1—Poor appetite or nausea |
| 2—Moderate nausea or vomiting |
| 3—Severe nausea and vomiting, incapacitating |
| Fatigue and/or weakness |
| 0—Not tired or weak |
| 1—Mild fatigue/weakness |
| 2—Moderate fatigue/weakness |
| 3—Severe fatigue/weakness, incapacitating |
| Dizziness/light-headedness |
| 0—No dizziness/light-headedness |
| 1—Mild dizziness/light-headedness |
| 2—Moderate dizziness/light-headedness |
| 3—Severe dizziness/light-headedness, incapacitating |
| AMS Clinical Functional Score |
| Overall, if you had AMS symptoms, how did they affect your activities? |
| 0—Not at all |
| 1—Symptoms present, but did not force any change in activity or itinerary |
| 2—My symptoms forced me to stop the ascent or to go down on my own power |
| 3—Had to be evacuated to a lower altitude |

AMS must not be confused with high-altitude cerebral edema (HACE). AMS alone exhibits no neurological findings, and is self-limited. In contrast, HACE, which usually comes on between 24 and 72 hours after a gain in altitude, is characterized by change in mental status and/or ataxia, occurs usually in a person with AMS or high-altitude pulmonary edema, and is a medical emergency (Hackett and Roach, 2004; Willmann et al., 2014).

### Directions for Using the Lake Louise AMS Score

This Lake Louise AMS score is for use by investigators studying AMS. It is not intended for use by clinicians, professional outdoor guides, and laypersons to diagnose or manage AMS. After a recent gain in altitude or induction of hypoxia, and an exposure of at least 6 hours duration, the AMS score is used as follows:

1. The Lake Louise AMS score is designed as a self-report questionnaire that research volunteers complete on their own. However, some investigators prefer to read the question to the volunteer and record the answers, whereas others use a two-step method wherein the volunteer first completes the score, then the investigator verbally verifies the answers. These options are acceptable as long as a uniform approach is used with all subjects in a study and the method of collecting data is clearly described in subsequent reports.
2. The Lake Louise AMS score for an individual is the sum of the score for the four symptoms (headache, nausea/vomiting, fatigue, and dizziness/light-headedness). For a positive AMS definition, it is mandatory to have a headache score of at least one point, and a total score of at least three points.

   *Example 1: A total score greater than two points but with no headache is defined as NO AMS for research purposes, although absence of a headache does not exclude a diagnosis for clinical purposes.*
   *Example 2: A score of three points for a severe headache, with no other AMS symptoms, is defined as AMS.*
3. We suggest using the AMS clinical functional score and reporting it when suitable to the study design (Roach et al., 1993; supplementary reprint of original article is available online at www.liebertpub.com/ham; Meier et al., 2017).

### Avenues for Future Research

Further research should focus on the following areas: (1) best methods for Lake Louise AMS score administration; that is, is investigator-led scoring different/better than volunteer-completed scores? (2) the impact of experimental design, the testing environment, and expectations of research volunteers (i.e., nocebo) (Benedetti et al., 2014) on reliability of Lake Louise AMS score; (3) the clinical and functional impact(s) of AMS score severity; (4) best practices for use of the Lake Louise AMS score and clinical functional score by nonexpert clinicians, mountain guides, and laypersons (Roach et al., 1993; supplementary reprint of original article is available online at www.liebertpub.com/ham; Meier et al., 2017); (5) the impact of disturbed sleep on overall well-being at high altitude, independent of AMS; and (6) the pathophysiology of typical AMS vs. presentation without headache (Roach et al., 2011; West, 2011). In addition, we strongly encourage researchers to publish all individual scores for all volunteers and all symptoms. This will allow other researchers to directly compare patterns of illness, to compile meta-analyses, and to examine the raw data for ideas and observations that will further refine the consensus definition and scoring of AMS.

### Author Disclosure Statement

No competing financial interests exist.

### References

Bärtsch P, Bailey DM, Berger MM, Knauth M, and Baumgartner RW. (2004). Acute mountain sickness: Controversies and advances. High Alt Med Biol 5:110–124.

Benedetti F, Durando J, and Vighetti S. (2014). Nocebo and placebo modulation of hypobaric hypoxia headache involves the cyclooxygenase-prostaglandins pathway. Pain 155:921–928.

Hackett PH, and Oelz O. (1992). The Lake Louise Consensus on the definition and quantification of altitude illness. In: Hypoxia and Mountain Medicine. JR Sutton, CS Houston, G Coates, eds. Queen City Press, Burlington, VT. pp 327–330.

Hackett PH, and Roach RC. (2004). High altitude cerebral edema. High Alt Med Biol 5:136–146.

Hall DP, MacCormick IJ, Phythian-Adams AT, Rzechorzek NM, Hope-Jones D, Cosens S, Jackson S, Bates MG, Collier DJ, Hume DA, et al. (2014). Network analysis reveals distinct clinical syndromes underlying acute mountain sickness. PLoS One 9:e81229.

MacInnis MJ, Lanting SC, Rupert JL, and Koehle MS. (2013). Is poor sleep quality at high altitude separate from acute mountain sickness? Factor structure and internal consistency of the Lake Louise Score Questionnaire. High Alt Med Biol 14:334–337.

Maggiorini M, Muller A, Hofstetter D, Bärtsch P, and Oelz O. (1998). Assessment of acute mountain sickness by different score protocols in the Swiss Alps. Aviat Space Environ Med 69:1186–1192.

Meier D, Collet TH, Locatelli I, Cornuz J, Kayser B, Simel DL, and Sartori C. (2017). Does this patient have acute mountain sickness?: The rational clinical examination systematic review. JAMA 318:1810–1819.

Milledge JS. (2014). Should sleep quality be part of the Lake Louise Acute Mountain Sickness Score? High Alt Med Biol 15:208.

Roach RC, Bärtsch P, Hackett PH, and Oelz O. (1993). The Lake Louise Acute Mountain Sickness Scoring System. In: Hypoxia and Molecular Medicine. JR Sutton, CS Houston, G Coates, eds. Queen City Press, Burlington, VT. pp 272–274.

Roach RC, Kayser B, and Hackett PH. (2011). Pro: Headache should be a required symptom for the diagnosis of acute mountain sickness. High Alt Med Biol 12:21–22.

West JB. (2011). Con: Headache should not be a required symptom for the diagnosis of acute mountain sickness. High Alt Med Biol 12:23–25.

Willmann G, Gekeler F, Schommer K, and Bärtsch P. (2014). Update on high altitude cerebral edema including recent work on the eye. High Alt Med Biol 15:112–122.

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WILDERNESS MEDICAL SOCIETY PRACTICE GUIDELINES

# Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Frostbite: 2019 Update

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The Wilderness Medical Society convened an expert panel to develop a set of evidence-based guidelines for prevention and treatment of frostbite. We present a review of pertinent pathophysiology. We then discuss primary and secondary prevention measures and therapeutic management. Recommendations are made regarding each treatment and its role in management. These recommendations are graded on the basis of the quality of supporting evidence and balance between the benefits and risks or burdens for each modality according to methodology stipulated by the American College of Chest Physicians. This is an updated version of the guidelines published in 2014.

*Keywords:* hypothermia, rewarming, aloe vera, thrombolysis, tPA, iloprost

## Introduction

The Wilderness Medical Society (WMS) convened an expert panel to develop a set of evidence-based guidelines for prevention and treatment of frostbite to guide clinicians and first responders and disseminate knowledge about best practices in this area of clinical care. We present the main prophylactic and therapeutic modalities and make recommendations about their role in injury management. Recommendations are graded on the basis of the quality of supporting evidence and balance between the benefits and risks or burdens for each modality. We then provide suggested approaches for prevention and management that incorporate these recommendations.

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The original expert panel was convened at the 2010 Annual Winter Meeting of the WMS in Park City, UT. Members were selected on the basis of their clinical or research experience. Relevant articles were identified through the MEDLINE database using the search terms frostbite, frostbite management, prehospital frostbite treatment, prehospital frostbite management, frostbite prevention, first aid frostbite treatment, and first aid frostbite and were restricted to the English language. Studies in these categories were reviewed, and level of evidence was assessed. The panel used a consensus approach to develop recommendations regarding each modality and graded each recommendation according to criteria stipulated by the American College of Chest Physicians statement on grading recommendations and strength of evidence in clinical guidelines (online Supplementary Table 1).[1] This is an updated version of the guidelines published in 2014.[2]

## Pathophysiology of frostbite

Frostbite is a freezing injury that may be divided into 4 overlapping pathologic phases: prefreeze, freeze–thaw,

vascular stasis, and late ischemic. The prefreeze phase consists of tissue cooling with accompanying vasoconstriction and ischemia and without actual ice crystal formation. Neuronal cooling and ischemia produce hyperesthesia or paresthesia. In the freeze−thaw phase, ice crystals form intracellularly (during a more rapid-onset freezing injury) or extracellularly (during a slower freeze), causing protein and lipid derangement, cellular electrolyte shifts, cellular dehydration, cell membrane lysis, and cell death.[3] The thawing process may initiate ischemia, reperfusion injury, and an inflammatory response. In the vascular stasis phase, vessels fluctuate between constriction and dilation; blood may leak from vessels or coagulate within them.[4–6] The late ischemic phase results from progressive tissue ischemia and infarction from a cascade of events, including inflammation mediated by thromboxane $A_2$, prostaglandin $F_2$alpha, bradykinin, and histamine; intermittent vasoconstriction of arterioles and venules; continued reperfusion injury; showers of emboli coursing through the microvessels[7,8]; and thrombus formation in larger vessels.[9] Destruction of the microcirculation is the main factor leading to cell death.[10] The initial cellular damage caused by ice crystals and the subsequent postthawing processes are made worse if refreezing follows thawing of injured tissues.[11,12]

## Classification of frostbite

Frostnip is superficial nonfreezing cold injury associated with intense vasoconstriction on exposed skin, usually cheeks, ears, or nose. Ice crystals, appearing as frost, form on the skin surface. Frostnip is distinct from and may precede frostbite. With frostnip, ice crystals do not form within the tissue and tissue loss does not occur. Numbness and pallor resolve quickly after warming the skin with appropriate clothing, direct contact, breathing with cupped hands over the nose, or gaining shelter. No long-term damage occurs. Frostnip signals conditions favorable for frostbite; appropriate action should be undertaken immediately to prevent injury.

Frostbite has historically been divided into 4 tiers or "degrees" of injury following the classification scheme for thermal burn injury. These classifications are based on acute physical findings and advanced imaging after rewarming.[13] The classifications can be difficult to assess in the field before rewarming because the still-frozen tissue is hard, pale, and anesthetic. An alternate 2-tiered classification more appropriate for field use (after rewarming but before imaging) is suggested with the following the 4-tier classification:

- First-degree frostbite causes numbness and erythema. A white or yellow, firm, and slightly raised plaque develops in the area of injury. No gross tissue infarction occurs; there may be slight epidermal sloughing. Mild edema is common.
- Second-degree frostbite injury causes superficial skin vesiculation; a clear or milky fluid is present in the blisters, surrounded by erythema and edema.
- Third-degree frostbite causes deeper hemorrhagic blisters, indicating that the injury has extended into the reticular dermis and beneath the dermal vascular plexus.
- Fourth-degree frostbite extends completely through the dermis and involves the comparatively avascular subcutaneous tissues, with necrosis extending into muscle and bone.

For field classification, after spontaneous or formal rewarming but before imaging, we favor the following 2 tier classification scheme:

- *Superficial*—no or minimal anticipated tissue loss, corresponding to first- and second-degree injury.
- *Deep*—anticipated tissue loss, corresponding to third- and fourth-degree injury.

Severity of frostbite may vary within a single extremity.

Once thawing occurs and a patient reaches a field clinic or hospital, one can further classify or characterize the frostbite injury via 2 additional methods. The Hennepin score[14] uses a system similar to that for measuring burns by total body surface area. The effect of treatment can then be quantified retrospectively. The Cauchy classification method[13] measures extent of frostbite anatomically using the following grades: 0—no lesion; 1—lesion on the distal phalanx; 2—lesion on the middle phalanx or proximal phalanx for the thumb/big toe; 3—lesion on the proximal phalanx except for the thumb/big toe; 4—lesion on the metacarpal/metatarsal; 5—lesion on the carpal/tarsal. Although not validated, grades correlate well with bone scans and clinical outcomes and may assist caregivers in predicting tissue loss. The Cauchy classification method may assist caregivers in predicting amputation risk, which helps to inform evacuation decisions. For example, a necrotic fingertip (labeled grade 4 by the 4-tiered system but unlikely to involve significant amputation) would be designated a grade 1 on the Cauchy classification method, designating lower severity. Higher grades in the Cauchy classification method designate more proximal injuries with greater risk for functionally important amputation.

## Prevention

The adage that "prevention is better than treatment" is especially true for frostbite, which is typically preventable and often not improved by treatment. Underlying

medical problems may increase risk of frostbite, so prevention must address both environmental and health-related aspects. Frostbite injury occurs when tissue heat loss exceeds the ability of local tissue perfusion to prevent freezing of soft tissues (blood flow delivers heat). One must both ensure adequate perfusion and minimize heat loss to prevent frostbite. The adventurer should recognize cold-induced "numbness" as a warning that frostbite injury may be imminent if protective or avoidance measures are not taken to decrease tissue cooling. Subsequent loss of sensation does not mean the situation has improved; rather, receptors and nerves are not conducting pain/cold signals because they are nearing the freezing point.

### MAINTAINING PERIPHERAL PERFUSION

Preventive measures to ensure local tissue perfusion include: 1) maintaining adequate core temperature and body hydration; 2) minimizing the effects of known diseases, medications, and substances (including awareness and symptoms of alcohol and drug use) that might decrease perfusion; 3) covering all skin and the scalp to insulate from the cold; 4) minimizing blood flow restriction, such as occurs with constrictive clothing, footwear, or immobility; 5) ensuring adequate nutrition; and 6) using supplemental oxygen in severely hypoxic conditions (eg, >7500 m). ***Recommendation Grade:*** 1C.

### EXERCISE

Exercise is a specific method to maintain peripheral perfusion. Exercise enhances the level and frequency of cold-induced peripheral vasodilation. In one study, exercise resulted in cold-induced peripheral vasodilation in the toes of 58% of exercising subjects vs 28% in non-exercising subjects.[15] Another study found increased skin temperature in the hands during exercise.[16] However, using exercise to increase warmth can lead to exhaustion, with subsequent profound systemic heat loss should exhaustion occur. Recognizing this caveat, exercise and its associated elevation in core and peripheral temperatures can be protective in preventing frostbite. ***Recommendation Grade:*** 1B.

### PROTECTION FROM COLD

Measures should be taken to minimize exposure of tissue to cold. These measures include the following: 1) avoiding environmental conditions that predispose to frostbite, specifically below −15°C, even with low wind speeds[17]; 2) protecting skin from moisture, wind, and cold; 3) avoiding perspiration or wet extremities; 4) increasing insulation and skin protection (eg, by adding clothing layers, changing from gloves to mitts); 5) ensuring beneficial behavioral responses to changing environmental conditions (eg, not being under the influence of illicit drugs, alcohol, or extreme hypoxemia)[18]; 6) using chemical hand and foot warmers and electric foot warmers to maintain peripheral warmth (note: warmers should be close to body temperature before being activated and must not be placed directly against skin or constrict flow if used within a boot); 7) regularly checking oneself and the group for extremity numbness or pain and warming the digits and/or extremities as soon as possible if there is concern that frostbite may be developing; 8) recognizing frostnip or superficial frostbite before it becomes more serious; and 9) minimizing duration of cold exposure. Emollients do not protect against—and might even increase—risk of frostbite.[19] The time that a digit or extremity can remain numb before developing frostbite is unknown; thus, digits or extremities with paresthesia should be warmed as soon as possible. An extremity at risk for frostbite (eg, numbness, poor dexterity, pale color) should be warmed with adjacent body heat from the patient or a companion, using the axilla or abdomen. ***Recommendation Grade:*** 1C.

## Field treatment and secondary prevention

If a body part is frozen in the field, the frozen tissue should be protected from further damage. Remove jewelry or other constrictive extraneous material from the body part. Do not rub or apply ice or snow to the affected area.[20]

### REFREEZING INJURY

A decision must be made whether to thaw the tissue. If environmental conditions are such that thawed tissue could refreeze, it is safer to keep the affected part frozen until a thawed state can be maintained. Prostaglandin and thromboxane release associated with the freeze−thaw cycle[20–22] causes vasoconstriction, platelet aggregation, thrombosis, and, ultimately, cellular injury. Refreezing thawed tissue further increases release of these mediators, and significant morbidity may result. One must absolutely avoid refreezing if field thawing occurs. ***Recommendation Grade:*** 1B.

### SPONTANEOUS OR PASSIVE THAWING

Most frostbite thaws spontaneously and should be allowed to do so if rapid rewarming (described in the following) cannot be readily achieved. Do not purposefully keep tissue below freezing temperatures because this will increase the duration that the tissue is frozen and might result in more proximal freezing and greater morbidity. If environmental and situational conditions allow

for spontaneous or slow thawing, tissue should be allowed to thaw. ***Recommendation Grade:*** 1C.

Strategies for 2 scenarios are presented:

Scenario 1: The frozen part has the potential for refreezing and is not actively thawed.

Scenario 2: The frozen part is thawed and kept warm without refreezing until evacuation is completed.

## THERAPEUTIC OPTIONS FOR BOTH SCENARIOS

Many of these guidelines parallel the State of Alaska cold injuries guidelines.[23] Therapeutic options include the following:

### *Treatment of hypothermia*

No studies examine concurrent hypothermia and frostbite. Hypothermia frequently accompanies frostbite and causes peripheral vasoconstriction that impairs blood flow to the extremities. Mild hypothermia may be treated concurrently with frostbite injury. Moderate and severe hypothermia should be treated effectively before treating frostbite injury. ***Recommendation Grade:*** 1C.

### *Hydration*

Vascular stasis can result from frostbite injury. No studies have specifically examined the effect of hydration status on frostbite outcomes, but it is believed that appropriate hydration and avoidance of hypovolemia are important for frostbite recovery. Oral fluids may be given if the patient is alert, capable of purposeful swallowing, and not vomiting. If the patient is nauseated or vomiting or has an altered mental status, IV normal saline should be given to maintain normal urine output. Intravenous fluids should optimally be warmed (minimally to 37˚C but preferably to 40 to 42˚C with a method that has been proven to be effective in the present environmental conditions) before infusion and be infused in small (eg, 250 mL), rapid boluses because slow infusion will result in fluid cooling and even freezing as it passes through the tubing. Fluid administration should be optimized to prevent clinical dehydration. ***Recommendation Grade:*** 1C.

### *Low molecular weight dextran*

Intravenous low molecular weight dextran (LMWD) decreases blood viscosity by preventing red blood cell aggregation and formation of microthrombi and can be given in the field once it has been warmed. In some animal studies, the extent of tissue necrosis was found to be significantly less than in control subjects when LMWD was used[24–27] and was more beneficial if given early.[28] In one animal trial,[28] tissue in the LMWD group thawed slightly more rapidly, but overall tissue loss was no different from that of control animals. Give a test dose before administration because of the low risk of anaphylaxis. This low risk of anaphylaxis should not deter administration. The slight risk of bleeding is minimal, and benefits seem to outweigh this risk; however, availability is limited in the United States. The use of LMWD has not been evaluated in combination with other treatments such as thrombolytics. LMWD should be given if the patient is not being considered for other systemic treatments, such as thrombolytic therapy. ***Recommendation Grade:*** 2C.

### *Ibuprofen*

Nonsteroidal anti-inflammatory drugs (NSAIDs) block the arachidonic acid pathway and decrease production of prostaglandins and thromboxanes.[29] These mediators can lead to vasoconstriction, dermal ischemia, and further tissue damage. No studies have demonstrated that any particular anti-inflammatory agent or dosing is clearly related to outcome. Aspirin has been proposed as an option and is used in many parts of the world for anti-inflammatory and platelet inhibition effects. One rabbit ear model study showed 23% tissue survival with aspirin vs 0% in the control group.[30] However, aspirin theoretically blocks production of certain prostaglandins that are beneficial to wound healing,[31] and the authors of the rabbit ear model study recommend ibuprofen in their treatment algorithm. No studies specifically compare aspirin with ibuprofen in frostbite. Ibuprofen should be started in the field at a dose of 12 $mg \cdot kg^{-1}$ per day divided twice daily (minimum to inhibit harmful prostaglandins[29]) to a maximum of 2400 $mg \cdot d^{-1}$ divided 4 times daily. ***Recommendation Grade:*** 2C.

## SPECIFIC RECOMMENDATIONS—SCENARIO 1

Therapeutic options for frostbite in Scenario 1 (no active thawing) include the following:

### *Dressings*

No evidence supports applying a dressing to a frostbitten part intended to remain frozen until rewarming can safely be achieved. If this is considered, it should only be done if practical and will not interfere with mobility. Bulky, clean, and dry gauze or sterile cotton dressings should be applied to the frozen part and between the toes and fingers. ***Recommendation Grade:*** 2C.

*Ambulation and protection*

If at all possible, a frozen extremity should not be used for walking, climbing, or other maneuvers until definitive care is reached. If use of the frozen extremity for mobility is considered, a risk−benefit analysis must consider the potential for further trauma and possible poorer outcome. Although it is reasonable to walk on a foot with frostbitten toes for evacuation purposes, it is inadvisable to walk on an entirely frostbitten foot because of the potential for resulting morbidity. This risk is theoretical and based on the panel's opinion. Mills described frostbite patients who ambulated on frozen extremities for days and sustained no or limited amputation.[32] If using a frozen extremity for locomotion or evacuation is unavoidable, the extremity should be padded, splinted, and kept as immobile as possible to minimize additional trauma. ***Recommendation Grade:*** 2C.

## SPECIFIC RECOMMENDATIONS—SCENARIO 2

Therapeutic options for frostbite in Scenario 2 (thawing and continued warming) include the following:

*Rapid field rewarming of frostbite*

Field rewarming by warm water bath immersion can and should be performed if the proper resources are available and definitive care is more than 2 h distant. Other heat sources (eg, fire, space heater, oven, heated rocks) should be avoided because of the risk of thermal burn injury. Rapid rewarming by water bath has been found to result in better outcomes than slow rewarming.[20,27,32] Field rewarming should only be undertaken if the frozen part can be kept thawed and warm until the victim arrives at definitive care. Water should be heated to 37 to 39°C (98.6 to 102.2°F), using a thermometer to maintain this range.[33] If a thermometer is not available, a safe water temperature can be determined by placing a caregiver's uninjured hand in the water for at least 30 s to confirm that the water temperature is tolerable and will not cause burn injury. Circulation of water around the frozen tissue will help maintain correct temperature.[34,35] Because the water may cool quickly after the rewarming process is started, the water should be continuously and carefully warmed to the target temperature. If the frozen part is being rewarmed in a pot, skin should not press against the bottom or sides. Rewarming is complete when the involved part takes on a red or purple appearance and becomes soft and pliable to the touch. This is usually accomplished in approximately 30 min, but the time is variable depending on the extent and depth of injury. The affected tissues should be allowed to air dry or be gently dried with a blotting technique (not rubbing) to minimize further damage. Under appropriate circumstances, this method of field rewarming is the first definitive step in frostbite treatment. ***Recommendation Grade:*** 1B.

*Antiseptic solution*

Most injuries do not become infected, but adding an antiseptic solution (eg, povidone-iodine, chlorhexidine) to the rewarming water has theoretical benefits of reducing skin bacteria. Evidence for this practice does not exist for frostbite care, however. Adding an antiseptic solution to the water while rewarming is unlikely to be harmful and might reduce the risk for cellulitis if severe edema is present in the affected extremity. ***Recommendation Grade:*** 2C.

*Pain control*

During rewarming, pain medication (eg, NSAIDs or an opiate analgesic) should be given to control symptoms as dictated by individual patient situation. ***Recommendation Grade:*** 1C.

*Spontaneous or passive thawing*

According to the foregoing guidelines, rapid rewarming is strongly recommended. If field rewarming is not possible, spontaneous or slow thawing should be allowed. Slow rewarming is accomplished by moving to a warmer location (eg, tent or hut) and warming with adjacent body heat from the patient or a caregiver, as previously described. The expert panel agrees that slow thawing is a reasonable course of action to initiate the rewarming process if it is the only means available. ***Recommendation Grade:*** 1C.

*Debridement of blisters*

Debridement of blisters should not be routinely performed in the field. If a clear, fluid-filled blister is tense and at high risk for rupture during evacuation, blister aspiration and application of a dry gauze dressing should be performed in the field to minimize infection risk. Hemorrhagic bullae should not be aspirated or debrided in the field. These recommendations are common practice but lack evidence beyond case series.[29] ***Recommendation Grade:*** 2C.

*Topical aloe vera*

Aloe vera ointment has been shown in an observational study[36] and an animal model[30] to improve frostbite outcome by reducing prostaglandin and thromboxane formation. Topical agents do not penetrate far into tissues, however, so aloe vera is theoretically only beneficial for

superficially injured areas. The study supporting the benefit of aloe vera examined its application on unroofed blebs where it would be able to penetrate underlying tissue. Topical aloe vera should be applied to thawed tissue before application of dressings. ***Recommendation Grade:*** 2C.

*Dressings*

Bulky, dry gauze dressings should be applied to the thawed parts for protection and wound care. Substantial edema should be anticipated, so circumferential dressings should be wrapped loosely to allow for swelling without placing pressure on the underlying tissue. ***Recommendation Grade:*** 1C.

*Ambulation and protection*

A risk−benefit analysis must consider the potential for further trauma and, ultimately, potentially higher morbidity if a thawed part is used for ambulation. For example, it might be reasonable to walk on a foot with thawed toes for evacuation purposes, but it is inadvisable to walk on a recently thawed frostbitten foot because of the potential resulting morbidity. Very little evidence is available to guide recommendations. In one study, mobilization within 72 h after thawing did not affect tissue loss, complications, or hospital length of stay.[37] After the rewarming process, swelling should be anticipated. If passive thawing has occurred, boots (or inner boots) may need to be worn continuously to compress swelling. Boots that were removed for active rewarming may not be able to be re-donned if tissue swelling has occurred during the warming process. The panel's clinical experience supports the concept that a recently thawed extremity should ideally not be used for walking, climbing, or other maneuvers and should be protected to prevent further trauma.[36,38] ***Recommendation Grade:*** 2C.

*Elevation of extremity*

If possible, the thawed extremity should be elevated above the level of the heart, which might decrease formation of dependent edema. ***Recommendation Grade:*** 1C.

*Oxygen*

Recovery of thawed tissue partly depends on the level of tissue oxygenation in the postfreezing period. One small study that measured hand temperature at normobaric hypoxia found decreased skin temperatures with decreasing $F_IO_2$.[39] However, hyperoxia has been found to cause vasoconstriction in the extremities[40]; therefore, oxygen should not be applied routinely to patients who are not hypoxic. Although evidence is lacking to support use of supplemental oxygen for frostbite, oxygen may be delivered by face mask or nasal cannula if the patient is hypoxic (oxygen saturation <88%) or at high altitude above 4000 m. ***Recommendation Grade:*** 2C.

For a summary of the suggested approach to the field treatment of frostbite, see Table 1.

**Immediate medical therapy—hospital (or high-level field clinic)**

Once the patient reaches the hospital or field clinic, a number of treatments should be initiated. After reaching the hospital or field clinic, potential therapeutic options for frostbite include the following:

TREATMENT OF HYPOTHERMIA

Similar recommendations apply to hospital or field clinic treatment of hypothermia before frostbite treatment (see previous). ***Recommendation Grade:*** 1C.

HYDRATION

Similar recommendations apply in the hospital or field clinic regarding hydration (see previous). ***Recommendation Grade:*** 1C.

LOW MOLECULAR WEIGHT DEXTRAN

Similar recommendations apply in the hospital or field clinic regarding LMWD (see previous). ***Recommendation Grade:*** 2C.

**Table 1.** Summary of field treatment of frostbite (>2 h from definitive care)

| |
|---|
| Treat hypothermia or serious trauma |
| 1. Remove jewelry or other extraneous material from the body part. |
| 2. Rapidly rewarm in water heated and maintained between 37 and 39°C (98.6 to 102.2°F) until area becomes soft and pliable to the touch (approximately 30 min); allow spontaneous or passive thawing if rapid rewarming is not possible. |
| 3. Ibuprofen (12 $mg \cdot kg^{-1}$ per day divided twice daily) if available. |
| 4. Pain medication (eg, opiate) as needed. |
| 5. Air dry (ie, do not rub at any point). |
| 6. Protect from refreezing and direct trauma. |
| 7. Apply topical aloe vera cream or gel if available. |
| 8. Dry, bulky dressings. |
| 9. Elevate the affected body part if possible. |
| 10. Systemic hydration. |
| 11. Avoid ambulation on thawed lower extremity (unless only distal toes are affected). |

## RAPID REWARMING OF FROZEN TISSUES

Frozen tissue should be assessed to determine whether spontaneous thawing has occurred. If tissue is completely thawed, further rewarming will not be beneficial. Rapid rewarming should be undertaken according to the field protocol described previously if the tissue remains partially or completely frozen. ***Recommendation Grade:*** 1B.

## MANAGEMENT OF BLISTERS

Clear or cloudy blisters contain prostaglandins and thromboxanes that may damage underlying tissue. Hemorrhagic blisters are thought to signify deeper tissue damage extending into the dermal vascular plexus. Common practice is to drain clear blisters (eg, by needle aspiration) while leaving hemorrhagic blisters intact.[34,36,38,41,42] Although this approach to frostbite blister management is recommended by many authorities, comparative studies have not been performed and data are insufficient to make absolute recommendations. Some authors argue that unroofing blisters might lead to the desiccation of exposed tissue and that blisters should only be removed if they are tense, likely to break or be infected, or interfere with the patient's range of motion.[43] In a remote field situation, draining or unroofing blisters may not be under control of the provider. Blisters most often will have been broken by the patient's boots. In this case, the most important treatment is applying aloe vera and a sterile dressing to the unroofed blister. Debridement or aspiration of clear, cloudy, or tense blisters is at the provider's discretion, with consideration of patient circumstances, until better evidence becomes available. ***Recommendation Grade:*** 2C.

## TOPICAL ALOE VERA

Topical aloe vera cream or gel should be applied to the thawed tissue before application of dressings. Aloe vera is reapplied at each dressing change or every 6 h.[36] ***Recommendation Grade:*** 2C.

## SYSTEMIC ANTIBIOTICS

Frostbite is not an inherently infection-prone injury. Therefore, antibiotic administration specifically for preventing infection during or after frostbite injury is not supported by evidence. Some authorities reserve antibiotics for situations when edema occurs after thawing because of the notion that edema increases skin susceptibility to infection by gram-positive bacteria.[38] However, this practice is not based on evidence. Systemic antibiotics, either oral or parenteral, should be administered to patients with significant trauma, other potential infectious sources, or signs and symptoms of cellulitis or sepsis. ***Recommendation Grade:*** 1C.

## TETANUS PROPHYLAXIS

Tetanus prophylaxis should be administered according to standard guidelines. ***Recommendation Grade:*** 1C.

## IBUPROFEN

If NSAIDs have not been initiated in the field, ibuprofen should be administered at a dose of 12 $mg \cdot kg^{-1}$ divided twice daily (to inhibit harmful prostaglandins but remain less injurious to the gastrointestinal system[29]) until the frostbite wound is healed or surgical management occurs (typically for 4–6 wk). ***Recommendation Grade:*** 2C.

## THROMBOLYTIC THERAPY

The goal of thrombolytic therapy in frostbite injury is to lyse and clear microvascular thromboses. For deep frostbite injury with potential significant morbidity, angiography and use of either IV or intra-arterial tissue plasminogen activator (tPA) within 24 h of thawing may salvage some or all tissue at risk. A retrospective, single-center review by Bruen et al[44] demonstrated reduction in digital amputation rates from 41% in those patients who did not receive tPA to 10% in patients receiving tPA within 24 h of injury. The 20-y series presented by the Regions Hospital group found that two-thirds of patients who received intra-arterial tPA responded well and that amputation rate correlated closely with angiographic findings.[45] The Massachusetts General Hospital group has proposed a screening and treatment tool for thrombolytic management of frostbite based on a case report and their evaluation of the Utah and Minneapolis experiences.[46] Twomey et al[47] from Hennepin County Medical Center have developed a specific protocol based on a small group of good outcomes with intravenous tPA. Further study is needed to compare intra-arterial vs IV tPA on tissue salvage and functional outcome. Animal studies demonstrate benefit from thrombolytics.[48]

When considering using a thrombolytic, a risk–benefit analysis should be performed. Only deep injuries with potential for significant morbidity (eg, extending into the proximal interphalangeal joints of digits) should be considered for thrombolytic therapy. Potential risks of tPA include systemic and catheter site bleeding, compartment syndrome, and failure to salvage tissue. The long-term, functional consequences of digit salvage using tPA have not been fully evaluated.

Thrombolytic treatment should be undertaken in a facility familiar with the technique and with intensive care monitoring capabilities. If a frostbite patient is being cared

for in a remote area, transfer to a facility with tPA administration and monitoring capabilities should be considered if tPA can be started within 24 h of tissue thawing. Time to thrombolysis appears to be very important, with best outcomes within 12 h and ideally as soon as possible. Recent work from Hennepin County has found that each hour of delay of thrombolytic therapy results in a 28% decrease in salvage.[49] Rare use of tPA in the field has shown variable success[50] and should only be undertaken with extreme caution because bleeding complications may be impossible to detect and treat. If other treatment options are limited or unavailable, tPA should be considered for field treatment only of severe frostbite extending to the proximal interphalangeal joint or more proximally (eg, Cauchy classification grade 3−5).

*Method of administration*

Dosing is typically a 3 mg bolus (30 mL of 0.1 $mg \cdot mL^{-1}$ solution) followed by infusion of 1 $mg \cdot mL^{-1}$ (10 $mL \cdot h^{-1}$) until specialists (eg, vascular, burn, radiology) recommend discontinuation. Heparin is administered concurrently: 500 $units \cdot h^{-1}$.[51]

Intra-arterial angiography or IV pyrophosphate scanning should be used to evaluate the initial injury and monitor progress after tPA administration as directed by local protocol and resources. As of the end of 2018,[52] the following have been published on tPA use in frostbite: 1 randomized controlled prospective trial (tPA plus iloprost, 16 patients),[53] 3 retrospective cohort studies (59 patients),[44,49,54] 8 retrospective case series (130 patients),[47,55−61] and 3 case reports.[46,62,63] Although further studies are needed to determine the absolute efficacy of tPA for frostbite injury and to compare intra-arterial tPA to IV prostacyclin, we recommend IV or intra-arterial tPA within 24 h of injury as a reasonable choice in an environment with appropriate monitoring capabilities. ***Recommendation Grade:*** 1C.

## IMAGING

In patients with delayed presentation (4−24 h from the time of the frostbite thawing), noninvasive imaging with technetium pyrophosphate[13] or magnetic resonance angiography[64] can be used at an early stage to predict the likely levels of tissue viability for amputation. Cauchy et al[13] described the combination of a clinical scoring system and technetium scanning to successfully predict subsequent level of amputation on day 2 after frostbite rewarming. Single photon emission computed tomography (CT)/CT combines the anatomic precision of CT with the functional vascular information obtained from multiphase bone scintigraphy. Kraft et al used single photon emission CT/CT for 7 patients with frostbite and found it improved surgical planning for deep frostbite injuries by enabling early and precise anatomic localization of nonviable tissues.[65,66]

If available, appropriate imaging should be used to assess tissue viability and guide timing and extent of amputation. ***Recommendation Grade:*** 1C.

Other potential useful imaging techniques include Doppler ultrasound[55]; triple phase technitium[58,67]; indocyanine green microangiography[68]; and thermal imaging.[39] Although some of these techniques show potential, further studies are required to determine their exact role.

## ILOPROST

Iloprost, a prostacyclin (PGI2) analogue, is a potent vasodilator that also inhibits platelet aggregation, downregulates lymphocyte adhesion to endothelial cells,[69] and may have fibrinolytic activity.[70] Intravenous iloprost was first used for treatment of frostbite by Groechenig in 1994, in 5 patients with second- and third-degree frostbite. He infused iloprost daily, starting at 0.5 $ng \cdot kg^{-1}$ and increasing to 2.0 $ng \cdot kg^{-1}$ total dose over 3 d, and then continued for between 14 and 42 d.[71] Recovery without amputation was achieved in all patients.

A randomized trial by Cauchy et al assessed the efficacy of aspirin plus: 1) buflomedil, an alpha-blocker vasodilator; 2) iloprost; or 3) intravenous tPA plus iloprost.[53] Forty-seven patients with severe frostbite, with 407 digits at risk, were randomly assigned to 8 d of treatment with the 3 different regimens. Iloprost alone (0% amputation rate) was found superior to tPA plus iloprost (19%) and buflomedil (60%) groups. A limitation of this study was that ischemia was not documented with angiography or technetium scanning before treatment; groups were randomized according to clinical severity.

A Canadian study documented full recovery of grade 3 frostbite when iloprost was started within 48 h of injury in 2 long distance runners.[72] In a Finnish study, iloprost was partially beneficial with digit salvage rate of 78% in 4 persons: 2 with contraindication for tPA, 1 with failed tPA therapy, and 1 with vasospasm without thrombosis on angiography.[55] One patient with minimal response to tPA had complete reperfusion with iloprost.

Despite the limitations of these initial studies, iloprost has shown consistently favorable effects.[73] Extending the treatment window, Pandey et al[74] reported good results with iloprost therapy up to 72 h after injury. In 5 Himalayan climbers with 34 digits at risk, 5 d of daily iloprost infusion produced excellent outcomes in 4 of 5 patients. Treatment delayed beyond 72 h has not been beneficial except in 1 patient.[74,75] No serious side effects have been noted in these studies.

Intravenous iloprost should be considered first-line therapy for grade 3 and 4 frostbite <72 h after injury, when tPA is contraindicated, and in austere environments where tPA infusion is considered risky or evacuation to a treatment facility will be delayed. Field use of both iloprost and IV tPA has been advocated to reduce delay in treatment for mountaineers who will invariably take >48 h for evacuation to a hospital.[50] In these situations, iloprost may be the safer alternative. The IV form of iloprost is not approved by the US Food and Drug Administration, however. Consider iloprost for deep frostbite to or proximal to the proximal interphalangeal joint; within 48 h after injury, especially if angiography is not available; or with contraindications to thrombolysis. Expedition physicians should consider adding iloprost to their medical armamentarium, especially if it can be safely sourced and when treatment is occurring outside of the United States. ***Recommendation Grade:*** 1B.

*Method of administration*

Iloprost dosage is given IV via controlled infusion or syringe pump. Iloprost is mixed with normal saline or dextrose in water. On days 1 through 3, start at an initial rate of 0.5 $ng \cdot kg^{-1} \cdot min^{-1}$, then gradually increase by 0.5 $ng \cdot kg^{-1} \cdot min^{-1}$ at 30-min intervals to a maximum dose of 2.0 $ng \cdot kg^{-1} \cdot min^{-1}$. If intolerable side effects (nausea, headache, flushing) emerge or blood pressure or heart rate are outside normal limits, reduce the rate by 0.5 $ng \cdot kg^{-1} \cdot min^{-1}$ until side effects are tolerable or vital signs normalize. Mild and tolerable side effects can be treated symptomatically, whereas hypotension or severe symptoms require dose reduction. Continue the highest dose achieved or a maximum of 2.0 $ng \cdot kg^{-1} \cdot min^{-1}$ for 6 h total. For days 4 through 5, start directly at the highest/optimum rate or a maximum of 2.0 $ng \cdot kg^{-1} \cdot min^{-1}$ for 6 h daily.[51] Some protocols recommend up to 8 d of treatment; the first dose is considered the most important.

HEPARIN

No evidence supports use of low molecular weight heparin or unfractionated heparin for initial management of frostbite in the field or hospital, although climbers and practitioners in many regions use these medications. Evidence supports use of heparin as adjunctive therapy in tPA protocols, as described previously. Heparin has been used in conjunction with iloprost as well; the 5 patients in the 1994 Groechenig iloprost study,[71] the 1 Israeli traveler with excellent outcome in the Kathmandu study,[74] and 4 patients in the Finnish study[55] were treated with low molecular weight heparin (enoxaparin) in addition to iloprost. Whether low molecular weight heparin offers additional benefit when combined with iloprost requires further investigation; currently data are insufficient for a recommendation on this combination. ***Recommendation Grade:*** Not recommended as monotherapy owing to insufficient data.

OTHER VASODILATOR THERAPY

Vasodilators, such as prostaglandin $E_1$,[76] nitroglycerin,[46] pentoxifylline,[77,78] phenoxybenzamine, nifedipine, reserpine,[79,80] and buflomedil,[53,81,82] have been used as primary and adjunctive therapies for treatment of frostbite. In addition to vasodilation, some of these agents might also prevent platelet aggregation and microvascular occlusion. Sheridan et al[46] recommend intra-arterial infusion of nitroglycerin during angiography before tPA infusion. A study in rabbits that did not undergo rapid rewarming found benefit from intra-arterial administration of prostaglandin E1.[76] Buflomedil is an alpha-adrenolytic agent that is used widely in Europe with preliminary and anecdotal evidence of good results[53,82]; however, animal models have not replicated these findings.[81] This medication is not approved by the US Food and Drug Administration. Intra-arterial reserpine studied in a controlled trial was found not to be effective.[79]

Pentoxifylline, a methylxanthine-derived phosphodiesterase inhibitor, has been widely used for treatment of peripheral vascular disease and yielded promising results in animal[78,83,84] and human frostbite.[77] Hayes et al[77] recommend pentoxifylline in the controlled-release form of one 400 mg tablet 3 times a day with meals, continued for 2 to 6 wk. Controlled studies of pentoxifylline in management of frostbite have not been performed.

Certain vasodilators have the potential to improve outcomes and can be used with minimal risk. However, as discussed earlier, data demonstrating benefit are limited. Iloprost is the only vasodilator with reasonable scientific evidence supporting its use.

For a summary of the suggested approach to hospital or advanced field clinic treatment of frostbite, see Table 2.

## Other post-thaw medical therapy

Once the patient has received initial frostbite therapy, long-term management is initiated to reduce long-term sequelae. Therapeutic options for frostbite after thawing include the following:

HYDROTHERAPY

Daily or twice-daily hydrotherapy at 37 to 39°C (98.6 to 102.2°F) has been recommended in the post-thaw period.[32,34–36,85] Hydrotherapy theoretically increases circulation, removes superficial bacteria, and debrides

**Table 2.** Summary of initial hospital management of frostbite

1. Treat hypothermia or serious trauma.
2. Rapidly rewarm in water heated and maintained between 37 and 39°C (98.6 to 102.2°F) until area becomes soft and pliable to the touch (approximately 30 min).
3. Ibuprofen (12 mg·kg$^{-1}$ per day divided twice daily).
4. Pain medication (eg, opiate) as needed.
5. Tetanus prophylaxis.
6. Air dry (ie, do not rub at any point).
7. Debridement: selectively drain (eg, by needle aspiration) clear blisters and leave hemorrhagic blisters intact.
8. Topical aloe vera every 6 h with dressing changes.
9. Dry, bulky dressings.
10. Elevate the affected body part if possible.
11. Systemic hydration.
12. Thrombolytic therapy: consider for deep frostbite at the distal interphalangeal joint or proximal if less than 24 h after thawing; use angiography for prethrombolytic intervention and monitoring of progress. Consider intravenous thrombolysis if angiography is not available.
13. Iloprost therapy: consider for deep frostbite to or proximal to the proximal interphalangeal joint, within 48 h after injury, especially if angiography is not available or with contraindications to thrombolysis.
14. Clinical examination (plus angiography or technetium-99 bone scan if necessary) to assist determination of surgical margins. Evaluation by an experienced surgeon for possible intervention.

devitalized tissue.[38] No trials support improved outcomes, but the practice has few negative consequences and has the potential to benefit recovery. Data are insufficient to recommend specific temperature, timing, or duration of therapy. ***Recommendation Grade:*** 1C.

## HYPERBARIC OXYGEN THERAPY

Many types of nonfrostbite wounds show accelerated or more complete healing as a result of increased tissue oxygenation from hyperbaric oxygen therapy (HBOT).[86] Because oxygen under pressure increases oxygen tension in the blood, HBOT is typically effective only if blood supply to distal tissues is competent and, therefore, may not be successful in frostbite. However, HBOT may have other effects such as making erythrocytes more malleable and decreasing bacterial load. Despite anecdotal success in extremely limited case series,[87–90] controlled studies have not been conducted. The time, expense, and availability of HBOT also limit its use. At this time, data are insufficient to recommend HBOT for frostbite treatment. ***Recommendation Grade:*** Not recommended owing to insufficient data.

## SYMPATHECTOMY

Because blood flow is partly determined by sympathetic tone, chemical or surgical sympathectomy has been proposed in the immediate postexposure phase to reduce tissue loss. In a rat lower limb model, early surgical denervation (within 24 h of exposure) reduced tissue loss but had no effect if performed after 24 h.[91] In a rabbit ear model, procaine-induced sympathectomy had no demonstrable beneficial effect.[92] Frostbite patients often experience long-term delayed symptoms, such as pain, paresthesia, and numbness. Chemical or surgical sympathectomy to treat these symptoms has been performed with variable results. In some studies, surgical sympathectomy has been found to reduce duration of pain and expedite demarcation of tissue necrosis. However, it has not been found to reduce the ultimate extent of tissue loss.[41,93] Acute treatment success with IV guanethidine has been reported[94] but was not beneficial in another case report.[95] Sympathectomy may have a role in preventing certain long-term sequelae of frostbite such as pain (putatively caused by vasospasm), paresthesia, and hyperhidrosis.[96,97] Despite many years of study, the data on surgical sympathectomy are limited and conflicting; therefore, a recommendation for their use cannot be made. ***Recommendation Grade:*** Not recommended owing to insufficient data.

## HOSPITALIZATION

Hospital admission and discharge are determined on an individual basis. Factors should include severity of the injury, coexisting injuries, comorbidities, and need for hospital-based interventions (tPA, vasodilators, surgery) or supportive therapy, as well as ease of access to appropriate community medical and nursing support. Significant swelling should prompt evaluation for compartment syndrome and admission for observation. Patients with superficial frostbite can usually be managed as outpatients or with brief inpatient stays followed by wound care instructions. Initially, deep frostbite should be managed in an inpatient setting. ***Recommendation Grade:*** 1C.

## FASCIOTOMY

Thawing results in reperfusion of ischemic tissue and, in turn, sometimes results in elevated pressures within closed soft-tissue compartments. Compartment syndrome clinically manifests as tense, painful distention with reduced movement and sensation. Urgent attention is necessary to evaluate compartment pressures. If elevated compartment pressures are present, prompt surgical decompression is indicated for limb salvage.[20] ***Recommendation Grade:*** 1C.

## SURGICAL TREATMENT OR AMPUTATION

After frostbite occurs, complete demarcation of tissue necrosis may take 1 to 3 mo. Angiography, technetium-99 bone scan, or magnetic resonance imaging may be used to assist determination of surgical margins[42,64,98] in conjunction with clinical findings. If the patient exhibits signs and symptoms of sepsis attributed to infected frostbitten tissue, amputation should be performed expeditiously.[85] Otherwise, amputation should be delayed until definitive demarcation occurs. The affected limb is often insensate. Therefore, an approach that addresses footwear and orthotics is essential to provide optimal function. Our experience has found that early involvement of a multidisciplinary rehabilitation team produces better long-term functional results. Telemedicine or electronic consultation with a surgical frostbite expert to guide local surgeons should be considered when no local expert is available. Because significant morbidity may result from unnecessary or premature surgical intervention, a surgeon with experience evaluating and treating frostbite should assess the need for and the timing of any amputation. ***Recommendation Grade:*** 1C.

## Conclusions

This summary provides evidence-based guidelines for prevention and treatment of frostbite. Many important questions remain and should serve as a focus for future research. This includes elucidation of pathophysiology, medications to assist in the prevention of frostbite, perithawing procedures to reduce injury and decrease morbidity, and post-thaw therapies that might improve long-term outcomes.

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## Supplementary materials

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## References

1. Guyatt G, Gutterman D, Baumann MH, Addrizzo-Harris D, Hylek EM, Phillips B, et al. Grading strength of recommendations and quality of evidence in clinical guidelines: report from an American College of Chest Physicians Task Force. *Chest*. 2006;129(1):174–81.
2. McIntosh SE, Opacic M, Freer L, Grissom CK, Auerbach PS, Rodway GW, et al. Wilderness Medical Society practice guidelines for the prevention and treatment of frostbite: 2014 update. *Wilderness Environ Med*. 2014; 25(4 suppl):S43–54.
3. Mazur P. Causes of injury in frozen and thawed cells. *Fed Proc*. 1965;24:S175–82.
4. Lange K, Boyd LJ, Loewe L. The functional pathology of frostbite and the prevention of gangrene in experimental animals and humans. *Science*. 1945;102(2641):151–2.
5. Meryman HT. Tissue freezing and local cold injury. *Physiol Rev*. 1957;37(2):233–51.
6. Quintanilla R, Krusen FH, Essex HE. Studies on frost-bite with special reference to treatment and the effect on minute blood vessels. *Am J Physiol*. 1947;149(1):149–61.
7. Robson MC, Heggers JP. Evaluation of hand frostbite blister fluid as a clue to pathogenesis. *J Hand Surg Am*. 1981;6 (1):43–7.
8. Zacarian S. Cryogenics: The cryolesion and the pathogenesis of cryonecrosis. In: Zacarian S, ed. *Cryosurgery for Skin Cancer and Cutaneous Disorders*. St. Louis: Mosby; 1985.
9. Kulka JP. Microcirculatory impairment as a factor in inflammatory tissue damage. *Ann N Y Acad Sci*. 1964;116:1018–44.
10. Daum PS, Bowers WD Jr, Tejada J, Hamlet MP. Vascular casts demonstrate microcirculatory insufficiency in acute frostbite. *Cryobiology*. 1987;24(1):65–73.
11. Bhatnagar A, Sarker BB, Sawroop K, Chopra MK, Sinha N, Kashyap R. Diagnosis, characterisation and evaluation of treatment response of frostbite using pertechnetate scintigraphy: a prospective study. *Eur J Nucl Med Mol Imaging*. 2002;29(2):170–5.
12. Petrone P, Kuncir EJ, Asensio JA. Surgical management and strategies in the treatment of hypothermia and cold injury. *Emerg Med Clin North Am*. 2003;21(4):1165–78.
13. Cauchy E, Chetaille E, Marchand V, Marsigny B. Retrospective study of 70 cases of severe frostbite lesions: a proposed new classification scheme. *Wilderness Environ Med*. 2001;12(4):248–55.
14. Nygaard RM, Whitley AB, Fey RM, Wagner AL. The Hennepin score: quantification of frostbite management efficacy. *J Burn Care Res*. 2016;37(4):e317–22.
15. Dobnikar U, Kounalakis SN, Mekjavic IB. The effect of exercise-induced elevation in core temperature on cold-induced vasodilatation response in toes. *Eur J Appl Physiol*. 2009;106(3):457–64.
16. Geurts CL, Sleivert GG, Cheung SS. Local cold acclimation during exercise and its effect on neuromuscular function of the hand. *Appl Physiol Nutr Metab*. 2006;31 (6):717–25.
17. Danielsson U. Windchill and the risk of tissue freezing. *J Appl Physiol*. 1996;81(6):2666–73.
18. Urschel JD, Urschel JW, Mackenzie WC. The role of alcohol in frostbite injury. *Scand J Soc Med*. 1990;18(4):273.
19. Lehmuskallio E. Emollients in the prevention of frostbite. *Int J Circumpolar Health*. 2000;59(2):122–30.

20. Mills WJ Jr. Frostbite. A discussion of the problem and a review of the Alaskan experience. 1973. *Alaska Med*. 1993;35(1):29–40.
21. Mills WJ Jr. Summary of treatment of the cold injured patient: frostbite. 1983. *Alaska Med*. 1993;35(1):61–6.
22. Mills WJ Jr. Summary of treatment of the cold injured patient. 1980. *Alaska Med*. 1993;35(1):50–3.
23. McLeron K. *State of Alaska Cold Injury Guidelines*. 7th ed. Juneau, AK: Department of Health and Social Services Division of Public Health Section of Community Health and EMS; 2003.
24. Martinez Villen G, Garcia Bescos G, Rodriguez Sosa V, Morandeira Garcia JR. Effects of haemodilution and rewarming with regard to digital amputation in frostbite injury: an experimental study in the rabbit. *J Hand Surg Br*. 2002;27(3):224–8.
25. Talwar JR, Gulati SM, Kapur BM. Comparative effects of rapid thawing, low molecular dextran and sympathectomy in cold injury in the monkeys. *Indian J Med Res*. 1971;59 (2):242–50.
26. Weatherley-White RC, Sjostrom B, Paton BC. Experimental studies in cold injury. II. the pathogenesis of frostbite. *J Surg Res*. 1964;4:17–22.
27. Webster DR, Bonn G. Low-molecular-weight dextran in the treatment of experimental frostbite. *Can J Surg*. 1965;8 (4):423–7.
28. Kapur BM, Gulati SM, Talwar JR. Low molecular dextran in the management of frostbite in monkeys. *Indian J Med Res*. 1968;56(11):1675–81.
29. Rainsford KD. Ibuprofen: pharmacology, efficacy and safety. *Inflammopharmacology*. 2009;17(6):275–342.
30. Heggers JP, Robson MC, Manavalen K, Weingarten MD, Carethers JM, Boertman JA, et al. Experimental and clinical observations on frostbite. *Ann Emerg Med*. 1987;16 (9):1056–62.
31. Robson MC, DelBeccaro EJ, Heggers JP, Loy GL. Increasing dermal perfusion after burning by decreasing thromboxane production. *J Trauma*. 1980;20(9):722–5.
32. Mills WJ Jr. Frostbite. A method of management including rapid thawing. *Northwest Med*. 1966;65(2):119–25.
33. Malhotra MS, Mathew L. Effect of rewarming at various water bath temperatures in experimental frostbite. *Aviat Space Environ Med*. 1978;49(7):874–6.
34. Imray C, Grieve A, Dhillon S. Cold damage to the extremities: frostbite and non-freezing cold injuries. *Postgrad Med J*. 2009;85(1007):481–8.
35. Mills WJ, Whaley R. Frostbite: experience with rapid rewarming and ultrasonic therapy. 1960-1. *Wilderness Environ Med*. 1998;9(4):226–47.
36. McCauley RL, Hing DN, Robson MC, Heggers JP. Frostbite injuries: a rational approach based on the pathophysiology. *J Trauma*. 1983;23(2):143–7.
37. Dole M, Endorf FW, Gayken J, Fey R, Nygaard RM. Early mobilization in lower extremity frostbite injury: preliminary experience at a single burn center. *J Burn Care Res*. 2018;39(3):339–44.
38. Reamy BV. Frostbite: review and current concepts. *J Am Board Fam Pract*. 1998;11(1):34–40.
39. Jones D, Covins SF, Miller GE, Morrison KI, Clark AG, Calcott SD, et al. Infrared thermographic analysis of surface temperature of the hands during exposure to normobaric hypoxia. *High Alt Med Biol*. 2018;19(4):388–93.
40. Rousseau A, Steinwall I, Woodson RD, Sjoberg F. Hyperoxia decreases cutaneous blood flow in high-perfusion areas. *Microvasc Res*. 2007;74(1):15–22.
41. Golant A, Nord RM, Paksima N, Posner MA. Cold exposure injuries to the extremities. *J Am Acad Orthop Surg*. 2008;16(12):704–15.
42. Murphy JV, Banwell PE, Roberts AH, McGrouther DA. Frostbite: pathogenesis and treatment. *J Trauma*. 2000;48 (1):171–8.
43. Biem J, Koehncke N, Classen D, Dosman J. Out of the cold: management of hypothermia and frostbite. *CMAJ*. 2003;168(3):305–11.
44. Bruen KJ, Ballard JR, Morris SE, Cochran A, Edelman LS, Saffle JR. Reduction of the incidence of amputation in frostbite injury with thrombolytic therapy. *Arch Surg*. 2007;142(6):546–51; discussion 551−3.
45. Jenabzadeh K, Mohr W, Ahrenholz D. Frostbite: a single institution's twenty year experience with intraarterial thrombolytic therapy. *J Burn Care Research*. 2006;30(2): S103.
46. Sheridan RL, Goldstein MA, Stoddard FJ Jr, Walker TG Case records of the Massachusetts General Hospital. Case 41-2009. A 16-year-old boy with hypothermia and frostbite. *N Engl J Med*. 2009;361(27):2654–62.
47. Twomey JA, Peltier GL, Zera RT. An open-label study to evaluate the safety and efficacy of tissue plasminogen activator in treatment of severe frostbite. *J Trauma*. 2005;59 (6):1350–4. discussion 1354−5.
48. Zdeblick TA, Field GA, Shaffer JW. Treatment of experimental frostbite with urokinase. *J Hand Surg Am*. 1988;13 (6):948–53.
49. Nygaard RM, Lacey AM, Lemere A, Dole M, Gayken JR, Lambert Wagner AL, et al. Time matters in severe frostbite: assessment of limb/digit salvage on the individual patient level. *J Burn Care Res*. 2017;38(1):53–9.
50. Cauchy E, Davis CB, Pasquier M, Meyer EF, Hackett PH. A new proposal for management of severe frostbite in the austere environment. *Wilderness Environ Med*. 2016;27(1):92–9.
51. Handford C, Buxton P, Russell K, Imray CE, McIntosh SE, Freer L, et al. Frostbite: a practical approach to hospital management. *Extrem Physiol Med*. 2014;3:7.
52. Hutchison RL, Miller HM, Michalke SK. The use of tPA in the treatment of frostbite: a systematic review. *Hand (N Y)*. 2019;14(1):13–8.
53. Cauchy E, Cheguillaume B, Chetaille E. A controlled trial of a prostacyclin and rt-PA in the treatment of severe frostbite. *N Engl J Med*. 2011;364(2):189–90.
54. Patel N, Srinivasa DR, Srinivasa RN, Gemmete JJ, Krishnamurthy V, Dasika N, et al. Intra-arterial thrombolysis for extremity frostbite decreases digital amputation rates and

hospital length of stay. *Cardiovasc Intervent Radiol*. 2017;40(12):1824–31.
55. Lindford A, Valtonen J, Hult M, Kavola H, Lappalainen K, Lassila R, et al. The evolution of the Helsinki frostbite management protocol. *Burns*. 2017;43(7):1455–63.
56. Wexler A, Zavala S. The use of thrombolytic therapy in the treatment of frostbite injury. *J Burn Care Res*. 2017;38(5):e877–e81.
57. Johnson AR, Jensen HL, Peltier G, DelaCruz E. Efficacy of intravenous tissue plasminogen activator in frostbite patients and presentation of a treatment protocol for frostbite patients. *Foot Ankle Spec*. 2011;4(6):344–8.
58. Jones LM, Coffey RA, Natwa MP, Bailey JK. The use of intravenous tPA for the treatment of severe frostbite. *Burns*. 2017;43(5):1088–96.
59. Ibrahim AE, Goverman J, Sarhane KA, Donofrio J, Walker TG, Fagan SP. The emerging role of tissue plasminogen activator in the management of severe frostbite. *J Burn Care Res*. 2015;36(2):e62–6.
60. Tavri S, Ganguli S, Bryan RG Jr, Goverman J, Liu R, Irani Z, et al Catheter-directed intraarterial thrombolysis as part of a multidisciplinary management protocol of frostbite injury. *J Vasc Interv Radiol*. 2016;27(8):1228–35.
61. Gonzaga T, Jenabzadeh K, Anderson CP, Mohr WJ, Endorf FW, Ahrenholz DH. Use of intra-arterial thrombolytic therapy for acute treatment of frostbite in 62 patients with review of thrombolytic therapy in frostbite. *J Burn Care Res*. 2016;37(4):e323–34.
62. Saemi AM, Johnson JM, Morris CS. Treatment of bilateral hand frostbite using transcatheter arterial thrombolysis after papaverine infusion. *Cardiovasc Intervent Radiol*. 2009;32(6):1280–3.
63. Wagner C, Pannucci CJ. Thrombolytic therapy in the acute management of frostbite injuries. *Air Med J*. 2011;30(1):39–44.
64. Barker JR, Haws MJ, Brown RE, Kucan JO, Moore WD. Magnetic resonance imaging of severe frostbite injuries. *Ann Plast Surg*. 1997;38(3):275–9.
65. Millet JD, Brown RK, Levi B, Kraft CT, Jacobson JA, Gross MD, et al. Frostbite: spectrum of imaging findings and guidelines for management. *Radiographics*. 2016;36(7):2154–69.
66. Kraft C, Millet JD, Agarwal S, Wang SC, Chung KC, Brown RK, et al. SPECT/CT in the evaluation of frostbite. *J Burn Care Res*. 2017;38(1):e227–34.
67. Handford C, Thomas O, Imray CHE. Frostbite. *Emerg Med Clin North Am*. 2017;35(2):281–99.
68. Masters T, Omodt S, Gayken J, Logue C, Westgard B, Hendriksen S, et al. Microangiography to monitor treatment outcomes following severe frostbite injury to the hands. *J Burn Care Res*. 2018;39(1):162–7.
69. Della Bella S, Molteni M, Mocellin C, Fumagalli S, Bonara P, Scorza R. Novel mode of action of iloprost: in vitro down-regulation of endothelial cell adhesion molecules. *Prostaglandins Other Lipid Mediat*. 2001;65(2-3):73–83.
70. Candela M, Pansoni A, Jannino L, Menditto VG, Natalini M, Ravaglia F, et al. Coagulative modifications in patients with systemic sclerosis treated with iloprost or nifedipine. *Ann Ital Med Int*. 2001;16(3):170–4.
71. Groechenig E. Treatment of frostbite with iloprost. *Lancet*. 1994;344(8930):1152–3.
72. Poole A, Gauthier J. Treatment of severe frostbite with iloprost in northern Canada. *CMAJ*. 2016;188(17-18):1255–8.
73. Kaller M. BET 2: treatment of frostbite with iloprost. *Emerg Med J*. 2017;34(10):689–90.
74. Pandey P, Vadlamudi R, Pradhan R, Pandey KR, Kumar A, Hackett P. Case report: severe frostbite in extreme altitude climbers—the Kathmandu iloprost experience. *Wilderness Environ Med*. 2018;29(3):366–74.
75. Irarrazaval S, Besa P, Cauchy E, Pandey P, Vergara J. Case report of frostbite with delay in evacuation: field use of iloprost might have improved the outcome. *High Alt Med Biol*. 2018;19(4):382–7.
76. Yeager RA, Campion TW, Kerr JC, Hobson RW 2nd, Lynch TG Treatment of frostbite with intra-arterial prostaglandin E1. *Am Surg*. 1983;49(12):665–7.
77. Hayes DW Jr, Mandracchia VJ, Considine C, Webb GE Pentoxifylline. Adjunctive therapy in the treatment of pedal frostbite. *Clin Podiatr Med Surg*. 2000;17(4):715–22.
78. Miller MB, Koltai PJ. Treatment of experimental frostbite with pentoxifylline and aloe vera cream. *Arch Otolaryngol Head Neck Surg*. 1995;121(6):678–80.
79. Bouwman DL, Morrison S, Lucas CE, Ledgerwood AM. Early sympathetic blockade for frostbite—is it of value? *J Trauma*. 1980;20(9):744–9.
80. Espinosa GA. Management of frostbite injuries. *J Natl Med Assoc*. 1981;73(12):1125–31.
81. Daum PS, Bowers WD Jr, Tejada J, Morehouse D, Hamlet MP An evaluation of the ability of the peripheral vasodilator buflomedil to improve vascular patency after acute frostbite. *Cryobiology*. 1989;26(1):85–92.
82. Foray J, Baisse PE, Mont JP, Cahen C. Treatment of frostbites. Analysis of results in twenty patients with buflomedil chlorhydrate (author's transl) [in French]. *Sem Hop*. 1980;56(9-10):490–7.
83. Purkayastha SS, Roy A, Chauhan SK, Verma SS, Selvamurthy W. Efficacy of pentoxifylline with aspirin in the treatment of frostbite in rats. *Indian J Med Res*. 1998;107:239–45.
84. Purkayastha SS, Bhaumik G, Chauhan SK, Banerjee PK, Selvamurthy W. Immediate treatment of frostbite using rapid rewarming in tea decoction followed by combined therapy of pentoxifylline, aspirin & vitamin C. *Indian J Med Res*. 2002;116:29–34.
85. Jurkovich GJ. Environmental cold-induced injury. *Surg Clin North Am*. 2007;87(1):247–67. viii.
86. Thom SR. Hyperbaric oxygen: its mechanisms and efficacy. *Plast Reconstr Surg*. 2011;127(suppl 1):131S–41S.
87. Finderle Z, Cankar K. Delayed treatment of frostbite injury with hyperbaric oxygen therapy: a case report. *Aviat Space Environ Med*. 2002;73(4):392–4.

88. Folio LR, Arkin K, Butler WP. Frostbite in a mountain climber treated with hyperbaric oxygen: case report. *Mil Med*. 2007;172(5):560–3.
89. von Heimburg D, Noah EM, Sieckmann UP, Pallua N. Hyperbaric oxygen treatment in deep frostbite of both hands in a boy. *Burns*. 2001;27(4):404–8.
90. Lansdorp CA, Roukema GR, Boonstra O, Dokter J. Delayed treatment of frostbite with hyperbaric oxygen: a report of two cases. *Undersea Hyperb Med*. 2017;44(4):365–9.
91. Gildenberg PL, Hardenbergh E. The effect of immediate sympathectomy on tissue survival following experimental frostbite. *Ann Surg*. 1964;160:160–8.
92. Fuhrman FA, Crismon JM. Studies on gangrene following cold injury; the effect of rutin and other chemical agents on the course of experimental frostbite in rabbits. *J Clin Invest*. 1948;27(3 Pt 1):364–71.
93. Christenson C, Stewart C. Frostbite. *Am Fam Physician*. 1984;30(6):111–22.
94. Kaplan R, Thomas P, Tepper H, Strauch B. Treatment of frostbite with guanethidine. *Lancet*. 1981;2 (8252):940–1.
95. Engkvist O. The effect of regional intravenous guanethidine block in acute frostbite. Case report. *Scand J Plast Reconstr Surg*. 1986;20(2):243–5.
96. Khan MI, Tariq M, Rehman A, Zafar A, Sheen SN. Efficacy of cervicothoracic sympathectomy versus conservative management in patients suffering from incapacitating Raynaud's syndrome after frost bite. *J Ayub Med Coll Abbottabad*. 2008;20(2):21–4.
97. Taylor MS. Lumbar epidural sympathectomy for frostbite injuries of the feet. *Mil Med*. 1999;164(8):566–7.
98. Cauchy E, Marsigny B, Allamel G, Verhellen R, Chetaille E. The value of technetium 99 scintigraphy in the prognosis of amputation in severe frostbite injuries of the extremities: A retrospective study of 92 severe frostbite injuries. *J Hand Surg Am*. 2000;25(5):969–78.

# Retrospective study of 70 cases of severe frostbite lesions: a proposed new classification scheme. Wild Envir Med 12: 248–255

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ORIGINAL RESEARCH

# Retrospective study of 70 cases of severe frostbite lesions: a proposed new classification scheme

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**Objective.**—Previous frostbite classifications were mainly based on retrospective diagnosis and, most of the time, could not be used to predict the final outcome of the lesions and especially the probability of an amputation and its level. The aim of this study was to suggest a new classification at day 0 based mainly on the topography of the lesions and on early bone scan results, which are more convenient and accurate in predicting the final outcome of frostbites.

**Methods.**—The retrospective study of the clinical histories of 70 patients hospitalized at Chamonix Hospital (Mont-Blanc Massif) from 1985 to 1999 for severe frostbite injuries of the extremities has allowed us to classify the aspects of the initial lesions on day 0 and to compare them with final outcomes.

**Results.**—A strong correlation was found between the extent of the lesion and the outcome of each finger or toe. When the initial lesion was on the distal phalanx, the probability of bone amputation was around 1% for the digit, 31% for the middle phalanx, 67% for the proximal phalanx, 98% for the metacarpal/metatarsal, and 100% for the carpal/tarsal.

**Conclusions.**—Based on these clinical results and on the results of bone scans (previously validated), a new classification of frostbite severity at day 0 is proposed. Four degrees of severity are defined: first degree, leading to recovery; second degree, leading to soft tissue amputation; third degree, leading to bone amputation, and fourth degree, leading to large amputation with systemic effects.

*Key words:* frostbite, bone scan, topography, classification, prognosis

## Introduction

Cold-induced lesions are very often the result of an inability to protect oneself from an adverse environment. A localized cold-induced lesion, or frostbite, is defined as tissue injury resulting from prolonged exposure of flesh to a temperature less than 0°C. These injuries frequently afflict people active in polar environments such as skiers and mountaineers. Frostbite injury most often involves the hands and feet and less often the ears, nose, and cheeks. The seriousness of the lesion essentially depends on the severity, the duration of exposure to the cold, and the means used to protect oneself.

Every year, the Chamonix Hospital treats a large number of patients, most of whom are mountaineers or skiers, suffering from frostbite injuries of the extremities. Those with serious lesions are hospitalized to facilitate treatment and healing. Frostbites requiring tissue or bone amputation are usually identified retrospectively after a few weeks of hospitalization.

Early establishment of the prognosis for patients with frostbite is hampered by the lack of useful, early, clinical guidelines.[1] The 3- to 6-week waiting period often necessary to determine the severity of the lesion and the prospect of amputation often causes mental anguish for patients. In addition, most recent hypotheses regarding frostbite pathology evoke the possibility of a secondary, progressive phase of necrosis in the first 48 hours following the primary phase, where vasospasm of frozen tissue predominates.[2] Current research efforts are focused on this secondary phase, where the use of experimental vasoactive drugs and potent antioxidants such as prostacyclin[3] and fibrinolytics (recombinant tissue plasminogen activator [r-TPA])[4,5] are administered in the first 48 hours. To effectively compare treatment regimes,

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one should start with an accurate initial assessment of the extent of the frostbite. Many authors suggest a classification based on the frostbite aspects observed at different stages of evolution, considering the depth of the lesion as for a burn injury without considering the extent of topography.[6–10] The only topographic classification for cold injury was proposed by Killian,[11] but the relationship with the final outcome was not studied.

The large number of frostbite injuries treated at our institution allowed us to precisely describe initial lesion characteristics just after rewarming. The relationship between the extent of the initial lesion immediately and following rewarming was assessed, and the final outcome was studied with the aim of developing a classification scheme for the early evaluation of frostbite severity.

## Materials and methods

### SUBJECTS

An average of 80 patients with frostbite injuries to the hands and feet present to the Chamonix Hospital every year. Between 1973 and 2000, 719 were hospitalized for deep second- or third-degree frostbite according to the classification proposed by Foray and Allamel[12] and were considered to have severe frostbite injuries for the purposes of this study. The need for hospitalization was decided by the extent and features of frostbite lesions, including the hypoanesthesic area, and cyanosis involving at least 1 finger or toe phalanx after external rewarming (1 hour in a 38°C bath). Among hospitalized patients, 70 were selected retrospectively for the study. The time between natural rewarming and evaluation had to be no more than 48 hours. Their initial records must have contained a complete clinical description of the lesion on day 0 with sketches and/or photos, and follow-up must have been complete.

### TREATMENT PROTOCOL

All patients received rapid rewarming in a 38°C bath with aspirin (250-mg IV) and chlorohydrate of buflomedil (400-mg IV).[13] Beyond this, the choice of treatment was variable and may have included one or more of the following approaches: hemodilution, platelet aggregation inhibitor (aspirin), peripheral vasodilators (ketanserin[14] or chlorohydrate of buflomedil[15]), prostacyclin analogs (iloprost),[3] and fibrinolytics (streptokinase, urokinase, or r-TPA[4,5]).

The different treatments were classified into 11 groups to assess correlation with the final outcome: 1) aspirin, 2) chlorohydrate of buflomedil, 3) iloprost, 4) r-TPA, 5) heparin, 6) dextran, 7) nonsteroidal anti-inflammatory agents, 8) naftidrofuryl, 9) hemodilution, 10) ketanserin, and 11) low-molecular-weight heparin. During the treatment, all patients had an initial bone scan near day 2. The scintigraphic method used was technetium 99m pertechnetate.

### GRADING OF EXTENT

Two independent investigators reinterpreted the patients' medical histories, including the extent of the initial lesions and the final amputation results. To create a baseline for our group of patients on day 0, we determined the initial lesion extent after rapid rewarming. Two kinds of frostbite injuries were identified on admission: frostbite due to 1) *conductive cooling* (eg, associated with compression from shoes or use of the hands to build a snow cave), which was usually overvaluated compared to the frostbite due to 2) *convective cooling*.[16]

The initial lesions on each digit were quantified using a scale of 0 to 5: 0 = no lesion, 1 = lesion on the distal phalanx, 2 = lesion on the middle phalanx or proximal phalanx for the thumb/big toe, 3 = lesion on the proximal phalanx except for the thumb/big toe, 4 = lesion on the metacarpal/metatarsal, and 5 = lesion on the carpal/tarsal. In terms of final outcome, lesions on each digit were graded according to need for bone amputation (0 = no amputation and 1 = amputation regardless of the level).

### STATISTICAL ANALYSIS

The evolution of each lesion was studied independently to evaluate any correlation between the initial clinical aspects of the lesion (defined by a grayness or cyanotic hypoanesthesic area) and its outcome, which was recorded usually more than 1 month later (±necrosis; ±bone amputation). The presence of an initial lesion on a phalanx that subsequently required an amputation was rated as a true positive. The presence of an initial lesion without subsequent need for amputation was a false positive. The absence of an initial lesion and no amputation was a true negative. The absence of an initial lesion in a digit ultimately requiring amputation was a false negative. Positive predictive values were calculated based on the final outcomes of lesions. The probability of bone amputation was determined (positive predictive value) with a 95% CI. A chi-square test was used to compare the frequencies of final outcomes of bone amputations.

## Results

### PATIENTS

After examining 719 patients, only 70 met all inclusion criteria (7 women, 63 men; mean age = 31.9 years).

Thirty patients (42.5%) sustained frostbite injuries involving the hands, and 28 (40%) had frostbite injuries involving the feet, with 12 (17.5%) patients having injuries to both hands and feet. Five patients had a past medical history of prior superficial frostbite injury. Thirteen patients (20.5%) had associated problems: hypothermia in 9 patients (12.3%) and 6 with various traumatic injuries (8.2%). Sixty-eight of 70 patients sustained their cold exposure while mountain climbing in the Mont-Blanc Massif. In the remaining 2, frostbite was related to alcohol intake or a psychiatric disorder leading to prolonged exposure to a cold environment. None had a history of peripheral vascular disease or diabetes, but 3 were smokers. For most patients, frostbites were the result of an unanticipated exposure to cold with inadequate protection due to poor knowledge of the terrain, dehydration, and/or exhaustion.

### THE INITIAL LESION

The initial lesion at hospitalization was characterized by cyanosis and grayness in color, which extended from the digit tip in a centripetal, ascending character toward the base of the limb. This aspect persisted despite rapid rewarming and was accompanied by anesthesia. In the study group, there were no blisters within 12 hours of beginning rewarming, except in 1 case with associated skin trauma (related to use of the hands to build a snow cave). For a few cases, the lesion was more heterogeneous with associated edema. The limit of the initial lesion was usually quite well demarcated just after initial treatment.

### ANALYSIS OF EXTENT

Each hand/foot that developed at least 1 severe lesion on a digit was analyzed with the other unaffected digits of the same hand/foot. Three hundred sixty-five fingers were monitored, with 239 being affected. Of 350 toes monitored, 255 were affected.

The results are presented in Table 1. For both the hands and feet, when lesions were localized to the distal phalanx, the probability of amputation approached 0. The probability of amputation increased progressively as more of the digit was involved, reaching 100% when the entire finger or toe was initially involved. The specificity of the appearance of the initial lesion compared to the final outcome was very low, around 30% (data not shown), indicating that the final amputation level has a low correlation with the initial clinical aspect of the lesion.

The risk of amputation was greater for the hands compared to the feet but not significantly.

**Table 1.** Probability of amputation based on the extent of the initial lesion

| | *Extent (level of involvement)* | *Probability of bone amputation (95% CI)* |
|---|---|---|
| Hand | 5 (carpal/tarsal) | 100 |
| | 4 (metacarpal/metatarsal) | 100 |
| | 3 (proximal phalanx) | 83 (66; 100) |
| | 2 (intermediary phalanx) | 39 (25; 52) |
| | 1 (distal phalanx) | 1 (00; 03) |
| Foot | 5 (carpal/tarsal) | 100 |
| | 4 (metacarpal/metatarsal) | 98 (93; 100) |
| | 3 (proximal phalanx) | 60 (45; 74) |
| | 2 (intermediary phalanx) | 23 (10; 35) |
| | 1 (distal phalanx) | 0 |
| Hand and foot | 5 (carpal/tarsal) | 100 |
| | 4 (metacarpal/metatarsal) | 98 (95, 100) |
| | 3 (proximal phalanx) | 67 (55; 79) |
| | 2 (intermediary phalanx) | 31 (22; 41) |
| | 1 (distal phalanx) | 1 (00; 02) |

No correlation by treatment protocol was found between the extent of the initial lesion and the final outcome, even after pooling the treatment drug by categories (data not shown). This was likely due to the small patient numbers in each group, the lack of standardized treatment protocols, and the retrospective, noncontrolled study design.

## Discussion

This retrospective study of patients with severe frostbite of the extremities demonstrates the importance of the extent of the initial lesion in predicting need for amputation. The relation between the initial frostbite topography and the final outcome was evaluated and quantified for the first time. The results suggest that the severity of the final outcome is correlated with the extent of the initial lesions. The extent of the initial lesion could not, however, be used to predict the level of the amputation. For this reason, isotopic bone scans (2-phase bone scanning [99mTc-HMDP]) should be done to complete the evaluation. Cauchy et al.[17] previously evaluated and published the prognostic value of 2-phase 99mTc bone scanning performed on 92 patients who presented with severe frostbite of the extremities. The study showed that an initial bone scan, as early as on the third day, has excellent specificity in evaluating the severity of frostbite injury. There was a direct correlation between the

**Table 2.** Proposed classification scheme for severity of frostbite injuries

| *Frostbite injuries of the extremities* | *Grade 1 (Figure 1)* | *Grade 2 (Figure 2)* | *Grade 3 (Figure 3)* | *Grade 4 (figure 4)* |
|---|---|---|---|---|
| Extent of initial lesion at day 0 after rapid rewarming | Absence of initial lesion | Initial lesion on distal phalanx | Initial lesion on intermediary (and) proximal phalanx | Initial lesion on carpal/ tarsal |
| Bone scanning at day 2 | Useless | Hypofixation of radiotracer uptake area | Absence of radiotracer uptake area on the digit | Absence of radiotracer uptake area on the carpal/tarsal |
| Blisters at day 2 | Absence of blisters | Clear blisters | Hemorrhagic blisters on the digit | Hemorrhagic blisters over carpal/tarsal |
| Prognosis at day 2 | No amputation | Tissue amputation | Bone amputation of digit | Bone amputation of the limb<br>± systemic involvement<br>± sepsis |
| | No sequelae | Fingernail sequelae | Functional sequelae | Functional sequelae |

uptake limit in the phalanges and the eventual level of amputation. The probability of an amputation was around 84% in the case of scan images demonstrating lack of radioactive tracer uptake. A second scan, on approximately day 8, was even more sensitive and informative, especially for initial scintigraphic hypofixated lesions. A strong correlation was shown between a positive uptake of the radiotracer and the probability of healing (around 99%).

Taking into account our results, a new classification is proposed. This new classification (Table 2) can be used immediately after rewarming of the frostbitten extremity to determine prognosis of the frozen lesions. Four severity levels are proposed, and the main differences from the previous classification scheme include the following:

1. Earlier prediction of the final outcome of the frostbite is possible (a minimum of 15 days was required with previous classifications);
2. At day 2, the approximate level for amputation is known; and
3. The new scale can be used to precisely classify the frozen lesions and manage the patient, even without any specific knowledge of the topic on the part of the treating physician.

Taking into account the low risk of amputation, Grade 1 (Figure 1) and 2 (Figure 2) lesions do not need hospitalization or bone scanning. Treatment with rapid rewarming over 60 minutes in a 38°C bath with antiseptic, aspirin, vasodilators by oral route for 8 to 21 days, and local treatment would be sufficient in most of these cases.

Grade 3 (Figure 3) injuries are correlated with an important risk of amputation, and patients should be hospitalized immediately for the same medical treatment (aspirin and chlorohydrate of buflomedil) but by an intravenous route. An isotopic bone scan performed on day 2 will allow a more precise determination of the extent of the frozen lesions and delimitation of the level of bone amputation. In the case of an abnormal result, surgical intervention should be planned after a second bone scan on day 8 (to allow stabilization of the frostbite bone lesions).

Grade 4 (Figure 4) lesions have a high probability of amputation and a high risk of major complications (eg, thrombosis, sepsis, and systemic involvement), which may require hospitalization in an intensive care unit. The use of more aggressive treatments such as thrombolytics or prostacycline might be appropriate. Even following prophylactic antibiotics, early amputation is often needed due to major sepsis. In such cases, the amputation level could be determined by the results of the isotopic bone scan. This alternative is particularly appropriate for those cases of severe frostbite in patients who are malnourished, weak, or have hepatocellular dysfunction. The operative approach may vary by surgeon's preference (amputation in 1 or 2 steps or salvage with flap transfer, etc). Early amputation decreases overall hospitalization and hastens reconstructive surgery.[18] The proposed management algorithm is listed in Table 3.

This proposed classification scheme may be useful in clinical trials evaluating various frostbite therapies. Prospective controlled studies are needed to validate the clinical efficacy of proposed therapies. This classification scheme may be modified in the future as new diagnostic modalities such as laser Doppler or magnetic nuclear resonance imaging are studied in the setting of

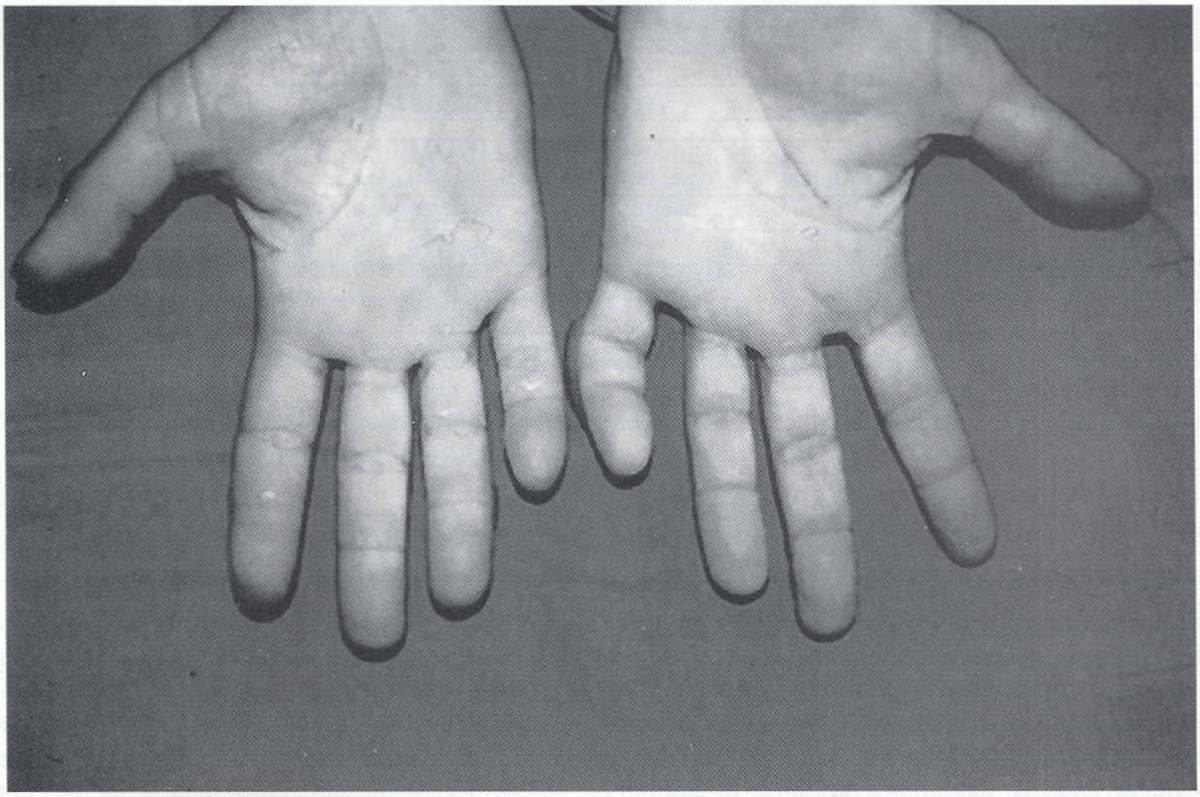


**Figure 1.** Frostbite injury of the hand at day 0: no initial lesion except erythema (Grade 1).

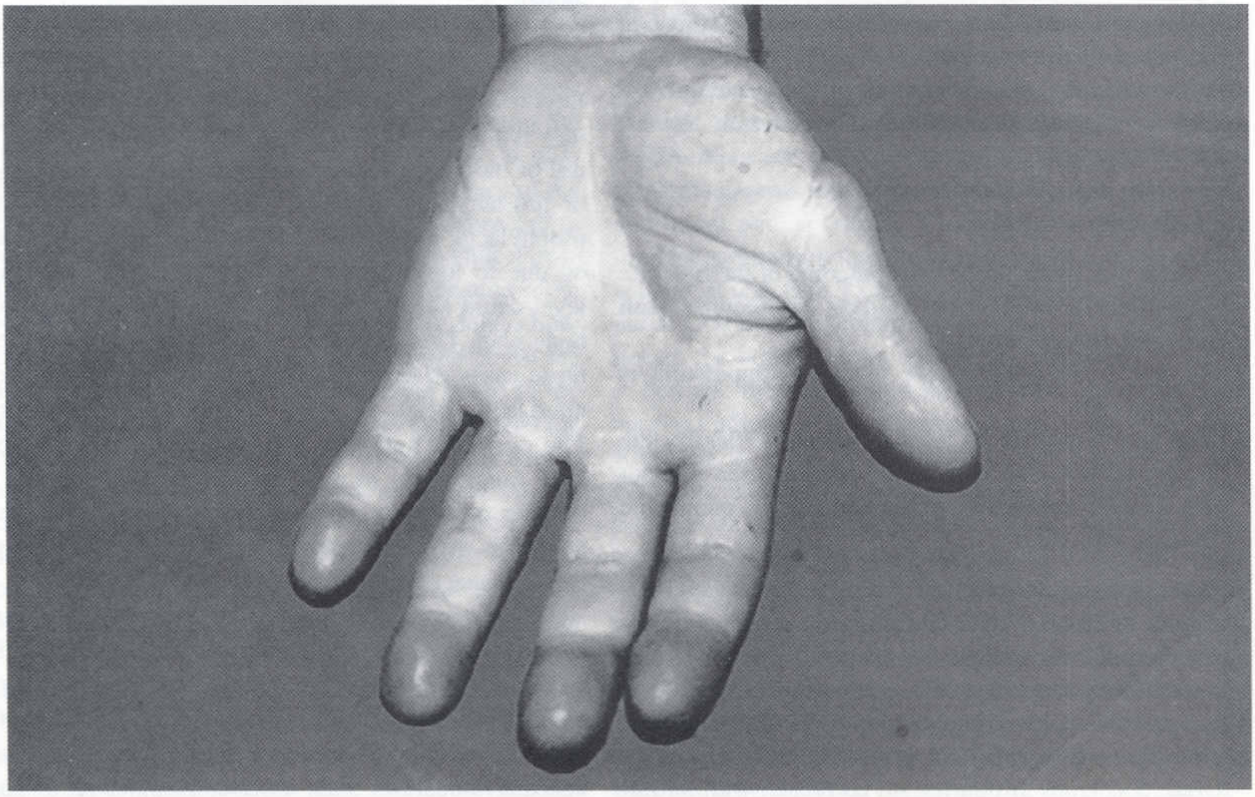


**Figure 2.** Frostbite injury of the hand at day 0: initial lesion limited to the distal phalanx (Grade 2).

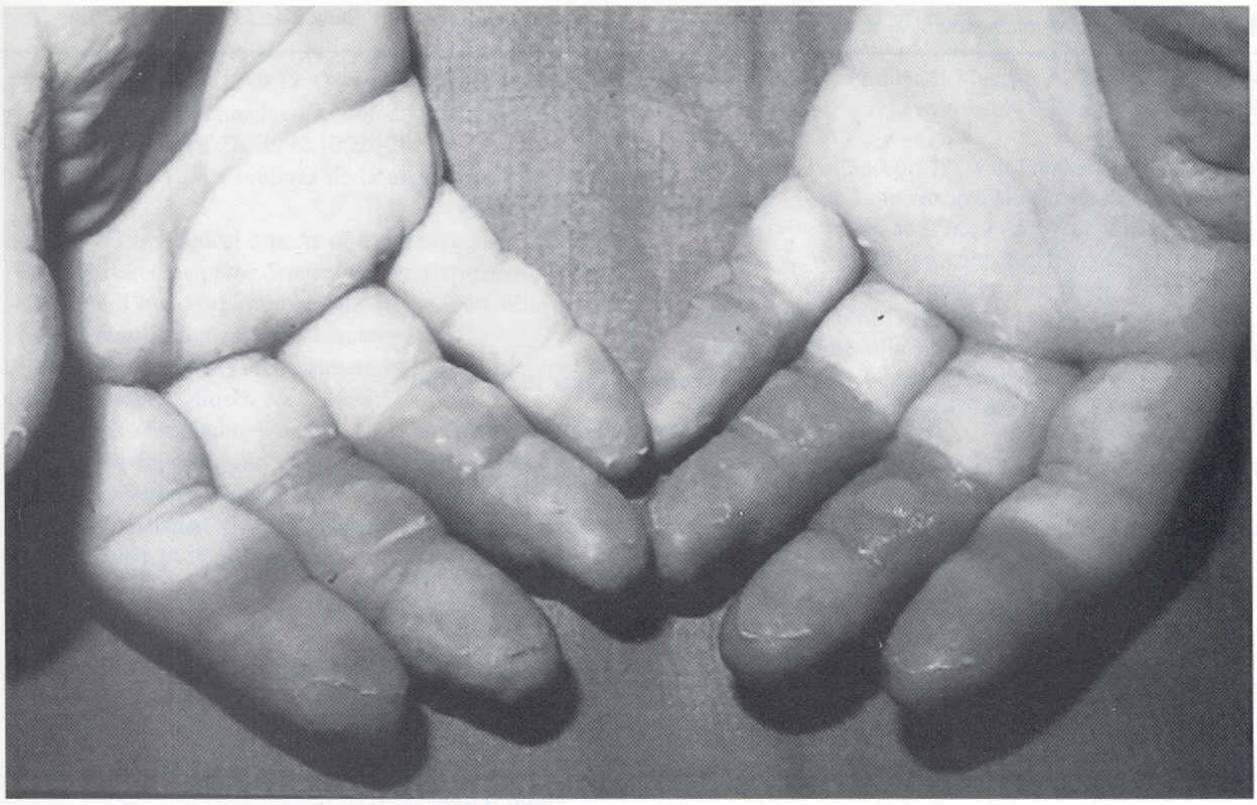


**Figure 3.** Frostbite injury of the hand at day 0: initial lesion extends beyond the distal phalanx (Grade 3).

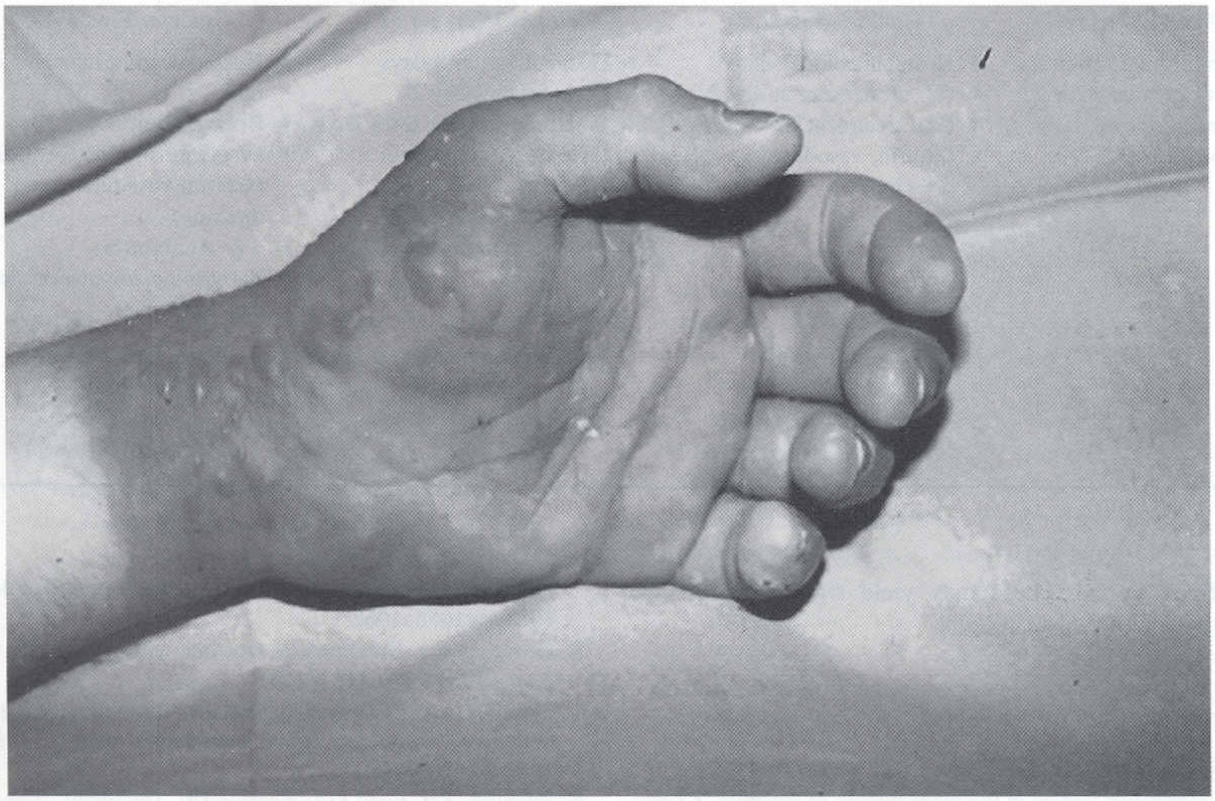
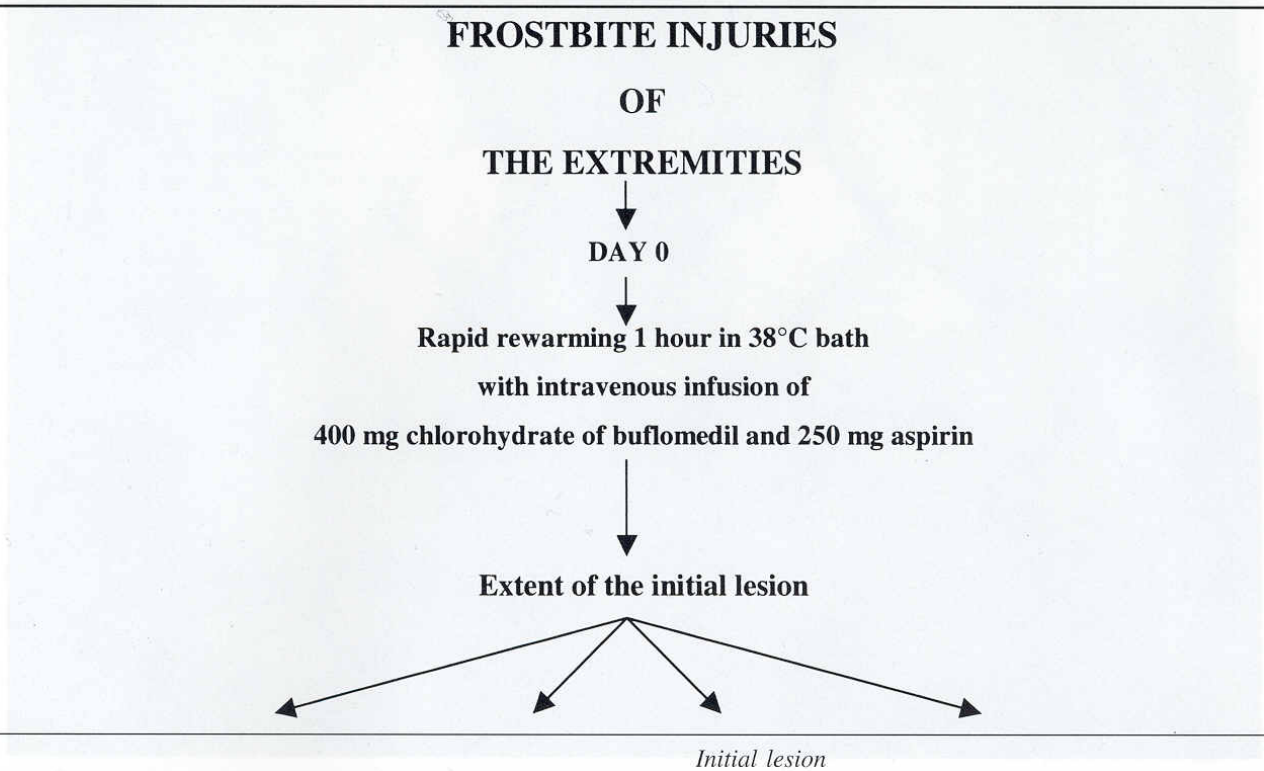


**Figure 4.** Frostbite injury of the hand at day 0, with initial lesion extending beyond the metacarpophalangeal joints (Grade 4).

**Table 3.** Algorithm of management at day 0




| *Absence of initial lesion* | *Initial lesion over distal phalanx* | *Initial lesion over intermediary (and) proximal phalanx* | *Initial lesion over carpal/tarsal* |
|---|---|---|---|
| Grade 1 (Figure 1) | Grade 2 (Figure 2) | Grade 3 (Figure 3) | Grade 4 (Figure 4) |
| • No hospitalization<br>• Oral treatment for 1 week (aspirin, vasodilator) | • Hospitalization 2 days<br>• +/−Bone scan at day 2<br>• Oral treatment for 3 weeks (aspirin, vasodilators, dressing) | • Hospitalization 8 days<br>• Bone scan at day 2<br>• IV administration for 8 days (aspirin, vasodilators, dressing)<br>• Bone scan near day 8<br>• Bone amputation near day 30 | • Hospitalization intensive care unit<br>• Bone scan at day 2<br>• IV administration for 8 days (aspirin, vasodilators, dressing)<br>• +/−Antibiotics<br>• Early bone amputation near day 3 if sepsis |
| Recovery | Recovery with moderate sequelae | Bone amputation of the digit with functional sequelae | Bone amputation of the limbs with systemic involvement |

frostbite injuries. These may yield even more precise evaluations of frozen lesions.

## References

1. Knize DM, Weatherley-White RC, Paton BC, Owens JC. Prognostics factors in the management of frostbite. *J Trauma.* 1969;9:749.
2. Heggers JP, Robson MC, Manavalen K, et al. Experimental and clinical observations on frostbite. *Ann Emerg Med.* 1987;16:1056–1062.
3. Groechenig E. Treatment of frostbite with iloprost [letter]. *Lancet.* 1994;344:1152–1153.
4. Skolnick AA. Early data suggest clot-dissolving drug may help save frostbitten limbs amputation [news]. *JAMA.* 1992;267:2008–2010.
5. Zdeblick TA, Field GA, Shaffer JW. Treatment of experimental frostbite with urokinase. *J Hand Surg Am.* 1988; 13:948–953.

6. Voinov AI. Clinical classification of cold injury and prognostication of the depth of tissue damage during the acute period. *Klin Khir.* 1989;12:41–43.
7. Chernetsov AA. The classification and treatment of frostbite. *Voenno-Med Zh.* 1992;10:26–28.
8. Botta-Kauer Y. Les brûlures de la main. *Med Hyg.* 1997; 55:2369–2372.
9. Mills WJ Jr. Clinical aspects of frostbite injury. IV. Frostbite. *Proceeding of the Symposium on Arctic Medicine and Biology.* 1964; Fort Wainwright, Alaska. Fort Wainwright, AL: Arctic Aeromedical Laboratory; 1964.
10. Mills WJ. Summery of treatment of the cold injured patient: frostbite. *Alaska Med.* 1993;35:61–66.
11. Killian H. Terminology and division into groups of localised cold injuries. In: *Cold and Frost Injuries.* Berlin: Springer-Verlag; 1981:25–37.
12. Foray J, Allamel G. Les gelures. In: *Encycl Med Chir Paris.* 1994;14-033-F-10.
13. Mazur P. Freezing of living cells: mechanisms and implications. *Am J Physiol.* 1984;247:125–142.
14. Vayssairat M, Priollet P, Magege A, Mousset E, Foray J. Does ketanserin relieve frostbite? *Practitioner.* 1986;230: 406–408.
15. Maurel A, Betrancourt JC, Van Frenkel R, et al. Action du buflomédil sur la microcirculation cutanée étudiée par un test de provocation au froid. *J Mal Vasc.* 1995;20:127–133.
16. Holmer I. Work in the cold. Review of methods for assessment of cold exposure. *Int Arch Occup Environ Health.* 1993;65:147–155.
17. Cauchy E, Chetaille E, Lefevre M, Kerelou E, Marsigny B. The role of bone scanning in severe frostbite of the extremities. A retrospective study of 88 cases. *Eur J Nucl Med.* 2000;48:497–502.
18. Greenwald D, Cooper B, Gottlieb L. An algorithm for early aggressive treatment of frostbite with limb salvage directed by triple-phase scanning. *Plast Reconstr Surg.* 1998;102:1069–1074.

WILDERNESS & ENVIRONMENTAL MEDICINE XXXX; XXX(XXX): 1–23

WILDERNESS MEDICAL SOCIETY CLINICAL PRACTICE GUIDELINES

# Wilderness Medical Society Clinical Practice Guidelines for the Out-of-Hospital Evaluation and Treatment of Accidental Hypothermia: 2019 Update

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To provide guidance to clinicians, the Wilderness Medical Society convened an expert panel to develop evidence-based guidelines for the out-of-hospital evaluation and treatment of victims of accidental hypothermia. The guidelines present the main diagnostic and therapeutic modalities and provide recommendations for the management of hypothermic patients. The panel graded the recommendations based on the quality of supporting evidence and a balance between benefits and risks/burdens according to the criteria published by the American College of Chest Physicians. The guidelines also provide suggested general approaches to the evaluation and treatment of accidental hypothermia that incorporate specific recommendations. This is the 2019 update of the Wilderness Medical Society Practice Guidelines for the Out-of-Hospital Evaluation and Treatment of Accidental Hypothermia: 2014 Update.

*Keywords:* rewarming, resuscitation, wilderness medicine, cold, shivering

## Introduction

Accidental hypothermia is defined as an unintentional drop in core temperature to 35°C or lower. Accidental hypothermia due to environmental exposure can occur during any season and in most climates, with cold and wet environments posing the greatest risk. Throughout history, it has been a disease of war and disasters, but those who work and recreate outside, especially in the wilderness, place themselves at risk for hypothermia.

In addition to occurring in wilderness environments, hypothermia is associated with urban homelessness, particularly with the use of alcohol and other intoxicating substances. Hypothermia can occur during resuscitation in emergency settings (iatrogenic hypothermia); is notably associated with trauma; and may be a feature of sepsis, diseases that decrease metabolic rate (including hypoendocrine states), and diseases that affect thermoregulation. Therapeutic hypothermia is beyond the scope of this review.

Hypothermia is the result of net heat loss from the body. Heat can be lost or gained by conduction, convection, and

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radiation and lost through evaporation. Conduction is direct transfer of heat from warmer to cooler objects that are in contact. Convection is transfer of heat to or from a gas or a liquid that is in motion. Radiation is transfer of heat in the form of electromagnetic energy between 2 objects that are visible to each other. Evaporation is loss of heat by vaporizing liquid (usually water from sweat or external sources) from the skin, clothing that is in contact with the skin, or respiration.

The human body attempts to maintain a core temperature at or near 37°C. The thermoregulatory control center in the hypothalamus receives input from central and peripheral thermal receptors. The integrated thermal signal triggers autonomic reflexes that control the initiation of cooling responses such as vasodilation or sweating (heat loss) or warming responses such as vasoconstriction (heat retention) or shivering (heat production).[1] Peripheral blood flow is also partly regulated by local skin temperature.

Humans originated in the tropics and have limited physiologic means to avoid developing hypothermia. Exercise and shivering can raise the metabolic rate to prevent hypothermia if nutritional reserves and insulation are adequate, but the benefit may be limited by environmental conditions. Prevention of hypothermia in humans mostly depends on behavior, chiefly wearing insulating clothing and using shelter.

## Methods

The Wilderness Medical Society (WMS) convened an expert panel to develop evidence-based clinical guidelines for prevention and out-of-hospital diagnosis and treatment of victims of accidental hypothermia to update the previous WMS Practice Guidelines for the Out-of-Hospital Evaluation and Treatment of Accidental Hypothermia: 2014 Update.[2] Panelists were selected by the WMS based on clinical and/or research experience and generated a set of questions (Figure 1) to define the most significant areas of interest. As part of the update process, the current panel identified additional questions not previously considered. A literature search identified relevant articles with a key word search of the MEDLINE database. Keywords were hypothermia, accidental hypothermia, wilderness hypothermia, shivering, rewarming, core temperature, and resuscitation. The panel considered only peer-reviewed randomized controlled trials, observational studies, case series, and case reports related to evaluation and treatment of accidental hypothermia. Although all articles were considered, those published between 2013 and March 2019 were the focus of this review.

The panel assessed the level of evidence supporting each diagnostic and therapeutic modality. Conclusions from review articles were not used in the formulation of recommendations, but the guidelines cite review articles when necessary to provide background information.

Questions considered by the panel

FIELD ASSESSMENT
- How should the level of hypothermia be classified?
- What is the best way to measure core temperature?

PREHOSPITAL TREATMENT
- What is the best treatment for a cold patient who is not hypothermic or for a patient with mild hypothermia in the field?
- What is the safest way to handle a patient with moderate to severe hypothermia in the field?
- What is the best treatment for moderate to severe hypothermia?
- When should a hypothermic patient without signs of life be resuscitated?
- Are there specific considerations regarding hypothermia in a trauma patient?
- Are there specific considerations regarding burn prevention in an actively warmed patient?
- When should rescuers start cardiopulmonary resuscitation (CPR) on a hypothermic patient?
- When and how should a hypothermic patient be defibrillated?
- What is the best method for giving CPR to a hypothermic patient?
- What are recommendations for delayed, intermittent, and prolonged CPR?
- What is the best way to manage the airway in a severely hypothermic patient?
- What is the best way to obtain vascular access in a hypothermic patient?
- What is the best way to manage fluids in a hypothermic patient?
- What is the role of Advanced Life Support (ALS) drugs in a hypothermic patient?
- Is there a role for transcutaneous cardiac pacing in a hypothermic patient?
- How should atrial dysrhythmias be managed during rewarming for a hypothermic patient?
- Is there a simple decision aid that can be used by any responders in the field?

TRANSPORT/TRIAGE
- How should the destination hospital be determined for a hypothermic patient?
- What is the tole of ECLS in the hypothermic patient?
- How can serum potassium be used to determine if CPR should be continued on a hypothermic patient?

**Figure 1.** Questions considered by the authors for the development of these practice guidelines.

The panel used a consensus approach to develop recommendations regarding each evaluation technique and intervention and its role in management. The panel graded each recommendation based on the quality of supporting evidence and balance between the benefits and risks/burdens, according to the criteria of the American College of Chest Physicians (see online Supplementary Table).[3]

## PATHOPHYSIOLOGY OF HYPOTHERMIA

The primary physiologic effects of tissue cooling are decreased resting metabolism and inhibition of central and peripheral neurologic function. During the initial stages of cooling of a neurologically intact victim, secondary responses to skin cooling predominate.[1] Shivering thermogenesis, triggered by skin cooling, results in increased metabolism due to the work of shivering and increased ventilation, cardiac output, and mean arterial pressure.[4] These physiologic parameters initially increase as core temperature decreases to approximately 32°C. The parameters then decrease with a further drop in core temperature.[1] Shivering ceases at and below a core temperature of approximately 30°C.[5] Once this occurs, metabolism decreases with further decreases in core temperature.

Clinical manifestations of accidental hypothermia relate predominantly to cerebral and cardiorespiratory effects. Brain activity begins to decline at a core temperature of approximately 33 to 34°C and continues to decline with further cooling.[6,7] Cooling of the brain leads to irritability, confusion, apathy, poor decision making, lethargy, somnolence, and eventually coma. Brain cooling decreases cerebral oxygen requirements.[8] This provides temporary protection during anoxic conditions such as cold-induced cardiac standstill and cold-water drowning. Cold stress reduces circulating blood volume due a combination of cold-induced diuresis, extravascular plasma shift, and inadequate fluid intake.[9] As the heart cools below 30°C, cardiac output decreases markedly, and bradycardia usually occurs. Abnormalities in electrical conduction lead to dysrhythmias such as premature atrial and ventricular contractions, atrial fibrillation, and ventricular fibrillation (VF).[10] Below 28°C, the heart is susceptible to VF, which can be triggered by acidosis, hypocarbia, hypoxia, or movement.[1] Decreased ventilatory response to carbon dioxide leads to hypoventilation and respiratory acidosis.[11]

## FIELD ASSESSMENT

### *Classification of hypothermia*

Most guidelines use a standard classification of hypothermia based on core temperature. Hypothermia is classified as mild at 35 to 32°C; moderate at 32 to 28°C; or severe at <28°C.[12–14] Some experts advocate a further category, profound hypothermia, at <24°C[12] or <20°C.[1] The chance of survival appears to be much lower in this range, probably because of a high likelihood of cardiac arrest. In cases of hypothermia secondary to cold water immersion, loss of airway protection and drowning may also contribute to causes of death. Although core temperature is used to classify hypothermia, individual variation to core temperature is wide, as is true of other physiologic parameters. Measuring core temperature is not always feasible in the out-of-hospital environment.[15]

### *Factors to guide treatment*

The standard classification of hypothermia by core temperature correlates with the status of the thermoregulatory system. From 35 to 32°C (mild hypothermia) thermoregulatory shivering control is functional and increases as core temperature decreases.[16] With further cooling, shivering generally becomes less effective, although it can still be strong at 31°C.[5] Below 32°C (moderate hypothermia), thermoregulation becomes less effective and rewarming is possible only with addition of exogenous heat. As the core temperature decreases below 32°C, level of consciousness decreases. Below 28°C (profound/severe hypothermia), most patients are unconscious and not shivering, and the risk of VF or asystole is high.[17]

***Recommendation.*** The key factors guiding hypothermia treatment are level of consciousness, alertness, shivering intensity, physical performance, and cardiovascular stability, which is based on blood pressure and cardiac rhythm (Figure 2). Core temperature can provide additional helpful information, but it is difficult to accurately obtain in the field, and the panel recommends that this should not be the sole basis for treatment (**Evidence grade:** 1C).

### *Simplified decision aid for field use*

We have developed a simplified "Cold Card"[18] (Figure 3) corresponding to the more technical flowchart in Figure 2.

***Recommendation.*** It is the recommendation of the working group that this decision aid be considered to facilitate evaluation and treatment of accidental hypothermia in the out-of-hospital setting for responders with varying levels of medical training.

### *Some patients are cold, but not hypothermic*

Patients can be cold and shivering, but not hypothermic. Shivering is triggered by skin cooling as a mechanism for preventing hypothermia. A shivering patient with a core temperature >35°C is cold-stressed, but not hypothermic. If temperature measurement is not possible, clinical judgment may be helpful to distinguish whether a patient is

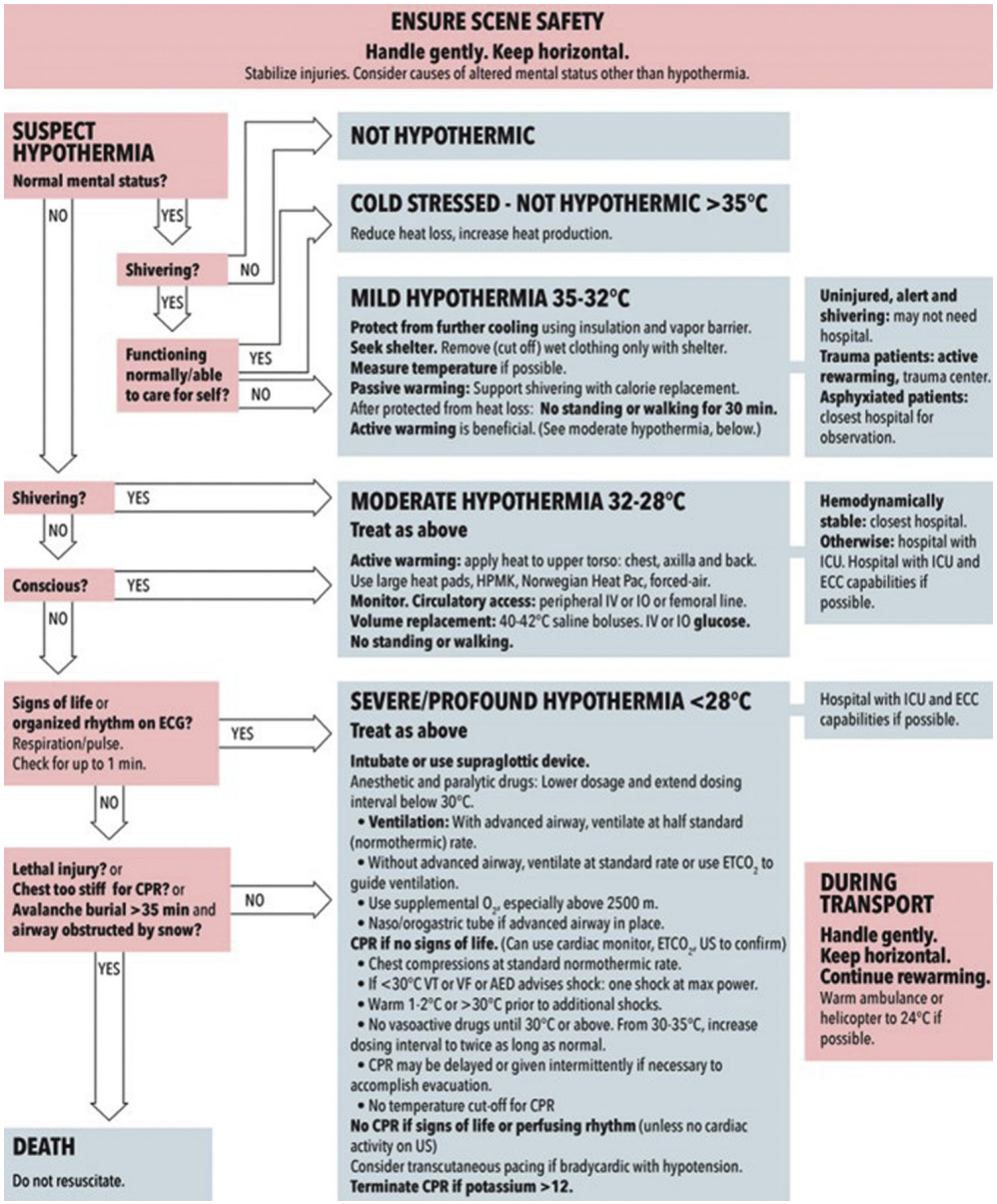


**Figure 2.** Recommendations for out-of-hospital evaluation and treatment of accidental hypothermia. *Abbreviations:* AED = automatic external defibrillator, CPR = cardiopulmonary resuscitation, ECC = extracorporeal circulation, ECG = electrocardiogram, $ETCO_2$ = end-tidal carbon dioxide, HPMK = Hypothermia Prevention Management Kit, ICU = intensive care unit, IV = intravenous, IO = intraosseous, $O_2$ = oxygen, PEA = pulseless electrical activity, US = ultrasound, VT = ventricular tachycardia, VF = ventricular fibrillation. From Zafren et al.[2] Reprinted with permission from the Wilderness Medical Society. ©2014 Wilderness Medical Society.

hypothermic or cold-stressed. For example, a patient who was not cold before being briefly immersed in cold water may be shivering but will not be hypothermic (Figures 2 and 3). Many alert, shivering patients who are well nourished and exhausted are not hypothermic.

***Recommendation.*** It is the recommendation of the panel that a patient who is shivering but able to function well and care for him- or herself be closely observed because this patient is unlikely to be hypothermic. A patient who is shivering, becoming incapacitated, and having difficulty caring for him- or herself is likely to be hypothermic. If there is any doubt, assume that the patient is hypothermic and treat accordingly.

### *Alternate classification of hypothermia*

The American Heart Association (AHA) 2010 Guidelines propose an alternate classification of hypothermia: mild (>34°C); moderate (34−30°C); and severe (<30°C).[19] Defibrillation is less likely to be successful at temperature below 30°C than above 30°C.

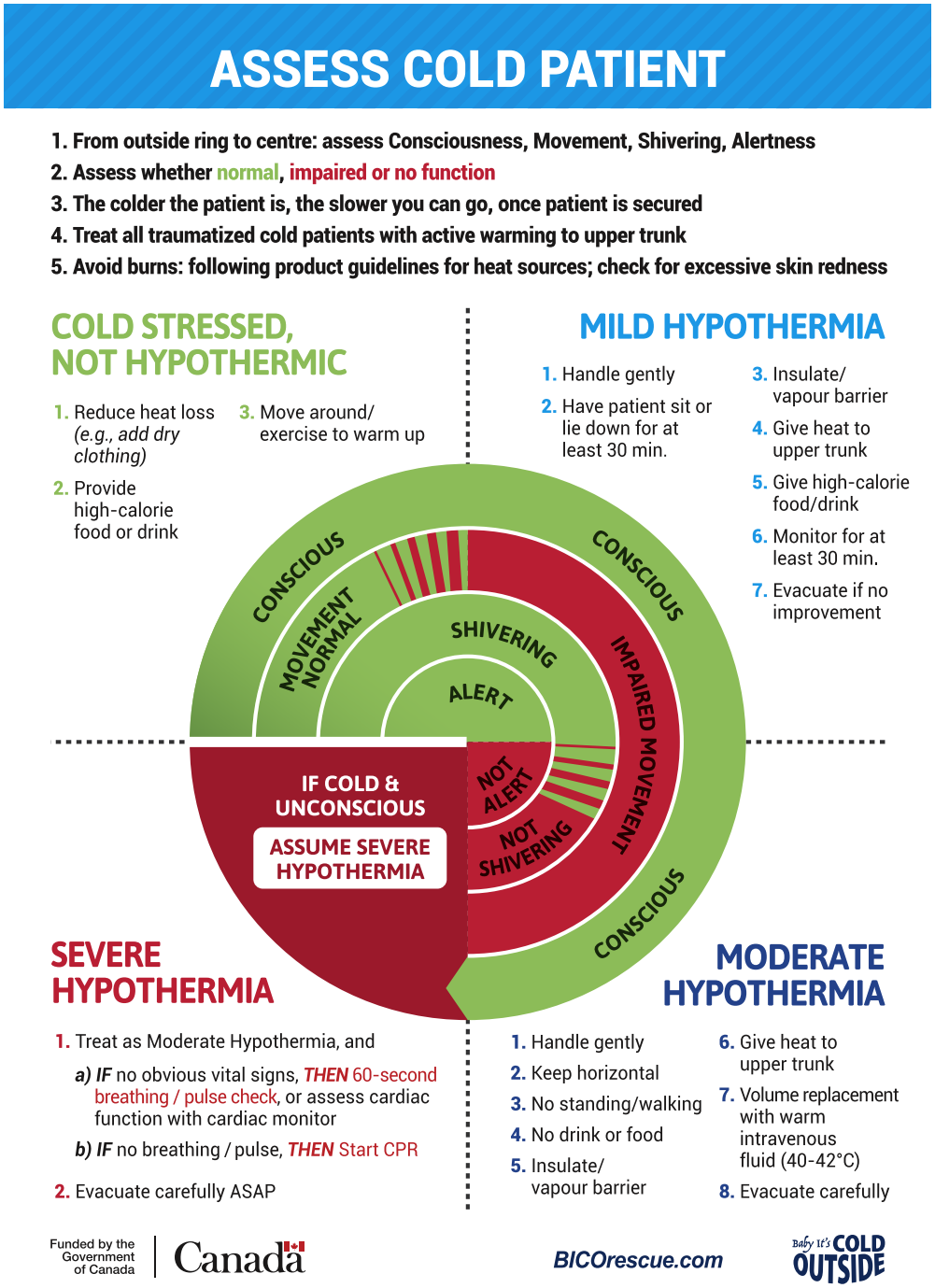


**Figure 3.** (A) Front of cold card — "assess cold patient". (B) Back of cold card — "care for cold patient." From Giesbrecht.[18] Reprinted with permission from the Wilderness Medical Society. ©2018 Wilderness Medical Society

***Recommendation.*** The panel recommends that the AHA scheme should not be used as the standard classification for out-of-hospital treatment of hypothermia because it changes the widely accepted definition of hypothermia and emphasizes response to defibrillation rather than physiologic changes.

*Field classification of hypothermia: the "Swiss" system*

The "Swiss" hypothermia classification was developed to help rescuers estimate core temperature by observing clinical signs.[12] Because individuals have variability in response to cold, estimating core temperature on the basis

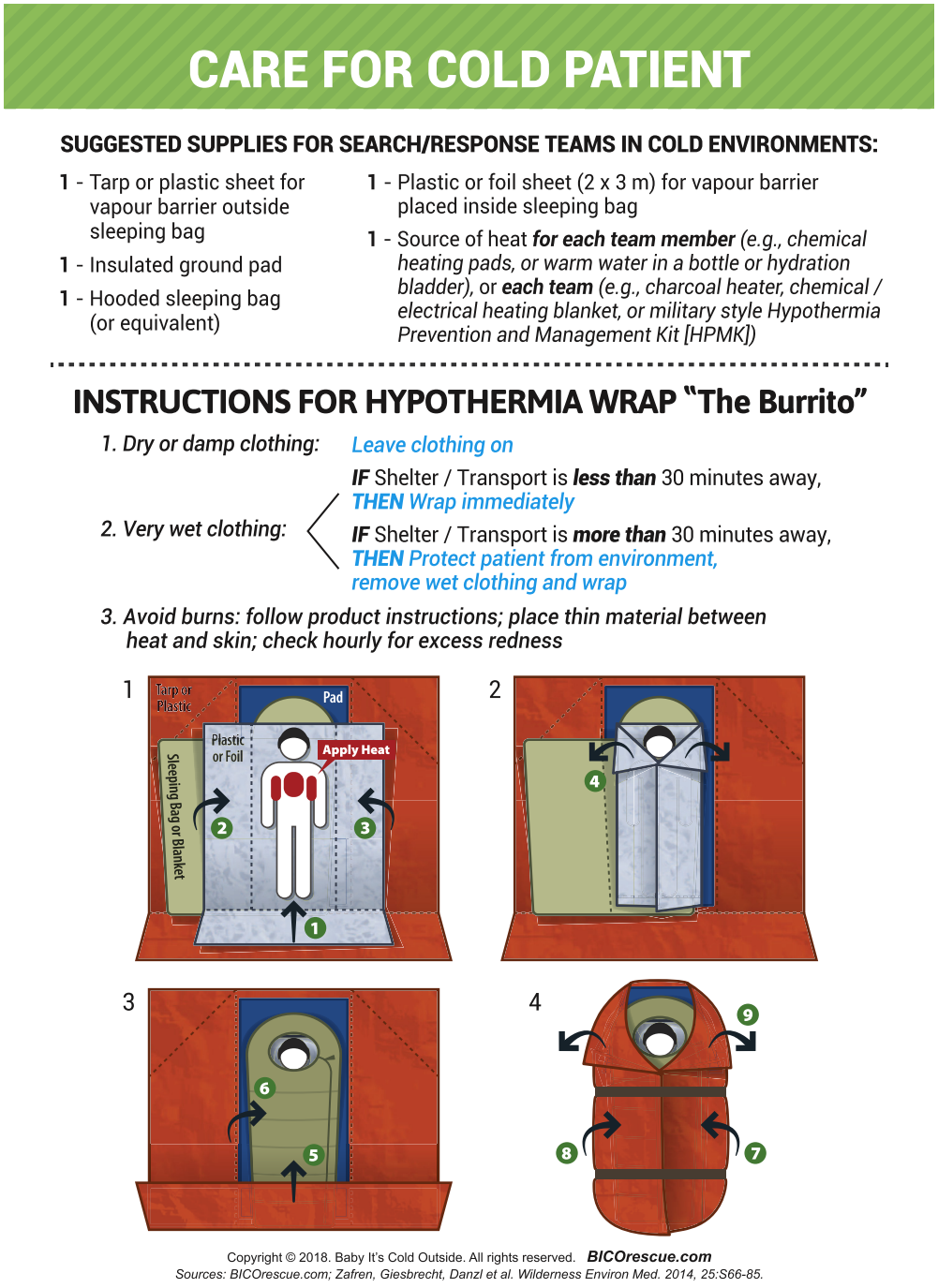


**Figure 3** (*continued*).

of clinical signs is only an approximation. The stages of the "Swiss" hypothermia (abbreviated "HT") grading system with descriptions and estimated core temperature are as follows:

•HT I—clear consciousness with shivering: 35 to 32°C
•HT II—impaired consciousness without shivering: 32 to 28°C
•HT III—unconscious: 28 to 24°C
•HT IV—apparent death: 24 to 13.7°C
•HT V—death due to irreversible hypothermia: <13.7°C? (<9°C?)[12]

A limitation of this system is that individuals vary in physiologic response to hypothermia. Shivering may be

maximal at 32 to 33°C but may continue at 31°C and may not cease until core temperature drops to approximately 30°C. A shivering patient with impaired consciousness should be treated for moderate, not mild, hypothermia. Temperature ranges for hypothermia stages should not be considered absolute but rather correlated with clinical observations. An analysis of reported cases of hypothermia revealed clinically significant temperature overlap with respect to hypothermia staging. The lowest recorded temperature was 28.1°C for HT I, 22°C for HT II, and 19.3°C for HT III.[20] It is advised that rescuers focus on the entire clinical picture rather than just shivering. Many case reports describe hypothermic patients with vital signs who had core temperatures below 24°C.[21–25] Individuals with core temperatures below 24°C are very susceptible to VF. Although the Swiss HT system can help guide rescuers in certain situations, we prefer to use the terms mild, moderate, severe, and profound hypothermia.

***Recommendation.*** Rescuers should classify hypothermia as mild, moderate, severe, and profound on the basis of clinical observations, remembering that shivering can occur below 32°C, usually with altered mental status, and that patients can have detectable vital signs with core temperatures below 24°C. Furthermore, rescuers should be aware of core temperature overlap between classification categories[20,25] (**Evidence grade:** 1C).

### *Associated conditions complicating the field classification of hypothermia*

In addition to hypothermia, many conditions can cause altered mental status and decreased level of consciousness. Conditions such as sepsis and severe trauma can decrease physiologic reserves and may decrease or abolish shivering.[26] Many drugs and medications[27] suppress shivering.[28]

***Recommendation.*** Clinicians should consider causes other than hypothermia to explain altered mental status or lack of shivering that do not correlate with the measured core temperature or are associated with a history of minimal cold exposure (**Evidence grade:** 1B).

## MEASUREMENT OF CORE TEMPERATURE

### *Esophageal temperature*

The most accurate minimally invasive method of measuring core temperature is esophageal temperature, with the probe inserted into the lower third of the esophagus.[29] The degree of accuracy afforded by esophageal temperature monitoring is helpful to guide treatment of patients with moderate or severe hypothermia. Placement of an esophageal probe via the pharynx may cause vomiting and aspiration. The airway must be protected with an endotracheal tube or supraglottic device that allows passage of a gastric tube before placement of an esophageal probe. Heated humidified oxygen does not significantly raise the temperature measured by a properly inserted esophageal probe.[30–32] If the esophageal probe is not inserted into the lower third of the esophagus, an average of 24 cm below the larynx in adults,[1] use of heated humidified oxygen may result in a falsely elevated esophageal temperature. Esophageal probes that do not have markings can be measured visually against the patient and marked to ensure the correct depth of insertion. Field conditions will rarely allow for placement of an esophageal probe; however, transporting air or ground medical services that have this capacity should place a probe as soon as possible.

***Recommendation.*** If available, an esophageal temperature probe should be placed in a patient whose airway has been protected and secured. Esophageal temperature is the preferred method of core temperature measurement (**Evidence grade:** 1C).

### *Epitympanic temperature*

Epitympanic (ear canal) temperature, measured using a soft probe with a thermistor in proximity to the tympanic membrane, reflects carotid artery temperature.[33] Epitympanic thermometers should not be confused with the more common and much less accurate infrared "tympanic" thermometers. In patients with adequate cardiac output, epitympanic temperature reflects core temperature. Epitympanic temperature can be lower than esophageal temperature during low flow (decreased cardiac output) or no-flow (cardiac arrest) states.[28] In out-of-hospital settings care must be taken to insulate the ear canal from the environment. With cold ambient temperature, epitympanic temperature may be falsely low, especially if the external auditory canal is blocked by cerumen, filled with snow, or not adequately sealed and properly covered with an isolating "cap."[33] Epitympanic temperature is much lower than esophageal temperature during initial cooling of the head in normothermic subjects. After 10 min of isolated head cooling, the mean difference between epitympanic and esophageal temperatures is about 1 to 2°C.[34] Epitympanic thermometers for use in the operating room are not suitable for field use; they are not designed for use in cold environments.

***Recommendation.*** Use an epitympanic thermometer designed for field conditions with an isolating ear cap in a patient whose airway has not been secured by endotracheal intubation or a supraglottic airway, or in a patient with a secured airway if an esophageal probe is not available

(**Evidence grade:** 1C). Infrared tympanic thermometers should never be used to measure core temperature in a hypothermic patient[15] (**Evidence grade:** 1A).

*Rectal temperature in the field*

The use of rectal thermometers is not advisable before the patient has been removed from the cold environment because the patient must be further exposed, increasing heat loss and potentially worsening hypothermia.

***Recommendation.*** Rectal temperature measurement should not be used unless the patient is in a warm environment (**Evidence grade:** 1C).

*Rectal and bladder temperatures during rewarming*

Rectal and bladder temperatures lag behind core temperature changes by as much as an hour and can give the false impression that the patient is still cooling.[4,9,35] Rectal and bladder temperature overestimate heart temperature during cooling and underestimate heart temperature during rewarming.

***Recommendation.*** Monitor rectal or bladder temperature during rewarming of an unconscious patient only if an esophageal or epitympanic probe is not available. If rectal or bladder temperature is used for monitoring during rewarming, allow for inaccuracy due to the time lag behind core temperature changes (**Evidence grade:** 1A).

*Oral temperature*

Oral temperatures are useful only to rule out hypothermia. Nonelectronic thermometers are typically unable to measure temperatures below 35.6°C. If mercury or alcohol thermometers are used to diagnose hypothermia, they must be special "low reading" thermometers.[1]

***Recommendation.*** Oral temperature measurement with a thermometer that cannot read below 35°C should not be used to diagnose hypothermia (**Evidence grade:** 1A).

"*Temporal artery*" *thermometer*

"Temporal artery" thermometers, used on the skin surface, do not provide accurate temperature measurements in hypothermia.[36]

***Recommendation.*** Do not use a temporal artery thermometer in a possibly hypothermic patient (**Evidence grade:** 1C).

*Zero-heat flux thermometer*

A noninvasive heat flux or "double sensor" thermometer is currently under development.[37] This technology, which combines a skin temperature sensor with a heat flux sensor, correlates well with esophageal temperature in operative and intensive care unit settings.[38,39]

***Recommendation.*** Because this technology has not been validated in field settings, no recommendation can be made at this time.

## OUT-OF-HOSPITAL TREATMENT

*Safety of the rescuers*

Rescuer safety is the first priority during rescue. The scene may be unsafe to enter, or the safety officer in a rescue may allow only brief entry. Unless there are obvious fatal injuries, rescuers might need to move the patient to a safe place before deciding to resuscitate.

***Recommendation.*** The decision to rescue or resuscitate a patient can only be made after the scene is secure and safe for the rescuers to enter and make an evaluation (**Evidence grade:** 1A). After rescuer safety has been assured, the priorities for out-of-hospital treatment of a hypothermic patient who is not in cardiac arrest are to avoid causing cardiovascular collapse during rescue, prevent further decrease in core temperature (afterdrop), and rewarm the patient in a safe manner. If a hypothermic patient is in cardiac arrest, rescuers should, if indicated, initiate resuscitation.

*Core temperature afterdrop*

Core temperature afterdrop refers to continued core cooling after removal from a cold environment. Afterdrop is caused by a combination of conductive heat loss from the warmer core to cooler peripheral tissue and convective heat loss from blood due to increased flow to cooler tissue and subsequent return to the central circulation and heart.[40–42] The convective component transfers more heat, and, unlike the conductive component, is affected by the method of rewarming. In a hypothermia victim, peripheral tissue is colder than the heart. Therefore, any action that increases blood flow to cold peripheral tissue (eg, hoisting or holding victim in a vertical position, allowing the victim to stand or walk, active or passive limb movement, immersion in warm water) will increase the volume of cold blood returning to the heart. This increases cardiac work and further decreases core temperature.

Afterdrop may be clinically important in victims who are at the threshold of moderate to severe hypothermia because they are susceptible to cardiovascular instability with a small further drop in core (heart) temperature. Afterdrop of as much as 5 to 6°C has been reported in hypothermic patients.[21,42–44] Therefore, care should be taken to prevent increased blood flow to the limbs during and after rescue.

### *Circumrescue collapse*

Circumrescue collapse refers to light-headedness, collapse, syncope, or sudden death occurring in victims of cold-water immersion just before, during, or after rescue and removal from water.[45] Circumrescue collapse can be caused by mental relaxation and decreased catecholamine output causing life-threatening hypotension or by sudden onset of cardiac dysrhythmia, likely VF.[4]

The act of removing a victim from water decreases hydrostatic pressure,[4] which is normally greatest around the legs. Removing hydrostatic pressure allows blood to pool in dependent areas, causing decreased blood return with resultant hypotension or cardiovascular collapse. A cold heart may not be able to compensate for decreasing blood pressure by increasing cardiac output. Blood that does return from dependent areas will be cooled and will contribute to core temperature afterdrop. Afterdrop is increased if the victim has to perform work to assist in rescue (eg, having to climb a ladder onto a boat).[45,46] Mechanical stimulation of the heart during rescue and extrication—combined with hypotension, afterdrop, and acidosis—may precipitate fatal dysrhythmias.[47]

When rescue is imminent, mental relaxation in conscious patients may be associated with decreased catecholamine release, causing decreased blood pressure with loss of consciousness and subsequent drowning.[47] Circumrescue collapse has also been described in terrestrial rescue situations.[23,48]

### *Handling of a hypothermic patient during rescue*

Keeping the patient in a horizontal position mitigates the effects of decreased hydrostatic pressure during rescue.[45] Avoiding physical effort protects against afterdrop.[46] Continued mental stimulus may help maintain catecholamine stimulus.

***Recommendation.*** Rescuers should keep a hypothermic patient horizontal, especially during rescue from water or a crevasse (**Evidence grade:** 1B) and should limit physical effort by the patient during rescue (**Evidence grade:** 1B). A conscious patient should be encouraged to be attentive and focus on survival (**Evidence grade:** 1C).

### *Gentle handling to prevent ventricular fibrillation*

Hypothermia lowers the threshold for VF, especially at core temperatures below 28°C.[1] Movement or significant warming of the extremities, as with warm water immersion, increases blood flow to colder tissues. Blood flows to the periphery, is cooled, and has the potential to cool the heart upon return to the core, increasing the risk of VF.[17,49,50] Additional blood return may also cause increased load on a heart that is already pumping ineffectively.

***Recommendation.*** Handle a hypothermic patient gently and continue to keep the patient horizontal (**Evidence grade:** 1B). Avoid any disturbance, especially movement of the extremities that might precipitate VF (**Evidence grade:** 1B). In an effort to minimize movement, clothes should be cut off of a patient once in a warm environment (**Evidence grade:** 1B).

### *Protection from further heat loss*

After rescue, the next priority for care of a hypothermic patient in the out-of-hospital setting is to maintain core temperature by preventing further heat loss.

Insulation protects from heat loss. Insulating materials include extra clothing, blankets, quilts, sleeping bags, insulated pads, and bubble wrap.[51,52] A sleeping bag should not be used like a blanket; rather the patient should be placed inside, and the enclosure should be completely zipped up. Multiple sleeping bags, if available, can be placed within each other to create a multilayered enclosure. Any available insulation (eg, spare parkas) should be incorporated within or outside the enclosure in such a way as to not compromise loft. Bubble wrap is an effective vapor barrier, but it provides less insulation than the other materials.[51,52] A large amount of heat can be lost to the ground by conduction.[53] Significant heat can also be lost from the head and neck due to necessary exposure of the face to allow breathing.[53,54]

Vapor barriers protect against convective and evaporative cooling (substantially reducing heat loss) and importantly also keep the insulation dry and more effective. Barriers can be made from bubble wrap, tarps, sheets of plastic, reflective blankets, or garbage bags with a hole cut out for the face. The vapor barrier(s) may be placed inside the insulation (to keep the insulation dry if the patient is packaged wet) and/or outside the insulation to protect the insulation from a wet environment.[52,55]

Extra insulation can compensate for the absence of a windproof layer or vapor barrier.[55] A combined method using 2 vapor barriers (1 against the patient and 1 outside the insulating layers) will protect the insulation from becoming wet from all sources.[52]

***Recommendations.*** Protect from further cooling by using insulation and vapor barriers until the patient has reached a warm environment, such as the warmed interior of an ambulance. Remove wet clothes, preferably by cutting them off, only when the patient has been protected from the cold (**Evidence grade:** 1C). Insulate the patient from the ground (eg, with sleeping pads) to protect from conductive heat loss. Minimize heat loss from the head and neck by covering these areas as effectively as possible (eg, toque, watch cap, hood, jacket) (**Evidence grade:** 1C).

*Protection from windy conditions*

In windy conditions, a windproof layer, ideally a vapor barrier, provides substantial protection from convective heat loss.[51]

***Recommendation.*** An outer windproof layer should be used to protect the patient from wind and especially from rotor wash when loading or unloading from a helicopter. If possible, add a second vapor barrier against the victim to protect the insulating layers (**Evidence grade:** 1C).

FIELD REWARMING

Once a hypothermic patient has been protected from further heat loss, the next priority is to rewarm the patient. The rewarming methods described in this section achieve the safe rewarming rate of 1 to 2°C·h$^{-1}$ and minimize the risk of afterdrop. Afterdrop can lead to hemodynamic instability and VF. The risk of afterdrop is reduced by limiting limb movement and by keeping the patient horizontal. Most patients with altered consciousness will require active rewarming.

It is important to recognize that the optimal rate of rewarming may not be the fastest rate. Even profound hypothermia may require slow, controlled rewarming. Only patients with hemodynamic instability should be considered for rapid rewarming via extracorporeal life support (ECLS).

*Shivering*

Vigorous shivering can increase heat production by 5 to 6 times the resting metabolic rate and up to 50% of maximal metabolic rate ($\dot{V}O_{2max}$).[5,56] Shivering can raise core temperature by 3 to 4°C·h$^{-1}$,[16,28,57] but it uses a large amount of energy, stresses the cardiovascular system, and causes patient discomfort.[17]

***Recommendation.*** Shivering is an effective method of rewarming in a patient who is cold-stressed or mildly hypothermic. The patient must be adequately insulated from the environment to retain the generated heat (**Evidence grade:** 1A). An alert patient who is shivering, and who is not at risk for aspiration, should receive high-carbohydrate liquids and/or food. Liquids and food may be warmed but should not be hot enough to burn the esophagus (**Evidence grade:** 1C).

*Delay exercise to protect against afterdrop*

Once a patient is protected from further heat loss and has adequate energy reserves, the most effective means of rescue may be for the patient to walk. Allowing the patient to shiver and rewarm, while insulated and before exercise, should help minimize afterdrop.[46] This time period should last 30 min but will depend upon the situation. Standing upright increases blood flow to and from the legs, worsening afterdrop and potentially decreasing blood pressure.[29] Walking or other exercise generates additional heat, but if initiated immediately after rescue, may cause a greater afterdrop in core temperature than if the patient remains at rest.[46] There may be situations when immediate movement is necessary to relocate a patient to a safer environment. When this is necessary, close monitoring is prudent.

***Recommendation.*** A shivering patient who may be hypothermic should be kept as warm as possible, given calorie replacement, and observed before exercising. After this period of observation, the alert patient may be allowed to stand. If the patient can stand without difficulty, exercise intensity should start low and increase gradually as tolerated. The patient should be closely monitored; if the condition worsens, the patient should stop exercising and be treated accordingly (**Evidence grade:** 1C).

*Active external rewarming*

Field methods of external rewarming are useful in both shivering and nonshivering patients. Active (exogenous) rewarming methods, such as large electric heat pads or blankets,[58] large chemical heat pads,[59,60] warm water bottles,[61] and the Norwegian charcoal-burning Heat Pac,[17,58,62] all provide significant external heat. In a shivering patient, the added heat attenuates shivering heat production. This results in a rate of core rewarming similar to that produced by shivering but has the advantages of increased comfort and decreased energy use with lower cardiac workload. In a nonshivering patient, added heat will warm the core, even if slowly, in a patient lacking capacity for endogenous heat production. The Heat Pac should be used with caution because it can generate potentially toxic levels of carbon monoxide (CO).[32]

To maximize total body net heat gain, active heating will be more effective in conjunction with insulation and vapor barrier(s) to create an effective hypothermia enclosure system. Five such systems were compared on normothermic subjects in −20°C conditions.[63] The systems (all including active heating and vapor barrier) included 3 commercial systems using heavy insulation enclosures, a user-assembled system using a 3-season sleeping bag, and the Hypothermia Prevention Management Kit (HPMK).[63] Initially evaluated for effectiveness between other rewarming systems,[64] the HPMK was commercially developed for the Department of Defense-Joint Trauma System (JTS) as a lightweight, compact kit designed for field use that combines an oxygen-activated self-heating liner with a vapor barrier. The HPMK was part of the JTS theater-wide strategy for battlefield casualties and has been used extensively

in military operations to decrease mortality from trauma-induced hypothermia.[65–67] System effectiveness (net body heat gain) generally depended on the mass of the insulation enclosure.[63] The 3 commercial systems were heavy and bulky and therefore only applicable at a point of care or if they could be delivered by sled or vehicle. The user-assembled and HPMK systems could both be transported by backpack; however, the HPMK was smaller and lighter and therefore more portable, but at the expense of providing less net body heat gain. Therefore, factors such as mass, volume, effectiveness, and cost will affect the type of system used in the field. Search and rescue teams, which usually consist of 2 to 4 persons, could realistically carry a more-effective user-assembled system because the items can be separated and dispersed to multiple backpacks (Figure 3). Alternatively, the HPMK should be complemented by incorporating a sleeping bag (or blankets) over the heated liner and inside the vapor barrier.

***Recommendations.*** Active sources of heat should be used (**Evidence grade:** 1B). Rewarming devices should be used in conjunction with vapor barriers and insulation (**Evidence grade:** 1B). The Heat Pac should only be used outdoors or with proper ventilation that is carefully monitored to prevent CO accumulation (**Evidence grade:** 1B). The single-package, small, and light HPMK is a practical system for transport in a single backpack and useful for military operations and should be used with an added layer of insulation if possible (**Evidence grade:** 1C).

*Body-to-body rewarming*

Body-to-body rewarming of a shivering patient with a warm person in a sleeping bag blunts the increase in shivering thermogenesis, resulting in rewarming rates no greater than shivering alone.[57,58] Body-to-body rewarming may make the cold patient more comfortable due to decreased shivering, but at the cost of delaying evacuation.

***Recommendation.*** Body-to-body rewarming can be used in mild hypothermia to increase patient thermal comfort if enough personnel are available and it does not delay evacuation to definitive care (**Evidence grade:** 1B).

*Applying heat to the axillae, chest, and back*

External heat is most effective if concentrated on the axillae, chest, and back (in that order), which are the areas with the highest potential for conductive heat transfer.[53] Upper torso rewarming is more effective than extremity rewarming.[68] Some scenarios may. however, preclude applying heat to the chest (eg, cardiopulmonary resuscitation [CPR] in progress or treatment of chest injury). Applying heat to the head, although requiring more technique to insulate and apply the heat, has been shown to be equally effective in shivering and nonshivering subjects, thus providing an alternative warming approach in extenuating circumstances.[69]

***Recommendations.*** Apply heat sources to the axillae, chest, and back. A large heat pad or blanket should be placed over the chest and, if large enough, extend into the axillae and under the back (**Evidence grade:** 1B). Additional heat can be applied to the neck if precautions are taken to prevent heat loss through any neck opening (**Evidence grade:** 1C). Avoid applying external heat to the extremities, although it is not necessary to insulate the arms from heat applied to the torso (**Evidence grade:** 1B). If application of heat to the chest is contraindicated (eg, CPR or some chest injuries), heat sources may be still be applied under the patient's upper back or to the head (**Evidence grade:** 1B). If applying heat sources to the back, rescuers must be able to observe for the development of burns on a regular basis (**Evidence grade:** 1C).

*Protection of cold skin*

Cold skin is very susceptible to injury from pressure or heat.[70] There have been reports of burns associated with use of a hot water bottle with lukewarm water applied directly to hypothermic skin,[71] the HPMK,[64] water-perfused warming blankets, a Heat Pac, and hot pads.[72] Burns have been reported both in controlled settings while researching rewarming methods and during rescue of hypothermic patients. It is important to visually inspect the heated skin at regular intervals (eg, 20 to 30 min) to observe for excess reddening or other signs of pending burns; in these cases, active heating should be stopped in the affected areas. This must be done segmentally and carefully to minimize heat loss. Heated pads should be applied with great caution to areas such as the back that are difficult to visualize or under constant pressure from body weight or immobilization systems.

***Recommendation.*** Avoid localized pressure to cold skin. Apply heat sources according to manufacturer instructions; this often precludes direct contact with the skin by placing some thin insulating material between the skin and heat source to prevent burning the skin (**Evidence grade:** 1C). Skin should be assessed every 20 to 30 min for excess reddening or other signs of impending thermal burns when active heat sources are being applied (**Evidence grade:** 1C).

*Do not use small chemical heat packs for rewarming*

Small chemical heat packs (eg, those used for hand and foot warming) do not provide sufficient heat to affect core

temperature. In addition, the high surface temperature of small chemical heat packs creates a risk of thermal burns.

***Recommendation.*** Do not use small chemical heat packs for core rewarming of a hypothermic patient (**Evidence grade:** 1B). However, these small chemical heat packs can be used to prevent local cold injury to the hands and feet during treatment and transport (**Evidence grade:** 1C).

*Heated humidified oxygen*

Although heated humidified oxygen prevents respiratory heat loss, the respiratory tract allows limited heat exchange. Heated humidified oxygen is not effective as a solitary rewarming method,[30–32] but it can be used as an adjunct to other methods.[26] Heated humidified oxygen has the potential to cause facial burns.[32]

***Recommendations.*** Heated humidified oxygen can be used in combination with other rewarming methods (**Evidence grade:** 2C), but it should not be relied on as the only rewarming method (**Evidence grade:** 1B).

*Do not use warm showers or baths for rewarming*

A warm shower or bath markedly increases peripheral blood flow, increasing afterdrop and potentially causing hypotension.[29,42] Using a warm shower or bath, even in a patient who is mildly hypothermic, may cause cardiovascular collapse. This method of warming may be considered for patients who are cold-stressed or after an initial period of rewarming for those with mild hypothermia.

***Recommendation.*** A warm shower or bath should not be used for initial rewarming, even if a patient appears to be only mildly hypothermic (**Evidence grade:** 1C).

*Distal limb warming*

Distal limb warming in 42 to 45°C water to the elbows and knees is effective for warming alert, mildly hypothermic patients.[9] This method works by opening arteriovenous anastomoses in the hands and feet, causing increased return flow of warmed blood directly from the arms and legs to the core. This is an exception to the general rule that peripheral rewarming is contraindicated in hypothermic patients. Because the warmed superficial venous blood bypasses the cold arteries in the extremities, there is little countercurrent heat exchange. In the 1 laboratory study that used this method, the afterdrop was less than the afterdrop for shivering.[9] Distal limb rewarming in water was designed for use on watercraft and is difficult to apply for other out-of-hospital transport.

***Recommendation.*** Distal limb warming to the elbows and knees in 42 to 45°C water can be used for rewarming a patient with mild hypothermia if the clinical setting is appropriate (**Evidence grade:** 1C).

*Rewarming during transport*

Continued rewarming is challenging during transport. A randomized, controlled study of care in helicopter and ground advanced life support units showed a small increase in core temperature with using large chemical heat pads but decreased core temperature with passive rewarming, reflective blankets, warm IV fluids, and warm IV fluids plus reflective blankets.[60]

Forced air warming, usually with an air-filled plastic baffled blanket with continuous heated airflow through perforations in the bottom of the blanket, is an effective way to rewarm a hypothermic patient.[30,73,74] In 1 study, afterdrop with forced air warming was less than with shivering.[75] Forced air warming is more effective and more practical than a liquid-filled heating blanket.

***Recommendations.*** Forced air warming should be used during air or ground transport, if available (**Evidence grade:** 1A). If forced air warming is not available, use of other heat sources can be continued. Care must be taken to prevent CO buildup with the charcoal Heat Pac in a ground ambulance; this can be done by igniting the device outside the vehicle, bringing it inside only after initial smoke production subsides, ventilating the vehicle compartment, and monitoring CO (**Evidence grade:** 1C). A charcoal Heat Pac should not be used in an aircraft (**Evidence grade:** 1C).

*Temperature in air or ground ambulances*

The temperature in patient compartments should ideally be 28°C, which is the temperature at which unclothed resting normothermic humans will neither gain nor lose heat.[1] Warming the patient compartment will protect patients from further heat loss when exposed for monitoring or other procedures. However, an air temperature of 28°C is usually uncomfortably hot for pilots, drivers, and medical providers. A slightly cooler temperature of 24°C will limit heat loss and is better tolerated by ambulance personnel.

***Recommendation.*** Patient compartments in ground and air ambulances should be heated to at least 24°C, if possible, to decrease further heat loss (**Evidence grade:** 1C).

*Treatment of cold stressed patients who are not hypothermic*

A cold patient who is alert and shivering but who has adequate energy reserves and is not hypothermic is at low risk for afterdrop or circumrescue collapse.

***Recommendation.*** It is the consensus of the panel that a cold-stressed patient who is not hypothermic need not be kept horizontal. The patient may be allowed to remove his or her own wet clothing and to put on dry clothing without shelter, if necessary. The patient may be allowed to rest in a sitting position, to eat and drink to maintain energy reserves and hydration, and to move or keep moving, if necessary. These patients will need close monitoring to ensure they do not become hypothermic.

## RESUSCITATION OF HYPOTHERMIC PATIENTS

### *Decision to resuscitate hypothermic patients without signs of life*

Hypothermic patients have survived with normal neurologic function even after cardiac arrest.[23,76–78] Many of the usual indicators of death, such as fixed, dilated pupils and apparent rigor mortis, are unreliable in hypothermic patients.[76,77] Dependent lividity is an unpredictable indicator of death in hypothermia.

***Recommendations.*** Fixed, dilated pupils, apparent rigor mortis, and dependent lividity are not considered contraindications to resuscitation of a severely hypothermic patient (**Evidence grade:** 1A for fixed, dilated pupils and apparent rigor mortis). Rescuers should attempt CPR and resuscitation unless contraindications exist (**Evidence grade:** 1A).

### *Contraindications to resuscitation of hypothermic patients*

The dictum that "no one is dead until they are warm and dead" is based on the difficulty of diagnosing death in a hypothermic patient in the field. However, some patients really are cold and dead. General contraindications to attempted resuscitation in the field include obvious fatal injuries, such as decapitation, open head injury with loss of brain matter, truncal transection, incineration, or a chest wall that is so stiff that compressions are not possible.[79]

***Recommendation.*** Do not attempt to resuscitate a patient with obvious fatal injuries or whose chest wall is too stiff for compressions (**Evidence grade:** 1A).

### *Indication for cardiopulmonary resuscitation*

CPR is only indicated in cardiac arrest and is contraindicated if there are signs of life. In a hypothermic patient in the out-of-hospital setting, signs of life may be very difficult to detect. The heart rate can be very slow and pulses difficult to palpate. The traditional method of checking a pulse by trying to feel the pulse with a finger placed over the presumed location of an artery is limited by cold. Cold fingers have decreased sensitivity to tactile stimuli. Breathing can be very slow and shallow but may be detectible in the absence of palpable pulses.[22] If cardiac monitoring is not available, the diagnosis of cardiac arrest can be difficult.

***Recommendation.*** Rescuers should make every effort to move the patient to a warm setting, such as a ground or air ambulance or a medical facility where cardiac monitoring is available to guide resuscitation and to start rewarming (**Evidence grade:** 1C). Prior to starting CPR, feel for a carotid pulse for 1 min. If a pulse is not palpated after 1 min, start CPR, including rescue breathing (**Evidence grade:** 1C).

### *No cut-off temperature for resuscitation*

The lowest known core temperature from which a patient with accidental hypothermia has been successfully resuscitated is 13.7°C.[80] The lowest core temperature ever induced therapeutically is 9°C.[81] Both patients survived neurologically intact. Induced hypothermia for cardiac or vascular surgery is usually to 18°C and—unlike accidental hypothermia—a very controlled situation. The lowest temperature from which humans with accidental hypothermia can be successfully resuscitated is not known, and reports of recovery from extremely low core temperatures make establishing a temperature cut-off for resuscitation challenging.

***Recommendation.*** Resuscitation attempts should be continued regardless of the measured core temperature (**Evidence grade:** 2C).

### *Electrocardiographic monitoring*

Electrocardiographic monitoring is the best way to diagnose cardiac arrest in the field. An organized rhythm without detectible pulses may be pulseless electrical activity or may be a perfusing rhythm with very weak pulses. In hypothermic patients, the amplitude of the QRS complexes may be decreased.[10]

Starting CPR in a hypothermic patient with an organized cardiac rhythm carries a risk of causing VF that would convert a perfusing rhythm to a nonperfusing rhythm. If end-tidal $CO_2$ ($ETCO_2$) monitoring is available, lack of waveform indicates lack of circulation or absence of metabolism.[13] If ultrasound is available, echocardiography can be used to determine if cardiac contractions correspond to electrical activity.[13]

***Recommendation.*** CPR should be started if a nonperfusing rhythm, including ventricular tachycardia, VF, or asystole, is detected. If there is a cardiac rhythm with organized QRS complexes, CPR should not be performed (**Evidence**

**grade:** 1C) unless $ETCO_2$ monitoring confirms lack of perfusion or echocardiography shows that there are no cardiac contractions corresponding to electrical activity (**Evidence grade:** 1B). Use maximal amplification on the monitor to search for QRS complexes (**Evidence grade:** 1C).

*Delaying CPR, intermittent CPR, and prolonged CPR*

Cooling reduces resting oxygen consumption of most human tissue by about 6% per 1°C decrease, with a greater decrease in brain tissue. Hypothermia preferentially protects the brain from hypoxia. At a core temperature of 28°C, whole body oxygen consumption is about 50% of normal,[1] while brain oxygen consumption may be reduced to about 35% of normal.[8] Surgical procedures employing deep hypothermic circulatory arrest (DHCA) have demonstrated a 7% decrease in cerebral oxygen consumption for every 1°C decrease in core temperature. Sixty percent of patients with a core temperature less than 18°C demonstrate an isoelectric electroencephalogram. DHCA is a controlled, rapid, decrease of core temperature from 18 to 20°C. Patients over the age of 60 y undergoing DHCA only tolerated an estimated 25 min of cardiac arrest, based upon incidence of postprocedural cognitive injury. Children tolerate longer periods of time, but there is a dearth of information for young and middle-aged adults.[82,83] There are many documented cases of full neurologic recovery, even after extended periods of cardiac arrest as long as 9 h[84,85] in persons who did not have asphyxia before they became hypothermic. Severely hypothermic patients have been resuscitated with good neurologic status after as long as 6 h 30 min of CPR.[23,86–88] Prolonged cardiac arrest in severely hypothermic patients does not necessarily cause brain injury as it does in normothermic patients.

In cardiac arrest, the classic teaching is that CPR must be started promptly and continued without interruption until return of spontaneous circulation (ROSC) can be established or death is confirmed. This CPR strategy may not be possible or warranted in patients with severe hypothermia. Multiple case reports describe survival with neurologic recovery when initiation of CPR was delayed and performed intermittently.[85,89] In 1 case report, a hypothermic avalanche victim was successfully resuscitated with complete neurologic recovery, although CPR was not started for 15 min after a monitored cardiac arrest.[23] In another case report, an avalanche victim was extricated apneic and pulseless after a 5 h burial in a crevasse. No attempt was made to resuscitate the patient, but the patient was flown to a nearby hospital where ECG showed asystole. CPR was started 70 min after rescue. The patient made a full neurologic recovery.[48] A third case report described successful resuscitation with good neurologic recovery of a hypothermic patient in cardiac arrest who was treated during evacuation with CPR in a stationary litter for 1-min periods alternating with 1-min periods of being carried without CPR.[86]

Continuous compressions are ideal, but intermittent compressions may be necessary to successfully and safely evacuate the patient. With properly performed compressions, it takes an estimated 5 min of cerebral oxygenation to overcome the ischemic threshold.[90]

***Recommendation.*** Immediate, high-quality CPR should be performed for a hypothermic patient in cardiac arrest. If it is impossible or unsafe to perform immediate and continuous CPR, rescuers should perform delayed or intermittent CPR. Ideally, compressions will not be delayed for longer than 10 min, a conservative interval based on the uncontrolled nature of out-of-hospital hypothermic cardiac arrest (**Evidence grade:** 1C). If CPR cannot be performed continuously, compressions should be performed for a minimum of 5 min, with interruptions between periods of compressions that should not exceed 5 min (**Evidence grade:** 1C).

*CPR technique in hypothermia*

A hypothermic patient will have a stiff chest wall that limits the effectiveness of chest compressions and bag-valve-mask ventilation. Myocardial and pulmonary compliance are also markedly reduced in severe hypothermia. During hypothermic cardiac arrest with CPR[91] in a swine model, cardiac output, cerebral blood flow, and myocardial blood flow averaged 50, 55, and 31%, respectively, of those achieved during normothermic closed-chest compressions. However, metabolic demands are also decreased. Although there are no data to support increased survival when a mechanical compression device is used,[92] mechanical devices reduce the incidence of rescuer fatigue and may permit longer periods of uninterrupted compressions, especially when bridging to ECLS.[86,93]

***Recommendation.*** Patients in cardiac arrest should have chest compressions delivered at the same rate as for normothermic patients (**Evidence grade:** 1C). Using a mechanical compression device may decrease interruptions and reduce rescuer fatigue (**Evidence grade:** 1C).

*Automated external defibrillator*

If an automated external defibrillator (AED) with a cardiac monitor is available, it can be used for cardiac monitoring. An AED without a cardiac monitor can also be used for diagnosis. The cardiac rhythms that may benefit from cardioversion or defibrillation (shockable rhythms) are VT and VF. VT is rare during moderate or severe hypothermia. The instruction “shock is advised” means that the rhythm is VT or VF. The instruction “no shock advised” on an

AED without monitoring capability can mean that the rhythm is asystole or an organized rhythm, which may be pulseless electrical activity. Current AHA guidelines recommend a single shock.[19]

***Recommendation.*** If shock is advised by the AED, rescuers should attempt defibrillation and start CPR. If no shock is advised on an AED, no carotid pulse is found after palpating for at least 1 min, normal breathing or other signs of life are not observed, and ultrasound is not available to verify cardiac activity or pulse, start CPR (**Evidence grade:** 1C).

*Initial defibrillation in hypothermia*

Defibrillation is only indicated for a shockable rhythm (pulseless VT or VF). An AED will only advise a shock if the rhythm is VT or VF. Current resuscitation guidelines recommend a single shock at maximum power for a patient whose core temperature is below 30°C.[13,17,94]

***Recommendation.*** If a monitor/defibrillator shows VT or VF in a patient whose core temperature is thought to be below 30°C, a single shock should be given at maximum power (**Evidence grade:** 1C).

*Repeat defibrillation attempts in hypothermia*

Patients have been successfully defibrillated at core temperatures below 26°C.[95–98] If defibrillation below 30°C is unsuccessful, delay further shocks until the temperature is greater than 30°C; below 30°C, defibrillation is less likely to be successful. Defibrillation in a patient whose core temperature has reached 30°C should follow guidelines for normothermic patients.[13]

***Recommendations.*** Wait until a patient has been rewarmed to 30°C before attempting further shocks (**Evidence grade:** 2C). Once the core temperature reaches 30°C, follow defibrillation guidelines for normothermic patients (**Evidence grade:** 1C).

*Airway management in hypothermia*

The principles of airway management are the same in a hypothermic patient as in a normothermic patient. In a patient who is not breathing spontaneously or who is breathing spontaneously but not protecting their airway owing to a decreased level of consciousness, advanced airway management with endotracheal intubation or a supraglottic airway device is indicated to provide adequate ventilation and to protect against aspiration.[13,99] Although there are case reports of VF occurring during endotracheal intubation of a hypothermic patient,[21,50,100,101] this is an uncommon complication. In a multicenter study, 117 hypothermic patients were intubated endotracheally after preoxygenation with 100% oxygen with no induced dysrhythmias.[102]

***Recommendations.*** The advantages of advanced airway management outweigh the risk of causing VF (**Evidence grade:** 1C). A nasogastric or orogastric tube should be placed after the airway is secured to decompress the stomach (**Evidence grade:** 1C).

***Practical considerations.*** Rapid-sequence intubation with paralysis may not be effective if the paralytic agent is unable to overcome the trismus produced by profound hypothermia. Fiber optic intubation or cricothyroidotomy may be required to place an endotracheal tube if cold-induced trismus prevents laryngoscopy. A supraglottic device may be preferable to endotracheal intubation in these conditions. Overinflation of an endotracheal tube or supraglottic device cuff with cold air should be avoided because the air inside the cuff will expand as the victim rewarms, potentially kinking the tube or rupturing the cuff.

*Ventilation in hypothermia without an advanced airway*

Hyperventilation has many potentially adverse effects in hypothermia, including decreased cerebral blood flow. As shown in the swine model, ventilation without an advanced airway is limited by decreased thoracic compliance.[91,103] If available, $ETCO_2$ monitoring can be used to prevent hyperventilation.

***Recommendation.*** In the absence of $ETCO_2$ monitoring, ventilation should be delivered at the same rate recommended for a normothermic patient,[13,19] unless an advanced airway is in place (see below) (**Evidence grade:** 2C).

*Ventilation in hypothermia with advanced airway*

If the patient is intubated or has a supraglottic device, ventilation is more effective than in a patient without advanced airway management.

***Recommendation.*** In a patient with an advanced airway, if $ETCO_2$ monitoring is not available, ventilation should be delivered at half the rate recommended for a normothermic patient to avoid hyperventilation (**Evidence grade:** 1C).

*Management of $ETCO_2$*

$ETCO_2$ monitoring can be used to keep $ETCO_2$ in the normal range. This range depends on altitude.

***Recommendation.*** If $ETCO_2$ monitoring is available, $ETCO_2$ should be kept within the normal range. In rescues at altitudes above 1200 m, advanced life support personnel should be aware of the normal range of $ETCO_2$ at a given altitude (**Evidence grade:** 1C).

*Anesthetic and neuromuscular blocking agents in hypothermia*

At low core temperatures, drug metabolism is decreased; anesthesia and neuromuscular blockade are prolonged.[104–106]

***Recommendation.*** In patients with core temperatures lower than 30°C, dosages of anesthetic and neuromuscular blocking agents should be decreased, and intervals should be extended according to the degree of hypothermia. Current data are insufficient to recommend specific protocols (**Evidence grade:** 1C).

*Supplemental oxygen*

Oxygen extraction is not a limiting factor in survival in hypothermia at sea level.[107]

***Recommendation.*** A hypothermic patient should receive supplemental oxygen, especially at altitudes over 2500 m, because of potential benefits and no known harm (**Evidence grade:** 1C).

*Circulatory access in hypothermia*

Obtaining intravenous (IV) access is often difficult in hypothermic patients. Intraosseous (IO) access is fast and reliable. Because the myocardium is irritable in hypothermia, catheters that contact the heart may cause dysrhythmias. Internal jugular or subclavian central lines that extend into the right atrium are contraindicated unless a short catheter is inserted. There is a risk of causing VF if the wire used during placement of a central venous catheter using the Seldinger technique is advanced into the heart. The femoral vein approach allows central venous access without the danger of inducing dysrhythmias, but it may be difficult in the field. Unsuccessful attempts often cause hematomas.

***Recommendations.*** If circulatory access cannot immediately be obtained with a peripheral IV catheter, access should be obtained by the IO method (**Evidence grade:** 1C). Central venous access can be obtained using a femoral line if no other option is available (**Evidence grade:** 1C).

*Volume replacement in hypothermia*

Circulating blood volume in moderate and severe hypothermia is reduced.[9,107] During rewarming, vasoconstriction that previously limited the vascular space is abolished. Volume should be replaced to avoid severe volume depletion with resultant shock, while avoiding administration of fluid sufficient to cause volume overload. To prevent further core temperature cooling, IV/IO fluid should be warmed to at least 40°C and preferably to 42°C. In the field, IV/IO bags and tubing should be insulated. Fluid warmers, preferably commercial products that have been proven effective, should be used. Because the effective perfused mass (thermal core) is decreased in hypothermia as a result of intense peripheral vasoconstriction,[9] administration of fluid warmed to 40 to 42°C may help increase core temperature. Because metabolism is depressed, glucose-containing fluid is not essential. The fluid of choice for volume replacement is normal saline. Lactated Ringer's solution should not be used in a hypothermic patient because the cold liver cannot metabolize lactate.[1] Some clinicians use a mixture of crystalloid and colloid.[1]

***Recommendation.*** Resuscitate a hypothermic patient with normal saline warmed to 40 to 42°C given IV or IO. Use caution to prevent volume overload (**Evidence grade:** 1B).

*Fluid management in hypothermia*

Giving fluids in boluses, as rapidly as possible, rather than by continuous infusion will alleviate problems with cooling of fluid or freezing of lines, which can occur even if lines are insulated. The ideal method is to saline lock the line when there will be a long pause after a bolus. Boluses of 500 mL can be titrated to maintain adequate systolic blood pressure, depending on the degree of hypothermia. There is no available evidence to quantify a target systolic blood pressure.

***Recommendations.*** When practical, fluids should be given as boluses rather than by continuous infusion (**Evidence grade:** 1C). The goal of fluid administration should be to maintain systolic blood pressure at a level that provides adequate perfusion, depending on the degree of hypothermia (**Evidence grade:** 1C).

*Use of exogenous glucose and insulin in hypothermia*

Hypo- and hyperglycemia have been reported in hypothermia.[96,108] Point-of-care glucose testing is routine in patients with an altered level of consciousness but may not be available in an out-of-hospital setting. Hyperglycemia has not been shown to be deleterious in hypothermic patients.[96]

***Recommendation.*** Glucose should be administered to the hypothermic patient who is hypoglycemic (**Evidence grade:** 1A). Insulin is not initially indicated for hyperglycemia (**Evidence grade:** 1B). If glucose testing is not available, IV glucose can be administered empirically to the hypothermic patient with altered mental status (**Evidence grade:** 1C).

*Effects of vasoactive and antidysrhythmic drugs in hypothermia*

There is limited evidence regarding drug effects in hypothermic cardiac arrest in humans. Most of the evidence comes from animal studies.[109] The cold heart has long been considered to be unresponsive to vasopressor or antiarrhythmic medications, although some animal studies have suggested otherwise. In a study of hypothermic dogs, epinephrine increased coronary perfusion pressure and ROSC after defibrillation.[110] In a hypothermic pig study, vasopressin increased coronary perfusion pressure with active compression-decompression CPR using an impedance threshold valve, but not with standard CPR.[111] Vasopressin improved ROSC and 1-h survival after defibrillation in a study of hypothermic pigs.[112] There is a case report of ROSC with vasopressin following unsuccessful use of epinephrine (2 mg) in a hypothermic patient, but the patient subsequently died OF multisystem failure.[113]

The ideal pharmacologic approach to ventricular dysrhythmias remains unresolved. Class III agents, such as bretylium and amiodarone, are theoretically ideal because they act directly against fibrillation. Amiodarone is less effective in hypothermia than in normothermia and carries a risk of inducing torsades des pointes.[114] The safety of amiodarone in hypothermia is not known. In a study of hypothermic dogs, the combination of epinephrine and amiodarone increased ROSC after defibrillation following administration of epinephrine alone.[110] Bretylium failed to increase the incidence of ROSC in a study of hypothermic dogs.[115] In another dog study, neither amiodarone nor bretylium improved ROSC.[116] There are 2 clinical reports of resolution of VF following infusion of bretylium.[117,118]

***Recommendation.*** The panel concurs that no recommendation can be made at this time owing to the limited evidence available.

*Dosing of drugs in hypothermia*

In hypothermia, drug metabolism is decreased and protein binding is increased.[11] Drugs given have little activity while the patient is hypothermic but may reach toxic levels with rewarming.

***Recommendations.*** Do not administer vasoactive drugs until the patient has been rewarmed to 30°C (**Evidence grade:** 1C). To minimize the potential for toxic accumulation of medications, the usual dose can be given, but dosing intervals should be twice as long as usual when the core temperature is 30 to 35°C (**Evidence grade:** 2C).

*Transcutaneous cardiac pacing in hypothermia*

Two case reports suggest that transcutaneous pacing may be beneficial in the hypothermic patient.[119] In both cases, transcutaneous pacing was instituted to increase blood pressure to facilitate arteriovenous rewarming rather than to control heart rate.

***Recommendation.*** It is the consensus of the panel that transcutaneous pacing may be beneficial in hypothermia in the setting of bradycardia with hypotension disproportionate to the core temperature (**Evidence grade:** 2C).

*Management of atrial dysrhythmias during rewarming of a hypothermic patient*

Atrial dysrhythmias in hypothermic patients during rewarming are common and resolve spontaneously once the patient has been sufficiently rewarmed.[120]

***Recommendation.*** No treatment is indicated for atrial dysrhythmias in a hemodynamically stable patient during rewarming (**Evidence grade:** IB).

TRANSPORT/TRIAGE

*Severe trauma*

Core temperatures <35°C are associated with decreased survival in patients with severe trauma.[121,122] Severe trauma can cause acidosis and coagulopathy. In trauma patients with hemorrhagic shock, the "lethal triad" of acidosis, coagulopathy, and hypothermia is associated with multiorgan system dysfunction[123] and extremely high mortality.[124]

***Recommendation.*** To prevent hypothermia, the severely injured patient should be treated early and aggressively with active rewarming during all phases of out-of-hospital care (**Evidence grade:** 1B).

*Stabilizing injuries for transport*

Stabilization of injuries for transport is the same in a hypothermic patient as in a normothermic patient.

***Recommendations.*** When preparing a patient for transport, potential spinal injuries should be stabilized[125] (**Evidence grade:** 1C). Fractures and dislocations should be reduced as much as possible to normal anatomic configuration (**Evidence grade:** 1C). Open wounds should be covered (**Evidence grade:** 1C).

*Patients with mild hypothermia who are alert*

Alert patients with mild hypothermia can be treated in the field.

***Recommendation.*** An uninjured patient who is completely alert and shivering may be treated without being transported to a hospital (**Evidence grade:** 1B).

*Choice of destination hospital for hypothermic patients*

Profoundly hypothermic patients (<28°C) and those with hemodynamic instability and witnessed out-of-hospital cardiac arrest may benefit from transport to centers capable of ECLS. ECLS includes the techniques of extracorporeal circulation, extracorporeal membrane oxygenation (ECMO), and coronary bypass. ECLS provides both oxygenation and hemodynamic support for unstable patients while allowing for controlled rewarming.

Patients who are not profoundly hypothermic or hemodynamically unstable should be transported to the nearest facility.[87,126–131]

*Hypothermic patients with hemodynamic instability*

Hemodynamically unstable patients require critical care and may benefit from ECLS with ECMO or CPB. ECMO is preferred overCPB,[127] but both have been used successfully to rewarm severely hypothermic patients. Profoundly hypothermic patients with witnessed cardiac arrest, regardless of return to spontaneous circulation in the field, have a greater chance of survival if transferred to a center where ECLS can be initiated.[87,126–131]

Many geographic areas do not have a hospital capable of ECLS. Bad weather or other factors may prevent transfer of a patient to a hospital with ECLS. Hemodynamically unstable hypothermic patients, including hypothermic patients in cardiac arrest, have been successfully resuscitated with complete neurologic recovery without using ECLS.[88,132–134]

***Recommendations.*** A patient with moderate to severe hypothermia who is hemodynamically stable can be transferred to the closest hospital or other appropriate medical facility, such as a rural clinic (**Evidence grade:** 1C). A patient who is hemodynamically unstable or with a core temperature <28°C should be transferred to a hospital capable of providing critical care and ECLS. If this will require significant additional time—generally more than an additional hour—of noncritical care transport, the patient should first be stabilized at a closer facility (**Evidence grade:** 1C). A patient in cardiac arrest should be transferred to a hospital capable of providing ECLS if possible. If all other factors are equal, ECMO is preferable over CPB (**Evidence grade:** 1B).

In geographic regions where there is no hospital capable of providing ECLS or when a hospital capable of providing ECLS is not accessible, transport a patient in cardiac arrest to the closest hospital where serum potassium can be measured and resuscitation methods not involving ECLS can be attempted for a patient whose serum potassium is <12 mmol·L$^{-1}$ (**Evidence grade:** 1C). (Please see section for use of biochemical markers.)

*Hypothermic patients who are alert but have comorbidities, including trauma or asphyxia*

Hypothermic patients with injuries or other medical comorbidities should be transferred to a facility able to appropriately manage the patient. Comorbidities can alter the clinical presentation of hypothermia and could potentially delay recognition of severe hypothermia.[135] Asphyxiated patients (from avalanche or drowning) may appear stable but are at risk for delayed complications and are likely to require a higher level of care.[127]

***Recommendations.*** A patient with injuries meeting trauma criteria should be transported to a trauma center (**Evidence grade:** 1B). The asphyxiated patient should be transported to a hospital for observation (**Evidence grade:** 1B).

***Use of biochemical markers to determine if resuscitation should be continued in a hypothermic patient without vital signs.*** Increased serum potassium in a hypothermic patient usually indicates that hypothermia was preceded by hypoxia. As such, it is a marker of cell lysis and death. The highest potassium in a patient resuscitated from hypothermia was 11.8 mmol·L$^{-1}$ in a 31-mo-old child. This level is questionable because the repeat potassium 25 min later was 4.8 mmol·L$^{-1}$ without mention of therapeutic intervention.[136] The highest levels recorded in patients who were resuscitated were 9.5 mmol·L$^{-1}$ in a 13-y-old[137] and 7.9 mmol·L$^{-1}$ in a 34-y-old.[138]

***Recommendation.*** If an adult hypothermic patient has a potassium >12 mmol·L$^{-1}$, CPR should be terminated (**Evidence grade:** 1B).

## Conclusions

To assist medical providers caring for patients with accidental hypothermia in the out-of-hospital setting, we have provided evidence-based recommendations for evaluation and treatment. There are several important areas of uncertainty that warrant future research. These areas include optimal methods for evaluating patients with accidental hypothermia, best treatments for patients with mild to moderate hypothermia, and optimal methods of resuscitating hypothermic patients in cardiac arrest.

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## Supplementary materials

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## References

1. Danzl DF. Accidental hypothermia. In: Auerbach PS, Cushing TA, Harris NS, eds. *Auerbach's Wilderness Medicine*. 7th ed. Philadelphia, PA: Elsevier; 2017:135−62.
2. Zafren K, Giesbrecht GG, Danzl DF, Brugger H, Sagalyn EB, Walpoth B, et al. Wilderness Medical Society practice guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia: 2014 update. *Wilderness Environ Med*. 2014;25(4 Suppl):S66−85.
3. Guyatt G, Gutterman D, Baumann MH, Addrizzo-Harris D, Hylek EM, Phillips B, et al. Grading strength of recommendations and quality of evidence in clinical guidelines: report from an american college of chest physicians task force. *Chest*. 2006;129(1):174−81.
4. Giesbrecht GG. Cold stress, near drowning and accidental hypothermia: a review. *Aviat Space Environ Med*. 2000;71(7):733−52.
5. Bristow GK, Giesbrecht GG. Contribution of exercise and shivering to recovery from induced hypothermia (31.2 degrees C) in one subject. *Aviat Space Environ Med*. 1988;59(6):549−52.
6. FitzGibbon T, Hayward JS, Walker D. EEG and visual evoked potentials of conscious man during moderate hypothermia. *Electroencephalogr Clin Neurophysiol*. 1984;58(1):48−54.
7. Giesbrecht GG, Arnett JL, Vela E, Bristow GK. Effect of task complexity on mental performance during immersion hypothermia. *Aviat Space Environ Med*. 1993;64(3 Pt 1):206−11.
8. Michenfelder JD, Milde JH. The relationship among canine brain temperature, metabolism, and function during hypothermia. *Anesthesiology*. 1991;75(1):130−6.
9. Vanggaard L, Eyolfson D, Xu X, Weseen G, Giesbrecht GG. Immersion of distal arms and legs in warm water (AVA rewarming) effectively rewarms mildly hypothermic humans. *Aviat Space Environ Med*. 1999;70(11):1081−8.
10. Duguid H, Simpson RG, Stowers JM. Accidental hypothermia. *Lancet*. 1961;2(7214):1213−9.
11. Giesbrecht GG. The respiratory system in a cold environment. *Aviat Space Environ Med*. 1995;66(9):890−902.
12. Durrer B, Brugger H, Syme D, International Commission for Mountain Emergency Medicine. The medical on-site treatment of hypothermia: ICAR-MEDCOM recommendation. *High Alt Med Biol*. 2003;4(1):99−103.
13. Soar J, Perkins GD, Abbas G, Alfonzo A, Barelli A, Bierens JJ, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 8. Cardiac arrest in special circumstances: Electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. *Resuscitation*. 2010;81(10):1400−33.
14. Zafren K, Giesbrecht GG. *State of Alaska Cold Injury Guidelines*. Juneau: State of Alaska; 2014.
15. Strapazzon G, Procter E, Paal P, Brugger H. Pre-hospital core temperature measurement in accidental and therapeutic hypothermia. *High Alt Med Biol*. 2014;15(2):104−11.
16. Tikuisis P, Giesbrecht GG. Prediction of shivering heat production from core and mean skin temperatures. *Eur J Appl Physiol Occup Physiol*. 1999;79(3):221−9.
17. Giesbrecht GG. Emergency treatment of hypothermia. *Emerg Med (Fremantle)*. 2001;13(1):9−16.
18. Giesbrecht GG. "Cold Card" to guide responders in the assessment and care of cold-exposed patients. *Wilderness Environ Med*. 2018;29(4):499−503.
19. Vanden Hoek TL, Morrison LJ, Shuster M, Donnino M, Sinz E, Lavonas EJ, et al. Part 12: cardiac arrest in special situations: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(18 Suppl 3):S829−61.
20. Deslarzes T, Rousson V, Yersin B, Durrer B, Pasquier M. An evaluation of the Swiss staging model for hypothermia using case reports from the literature. *Scand J Trauma Resusc Emerg Med*. 2016;24:16.
21. Baumgartner FJ, Janusz MT, Jamieson WR, Winkler T, Burr LH, Vestrup JA. Cardiopulmonary bypass for resuscitation of patients with accidental hypothermia and cardiac arrest. *Can J Surg*. 1992;35(2):184−7.
22. Feiss P, Mora C, Devalois B, Gobeaux R, Christides C. [Accidental deep hypothermia and circulatory arrest. Treatment with extracorporeal circulation]. *Ann Fr Anesth Reanim*. 1987;6(3):217−8.
23. Oberhammer R, Beikircher W, Hormann C, Lorenz I, Pycha R, Adler-Kastner L, et al. Full recovery of an avalanche victim with profound hypothermia and prolonged cardiac arrest treated by extracorporeal re-warming. *Resuscitation*. 2008;76(3):474−80.
24. Papenhausen M, Burke L, Antony A, Phillips JD. Severe hypothermia with cardiac arrest: complete neurologic recovery in a 4-year-old child. *J Pediatr Surg*. 2001;36(10):1590−2.
25. Pasquier M, Zurron N, Weith B, Turini P, Dami F, Carron PN, et al. Deep accidental hypothermia with core temperature below 24°C presenting with vital signs. *High Alt Med Biol*. 2014;15(1):58−63.
26. Stoner HB. Thermoregulation after injury. *Adv Exp Med Biol*. 1972;33(0):495−9.
27. Jain A, Gray M, Slisz S, Haymore J, Badjatia N, Kulstad E. Shivering treatments for targeted temperature management: a review. *J Neurosci Nurs*. 2018;50(2):63−7.
28. Giesbrecht GG, Goheen MS, Johnston CE, Kenny GP, Bristow GK, Hayward JS. Inhibition of shivering increases

core temperature afterdrop and attenuates rewarming in hypothermic humans. *J Appl Physiol (1985)*. 1997;83(5):1630–4.
29. Hayward JS, Eckerson JD, Kemna D. Thermal and cardiovascular changes during three methods of resuscitation from mild hypothermia. *Resuscitation*. 1984;11(1–2):21–33.
30. Goheen MS, Ducharme MB, Kenny GP, Johnston CE, Frim J, Bristow GK, et al. Efficacy of forced-air and inhalation rewarming by using a human model for severe hypothermia. *J Appl Physiol (1985)*. 1997;83(5):1635–40.
31. Mekjavic IB, Eiken O. Inhalation rewarming from hypothermia: an evaluation in -20 degrees C simulated field conditions. *Aviat Space Environ Med*. 1995;66(5):424–9.
32. Sterba JA. Efficacy and safety of prehospital rewarming techniques to treat accidental hypothermia. *Ann Emerg Med*. 1991;20(8):896–901.
33. Walpoth BH, Galdikas J, Leupi F, Muehlemann W, Schlaepfer P, Althaus U. Assessment of hypothermia with a new "tympanic" thermometer. *J Clin Monit*. 1994;10(2):91–6.
34. Skaiaa SC, Brattebø G, Aßmus J, Thomassen Ø. The impact of environmental factors in pre-hospital thermistor-based tympanic temperature measurement: a pilot field study. *Scand J Trauma Resusc Emerg Med*. 2015;23:72.
35. Grissom CK, Harmston CH, McAlpine JC, Radwin MI, Ellington B, Hirshberg EL, et al. Spontaneous endogenous core temperature rewarming after cooling due to snow burial. *Wilderness Environ Med*. 2010;21(3):229–35.
36. Kimberger O, Cohen D, Illievich U, Lenhardt R. Temporal artery versus bladder thermometry during perioperative and intensive care unit monitoring. *Anesth Analg*. 2007;105(4):1042–7.
37. Gunga HC, Werner A, Stahn A, Steinach M, Schlabs T, Koralewski E, et al. The double sensor-a non-invasive device to continuously monitor core temperature in humans on earth and in space. *Respir Physiol Neurobiol*. 2009;169(Suppl 1):S63–8.
38. Kimberger O, Thell R, Schuh M, Koch J, Sessler DI, Kurz A. Accuracy and precision of a novel non-invasive core thermometer. *Br J Anaesth*. 2009;103(2):226–31.
39. Dahyot-Fizelier C, Lamarche S, Kerforne T, Benard T, Giraud B, Bellier R, et al. Accuracy of zero-heat-flux cutaneous temperature in intensive care adults. *Crit Care Med*. 2017;45(7):e715–7.
40. Giesbrecht GG, Bristow GK. A second postcooling afterdrop: more evidence for a convective mechanism. *J Appl Physiol (1985)*. 1992;73(4):1253–8.
41. Golden FS, Hervey GR. The mechanism of the after-drop following immersion hypothermia in pigs [proceedings]. *J Physiol*. 1977;272(1):26P–7P.
42. Romet TT. Mechanism of afterdrop after cold water immersion. *J Appl Physiol (1985)*. 1988;65(4):1535–8.
43. Fox JB, Thomas F, Clemmer TP, Grossman M. A retrospective analysis of air-evacuated hypothermia patients. *Aviat Space Environ Med*. 1988;59(11 Pt 1):1070–5.
44. Stoneham MD, Squires SJ. Prolonged resuscitation in acute deep hypothermia. *Anaesthesia*. 1992;47(9):784–8.
45. Golden FS, Hervey GR, Tipton MJ. Circum-rescue collapse: collapse, sometimes fatal, associated with rescue of immersion victims. *J R Nav Med Serv*. 1991;77(3):139–49.
46. Giesbrecht GG, Bristow GK. The convective afterdrop component during hypothermic exercise decreases with delayed exercise onset. *Aviat Space Environ Med*. 1998;69(1):17–22.
47. Giesbrecht GG, Hayward JS. Problems and complications with cold-water rescue. *Wilderness Environ Med*. 2006;17(1):26–30.
48. Althaus U, Aeberhard P, Schupbach P, Nachbur BH, Muhlemann W. Management of profound accidental hypothermia with cardiorespiratory arrest. *Ann Surg*. 1982;195(4):492–5.
49. Lee CH, Van Gelder C, Burns K, Cone DC. Advanced cardiac life support and defibrillation in severe hypothermic cardiac arrest. *Prehosp Emerg Care*. 2009;13(1):85–9.
50. Osborne L, Kamal El-Din AS, Smith JE. Survival after prolonged cardiac arrest and accidental hypothermia. *Br Med J (Clin Res Ed)*. 1984;289(6449):881–2.
51. Henriksson O, Lundgren JP, Kuklane K, Holmer I, Bjornstig U. Protection against cold in prehospital care-thermal insulation properties of blankets and rescue bags in different wind conditions. *Prehosp Disaster Med*. 2009;24(5):408–15.
52. Thomassen Ø, Faerevik H, Osteras Ø, Sunde GA, Zakariassen E, Sandsund M, et al. Comparison of three different prehospital wrapping methods for preventing hypothermia–a crossover study in humans. *Scand J Trauma Resusc Emerg Med*. 2011;19:41.
53. Hayward JS, Collis M, Eckerson JD. Thermographic evaluation of relative heat loss areas of man during cold water immersion. *Aerosp Med*. 1973;44(7):708–11.
54. Pretorius T, Bristow GK, Steinman AM, Giesbrecht GG. Thermal effects of whole head submersion in cold water on nonshivering humans. *J Appl Physiol (1985)*. 2006;101(2):669–75.
55. Henriksson O, Lundgren P, Kuklane K, Holmer I, Naredi P, Bjornstig U. Protection against cold in prehospital care: evaporative heat loss reduction by wet clothing removal or the addition of a vapor barrier–a thermal manikin study. *Prehosp Disaster Med*. 2012;27(1):53–8.
56. Iampietro PF, Vaughan JA, Goldman RF, Kreider MB, Masucci F, Bass DE. Heat production from shivering. *J Appl Physiol*. 1960;15:632–4.
57. Giesbrecht GG, Sessler DI, Mekjavic IB, Schroeder M, Bristow GK. Treatment of mild immersion hypothermia by direct body-to-body contact. *J Appl Physiol (1985)*. 1994;76(6):2373–9.
58. Hultzer MV, Xu X, Marrao C, Bristow G, Chochinov A, Giesbrecht GG. Pre-hospital torso-warming modalities for severe hypothermia: a comparative study using a human model. *CJEM*. 2005;7(6):378–86.

59. Watts DD, Roche M, Tricarico R, Poole F, Brown JJ Jr, Colson GB, et al. The utility of traditional prehospital interventions in maintaining thermostasis. *Prehosp Emerg Care*. 1999;3(2):115−22.
60. Lundgren P, Henriksson O, Naredi P, Bjornstig U. The effect of active warming in prehospital trauma care during road and air ambulance transportation - a clinical randomized trial. *Scand J Trauma Resusc Emerg Med*. 2011;19:59.
61. Lundgren JP, Henriksson O, Pretorius T, Cahill F, Bristow G, Chochinov A, et al. Field torso-warming modalities: a comparative study using a human model. *Prehosp Emerg Care*. 2009;13(3):371−8.
62. Giesbrecht GG, Bristow GK, Uin A, Ready AE, Jones RA. Effectiveness of three field treatments for induced mild (33.0 degrees C) hypothermia. *J Appl Physiol (1985)*. 1987;63(6):2375−9.
63. Dutta R, Kulkarni K, Gardiner P, Steinman A, Giesbrecht G. PW 2321 Human responses to five heated hypothermia enclosure systems in a cold environment. *Injury Prevention*. 2018;24:A216.1−A.
64. Allen PB, Salyer SW, Dubick MA, Holcomb JB, Blackbourne LH. Preventing hypothermia: comparison of current devices used by the US Army in an in vitro warmed fluid model. *J Trauma*. 2010;69(Suppl 1):S154−61.
65. Arthurs Z, Cuadrado D, Beekley A, Grathwohl K, Perkins J, Rush R, et al. The impact of hypothermia on trauma care at the 31st combat support hospital. *Am J Surg*. 2006;191(5):610−4.
66. Palm K, Apodaca A, Spencer D, Costanzo G, Bailey J, Blackbourne LH, et al. Evaluation of military trauma system practices related to damage-control resuscitation. *J Trauma Acute Care Surg*. 2012;73(6 Suppl 5):S459−64.
67. Bennett BL, Holcomb JB. Battlefield trauma-induced hypothermia: transitioning the preferred method of casualty rewarming. *Wilderness Environ Med*. 2017;28(2S):S82−9.
68. Ducharme MB, Tikuisis P. Role of blood as heat source or sink in human limbs during local cooling and heating. *J Appl Physiol (1985)*. 1994;76(5):2084−94.
69. Kulkarni K, Hildahl E, Dutta R, Webber SC, Passmore S, McDonald GK, et al. Efficacy of head and torso rewarming using a human model for severe hypothermia. *Wilderness Environ Med*. 2019;30(1):35−43.
70. Steinman AM. Cardiopulmonary resuscitation and hypothermia. *Circulation*. 1986;74(6 Pt 2):IV29−32.
71. Giesbrecht GG. Immersion into cold water. In: Auerbach PS, Cushing TA, Harris NS, eds. *Auerbach's Wilderness Medicine*. 7th ed. Vol 1. Philadelphia, PA: Elsevier; 2017:162.
72. Giesbrecht GG, Walpoth B. Risk of burns during active external rewarming for accidental hypothermia. *Wilderness Environ Med*. 2019 [Epub ahead of print].
73. Ducharme MB, Giesbrecht GG, Frim J, Kenny GP, Johnston CE, Goheen MS, et al. Forced-air rewarming in -20 degrees C simulated field conditions. *Ann N Y Acad Sci*. 1997;813:676−81.
74. Steele MT, Nelson MJ, Sessler DI, Fraker L, Bunney B, Watson WA, et al. Forced air speeds rewarming in accidental hypothermia. *Ann Emerg Med*. 1996;27(4):479−84.
75. Giesbrecht GG, Schroeder M, Bristow GK. Treatment of mild immersion hypothermia by forced-air warming. *Aviat Space Environ Med*. 1994;65(9):803−8.
76. Ko CS, Alex J, Jeffries S, Parmar JM. Dead? Or just cold: profoundly hypothermic patient with no signs of life. *Emerg Med J*. 2002;19(5):478−9.
77. Leitz KH, Tsilimingas N, Guse HG, Meier P, Bachmann HJ. [Accidental drowning with extreme hypothermia–rewarming with extracorporeal circulation]. *Chirurg*. 1989;60(5):352−5.
78. Walpoth BH, Walpoth-Aslan BN, Mattle HP, Radanov BP, Schroth G, Schaeffler L, et al. Outcome of survivors of accidental deep hypothermia and circulatory arrest treated with extracorporeal blood warming. *N Engl J Med*. 1997;337(21):1500−5.
79. Paal P, Milani M, Brown D, Boyd J, Ellerton J. Termination of cardiopulmonary resuscitation in mountain rescue. *High Alt Med Biol*. 2012;13(3):200−8.
80. Gilbert M, Busund R, Skagseth A, Nilsen PA, Solbo JP. Resuscitation from accidental hypothermia of 13.7 degrees C with circulatory arrest. *Lancet*. 2000;355(9201):375−6.
81. Niazi SA, Lewis FJ. Profound hypothermia in man; report of a case. *Ann Surg*. 1958;147(2):264−6.
82. Englum BR, Andersen ND, Husain AM, Mathew JP, Hughes GC. Degree of hypothermia in aortic arch surgery - optimal temperature for cerebral and spinal protection: deep hypothermia remains the gold standard in the absence of randomized data. *Ann Cardiothorac Surg*. 2013;2(2):184−93.
83. Svensson LG, Crawford ES, Hess KR, Coselli JS, Raskin S, Shenaq SA, et al. Deep hypothermia with circulatory arrest. Determinants of stroke and early mortality in 656 patients. *J Thorac Cardiovasc Surg*. 1993;106(1):19−28.
84. Meyer M, Pelurson N, Khabiri E, Siegenthaler N, Walpoth BH. Sequela-free long-term survival of a 65-year-old woman after 8 hours and 40 minutes of cardiac arrest from deep accidental hypothermia. *J Thorac Cardiovasc Surg*. 2014;147(1):e1−2.
85. Forti A, Brugnaro P, Rauch S, Crucitti M, Brugger H, Cipollotti G, et al. Hypothermic cardiac arrest with full neurologic recovery after approximately nine hours of cardiopulmonary resuscitation: management and possible complications. *Ann Emerg Med*. 2019;73(1):52−7.
86. Boue Y, Lavolaine J, Bouzat P, Matraxia S, Chavanon O, Payen JF. Neurologic recovery from profound accidental hypothermia after 5 hours of cardiopulmonary resuscitation. *Crit Care Med*. 2014;42(2):e167−70.
87. Hilmo J, Naesheim T, Gilbert M. "Nobody is dead until warm and dead": prolonged resuscitation is warranted in arrested hypothermic victims also in remote areas–a retrospective study from northern Norway. *Resuscitation*. 2014;85(9):1204−11.
88. Lexow K. Severe accidental hypothermia: survival after 6 hours 30 minutes of cardiopulmonary resuscitation. *Arctic Med Res*. 1991;50(Suppl 6):112−4.

89. Gordon L, Paal P, Ellerton JA, Brugger H, Peek GJ, Zafren K. Delayed and intermittent CPR for severe accidental hypothermia. *Resuscitation*. 2015;90:46−9.
90. Imberti R, Bellinzona G, Riccardi F, Pagani M, Langer M. Cerebral perfusion pressure and cerebral tissue oxygen tension in a patient during cardiopulmonary resuscitation. *Intensive Care Med*. 2003;29(6):1016−9.
91. Maningas PA, DeGuzman LR, Hollenbach SJ, Volk KA, Bellamy RF. Regional blood flow during hypothermic arrest. *Ann Emerg Med*. 1986;15(4):390−6.
92. Pietsch U, Lischke V, Pietsch C, Kopp KH. Mechanical chest compressions in an avalanche victim with cardiac arrest: an option for extreme mountain rescue operations. *Wilderness Environ Med*. 2014;25(2):190−3.
93. Wik L, Kiil S. Use of an automatic mechanical chest compression device (LUCAS) as a bridge to establishing cardiopulmonary bypass for a patient with hypothermic cardiac arrest. *Resuscitation*. 2005;66(3):391−4.
94. Ujhelyi MR, Sims JJ, Dubin SA, Vender J, Miller AW. Defibrillation energy requirements and electrical heterogeneity during total body hypothermia. *Crit Care Med*. 2001;29(5):1006−11.
95. DaVee TS, Reineberg EJ. Extreme hypothermia and ventricular fibrillation. *Ann Emerg Med*. 1980;9(2):100−2.
96. Koller R, Schnider TW, Neidhart P. Deep accidental hypothermia and cardiac arrest–rewarming with forced air. *Acta Anaesthesiol Scand*. 1997;41(10):1359−64.
97. Thomas R, Cahill CJ. Successful defibrillation in profound hypothermia (core body temperature 25.6 degrees C). *Resuscitation*. 2000;47(3):317−20.
98. Mair P, Gasteiger L, Mair B, Stroehle M, Walpoth B. Successful defibrillation of four hypothermic patients with witnessed cardiac arrest. *High Alt Med Biol*. 2019;20(1):71−7.
99. Morrison LJ, Deakin CD, Morley PT, Callaway CW, Kerber RE, Kronick SL, et al. Part 8: Advanced life support: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*. 2010;122(16 Suppl 2):S345−421.
100. Binnema R, van der Wal A, Visser C, Schepp R, Jekel L, Schroder P. Treatment of accidental hypothermia with cardiopulmonary bypass: a case report. *Perfusion*. 2008;23(3):193−6.
101. Hauty MG, Esrig BC, Hill JG, Long WB. Prognostic factors in severe accidental hypothermia: experience from the Mt. Hood tragedy. *J Trauma*. 1987;27(10):1107−12.
102. Danzl DF, Pozos RS, Auerbach PS, Glazer S, Goetz W, Johnson E, et al. Multicenter hypothermia survey. *Ann Emerg Med*. 1987;16(9):1042−55.
103. Deal CW, Warden JC, Monk I. Effect of hypothermia on lung compliance. *Thorax*. 1970;25(1):105−9.
104. Caldwell JE, Heier T, Wright PM, Lin S, McCarthy G, Szenohradszky J, et al. Temperature-dependent pharmacokinetics and pharmacodynamics of vecuronium. *Anesthesiology*. 2000;92(1):84−93.
105. Heier T, Caldwell JE. Impact of hypothermia on the response to neuromuscular blocking drugs. *Anesthesiology*. 2006;104(5):1070−80.
106. Leslie K, Sessler DI, Bjorksten AR, Moayeri A. Mild hypothermia alters propofol pharmacokinetics and increases the duration of action of atracurium. *Anesth Analg*. 1995;80(5):1007−14.
107. Kondratiev TV, Flemming K, Myhre ES, Sovershaev MA, Tveita T. Is oxygen supply a limiting factor for survival during rewarming from profound hypothermia? *Am J Physiol Heart Circ Physiol*. 2006;291(1):H441−50.
108. Strapazzon G, Nardin M, Zanon P, Kaufmann M, Kritzinger M, Brugger H. Respiratory failure and spontaneous hypoglycemia during noninvasive rewarming from 24.7 degrees C (76.5 degrees F) core body temperature after prolonged avalanche burial. *Ann Emerg Med*. 2012;60(2):193−6.
109. Wira CR, Becker JU, Martin G, Donnino MW. Anti-arrhythmic and vasopressor medications for the treatment of ventricular fibrillation in severe hypothermia: a systematic review of the literature. *Resuscitation*. 2008;78(1):21−9.
110. Wira C, Martin G, Stoner J, Margolis K, Donnino M. Application of normothermic cardiac arrest algorithms to hypothermic cardiac arrest in a canine model. *Resuscitation*. 2006;69(3):509−16.
111. Raedler C, Voelckel WG, Wenzel V, Bahlmann L, Baumeier W, Schmittinger CA, et al. Vasopressor response in a porcine model of hypothermic cardiac arrest is improved with active compression-decompression cardiopulmonary resuscitation using the inspiratory impedance threshold valve. *Anesth Analg*. 2002;95(6):1496−502.
112. Schwarz B, Mair P, Raedler C, Deckert D, Wenzel V, Lindner KH. Vasopressin improves survival in a pig model of hypothermic cardiopulmonary resuscitation. *Crit Care Med*. 2002;30(6):1311−4.
113. Sumann G, Krismer AC, Wenzel V, Adelsmayr E, Schwarz B, Lindner KH, et al. Cardiopulmonary resuscitation after near drowning and hypothermia: restoration of spontaneous circulation after vasopressin. *Acta Anaesthesiol Scand*. 2003;47(3):363−5.
114. Khan JN, Prasad N, Glancy J. Amiodarone use in therapeutic hypothermia following cardiac arrest due to ventricular tachycardia and ventricular fibrillation. *Europace*. 2009;11(11):1566−7.
115. Elenbaas RM, Mattson K, Cole H, Steele M, Ryan J, Robinson W. Bretylium in hypothermia-induced ventricular fibrillation in dogs. *Ann Emerg Med*. 1984;13(11):994−9.
116. Stoner J, Martin G, O'Mara K, Ehlers J, Tomlanovich M. Amiodarone and bretylium in the treatment of hypothermic ventricular fibrillation in a canine model. *Acad Emerg Med*. 2003;10(3):187−91.
117. Danzl DF, Sowers MB, Vicario SJ, Thomas DM, Miller JW. Chemical ventricular defibrillation in severe accidental hypothermia. *Ann Emerg Med*. 1982;11(12):698−9.
118. Lloyd EL. Accidental hypothermia. *Resuscitation*. 1996;32(2):111−24.

119. Ho JD, Heegaard WG, Brunette DD. Successful transcutaneous pacing in 2 severely hypothermic patients. *Ann Emerg Med*. 2007;49(5):678−81.
120. Rankin AC, Rae AP. Cardiac arrhythmias during rewarming of patients with accidental hypothermia. *Br Med J (Clin Res Ed)*. 1984;289(6449):874−7.
121. Jurkovich GJ, Greiser WB, Luterman A, Curreri PW. Hypothermia in trauma victims: an ominous predictor of survival. *J Trauma*. 1987;27(9):1019−24.
122. Martin RS, Kilgo PD, Miller PR, Hoth JJ, Meredith JW, Chang MC. Injury-associated hypothermia: an analysis of the 2004 National Trauma Data Bank. *Shock*. 2005;24(2):114−8.
123. Beilman GJ, Blondet JJ, Nelson TR, Nathens AB, Moore FA, Rhee P, et al. Early hypothermia in severely injured trauma patients is a significant risk factor for multiple organ dysfunction syndrome but not mortality. *Ann Surg*. 2009;249(5):845−50.
124. Mitra B, Tullio F, Cameron PA, Fitzgerald M. Trauma patients with the 'triad of death'. *Emerg Med J*. 2012;29(8):622−5.
125. Quinn R, Williams J, Bennett B, Stiller G, Islas A, McCord S, et al. Wilderness Medical Society practice guidelines for spine immobilization in the austere environment. *Wilderness Environ Med*. 2013;24(3):241−52.
126. Debaty G, Moustapha I, Bouzat P, Maignan M, Blancher M, Rallo A, et al. Outcome after severe accidental hypothermia in the French Alps: A 10-year review. *Resuscitation*. 2015;93:118−23.
127. Ruttmann E, Weissenbacher A, Ulmer H, Muller L, Hofer D, Kilo J, et al. Prolonged extracorporeal membrane oxygenation-assisted support provides improved survival in hypothermic patients with cardiocirculatory arrest. *J Thorac Cardiovasc Surg*. 2007;134(3):594−600.
128. Ruttmann E, Dietl M, Kastenberger T, El Attal R, Strohle M, Ulmer H, et al. Characteristics and outcome of patients with hypothermic out-of-hospital cardiac arrest: experience from a European trauma center. *Resuscitation*. 2017;120:57−62.
129. Khorsandi M, Dougherty S, Young N, Kerslake D, Giordano V, Lendrum R, et al. Extracorporeal life support for refractory cardiac arrest from accidental hypothermia: a 10-year experience in Edinburgh. *J Emerg Med*. 2017;52(2):160−8.
130. Darocha T, Kosinski S, Jarosz A, Sobczyk D, Galazkowski R, Piatek J, et al. The chain of survival in hypothermic circulatory arrest: encouraging preliminary results when using early identification, risk stratification and extracorporeal rewarming. *Scand J Trauma Resusc Emerg Med*. 2016;24:85.
131. Jarosz A, Darocha T, Kosinski S, Galazkowski R, Mazur P, Piatek J, et al. Profound accidental hypothermia: systematic approach to active recognition and treatment. *ASAIO J*. 2017;63(3):e26−30.
132. Gruber E, Beikircher W, Pizzinini R, Marsoner H, Pornbacher M, Brugger H, et al. Non-extracorporeal rewarming at a rate of 6.8°C per hour in a deeply hypothermic arrested patient. *Resuscitation*. 2014;85(8):e119−20.
133. Roggero E, Stricker H, Biegger P. [Severe accidental hypothermia with cardiopulmonary arrest: prolonged resuscitation without extracorporeal circulation]. *Schweiz Med Wochenschr*. 1992;122(5):161−4.
134. Turtiainen J, Halonen J, Syvaoja S, Hakala T. Rewarming a patient with accidental hypothermia and cardiac arrest using thoracic lavage. *Ann Thorac Surg*. 2014;97(6):2165−6.
135. Woehrle T, Lichtenauer U, Bayer A, Brunner S, Angstwurm M, Schafer ST, et al. Misleading symptoms and successful noninvasive rewarming of a patient with severe hypothermia (23.1°C). *Anaesthesist*. 2018;67(12):931−5.
136. Dobson JA, Burgess JJ. Resuscitation of severe hypothermia by extracorporeal rewarming in a child. *J Trauma*. 1996;40(3):483−5.
137. von Segesser LK, Garcia E, Turina M. Perfusion without systemic heparinization for rewarming in accidental hypothermia. *Ann Thorac Surg*. 1991;52(3):560−1.
138. Farstad M, Andersen KS, Koller ME, Grong K, Segadal L, Husby P. Rewarming from accidental hypothermia by extracorporeal circulation. A retrospective study. *Eur J Cardiothorac Surg*. 2001;20(1):58−64.

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WILDERNESS MEDICAL SOCIETY PRACTICE GUIDELINES

# Wilderness Medical Society Practice Guidelines for the Prevention and Treatment of Heat Illness: 2019 Update

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The Wilderness Medical Society convened an expert panel in 2011 to develop a set of evidence-based guidelines for the recognition, prevention, and treatment of heat illness. We present a review of the classifications, pathophysiology, and evidence-based guidelines for planning and preventive measures, as well as best practice recommendations for both field- and hospital-based therapeutic management of heat illness. These recommendations are graded based on the quality of supporting evidence and balance the benefits and risks or burdens for each modality. This is an updated version of the original Wilderness Medical Society Practice Guidelines for the Treatment and Prevention of Heat-Related Illness published in 2013.

*Keywords:* heat stroke, hyperthermia, prevention, recognition, treatment

## Introduction

Heat illness is a common occurrence worldwide. The European heat wave of 2003 resulted in at least 70,000 fatalities,[1] and in the last decade the United States averaged over 600 deaths annually associated with excessive heat exposure.[2] Currently, heat illness is the leading cause of morbidity and mortality among US high school athletes.[3] Heat stroke mortality approaches 10%[4] and when presenting with hypotension increases to 33%.[5] Outcome is directly attributed to both the magnitude and duration of hyperthermia,[6–8] making early recognition and treatment a priority. The Wilderness Medical Society convened an expert panel to develop a set of practice guidelines for the recognition, prevention, and treatment of heat illness. We present a review of the classifications, pathophysiology, and evidence-based guidelines for planning and preventive measures, as well as best practice recommendations for both field- and hospital-based therapeutic management of heat illness. Although the spectrum of heat illness is discussed, this practice group's focus was on the exploration of exertional heat stroke (EHS), which is synonymous with the term "heat stroke" in this article unless otherwise specified.

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## Methods

Specialists in emergency medicine, primary care, and critical care from both civilian and military backgrounds were chosen based on their clinical or research experience. In 2011,[9] and for subsequent practice guideline updates,[10] relevant articles were identified through the PubMed database using the following key words: hyperthermia, heat stroke, heat illness, heat syncope, and heat exhaustion. This was supplemented by a hand search of articles from references in the initial PubMed search. Studies in these categories, including randomized controlled trials, observational studies, and case series, were reviewed. Abstract-only reports were not included. Conclusions from review articles were cited to provide background information but were not considered in the formulation of recommendation grades. The panel used a consensus approach to develop recommendations for

the recognition and management of heat illness, with level of evidence assigned according to methodology stipulated by the American College of Chest Physicians for grading of evidence and recommendations (Supplementary Table 1). These recommendations are graded based on the quality of supporting evidence and balance between the benefits and risks or burdens for each modality or intervention.

## Definition of heat illness

Heat illness can be manifested as a spectrum of disease from minor to severe, such as heat cramps, heat syncope, heat exhaustion, and life-threatening heat stroke. *Hyperthermia* is a deviation above the body's normal physiologic setpoint and should be considered separately from the concept of heat illness. It is an expected physiologic response when core body temperature rises as a result of exposure to elevated ambient temperatures or when internally generated heat from muscular activity accumulates faster than it can be dissipated. Hyperthermia is a natural outcome of exertion, and increased metabolic rate has been shown to be the most important factor in elevation of body temperature.[11] Studies of asymptomatic runners have found 15 to 56% with core temperatures ≥40°C and 11% ≥42°C.[12,13] As such, absolute temperature thresholds alone should not be routinely applied to asymptomatic individuals as a pathologic indicator of heat illness.

As with any syndrome, the terms used to define heat illness do not necessarily confer direct cause and effect but rather a strong contextual association that may have descriptive, prognostic, and epidemiological merit, if not pathophysiologic precision.[14,15] *Heat cramps* were initially defined in the 1930s to describe the clinical phenomenon of involuntary diffuse large-muscle contractions associated with exertion in hot environments.[16] These heat cramps are likely distinct from the focal muscle cramping in an athlete during repetitive exercises.[17] Dehydration and electrolyte disturbances have been associated with heat cramps,[18] and isotonic rehydration has been found to be restorative.[16] *Heat edema* is a benign self-limiting condition. Interstitial fluid accumulates in dependent extremities as a result of hydrostatic pressure, vascular leak, and cutaneous vasodilation. *Heat syncope* refers to a multifactorial syndrome involving transient loss of consciousness in the context of heat exposure with a relatively rapid return to normal function and baseline. Contributing factors may include peripheral vasodilation, orthostatic pooling of blood, prolonged standing, advanced age, dehydration, and coexisting medical conditions such as ischemic heart disease that reduces cardiac output. Although syncope can occur in both milder and more severe forms of heat illness, heat syncope generally refers to a more benign clinical condition that should resolve with rest and possibly rehydration at comfortable ambient temperatures.[19,21] Syncope may also occur during exertion from impaired baroreceptor reflex and lower extremity venous pooling in the absence of hyperthermia or dehydration, a syndrome known as *exercise-associated collapse*.[19]

*Heat exhaustion* results from exposure to high ambient temperature or strenuous exertion. It manifests as a constellation of symptoms that range from uncomfortable to debilitating[6,21] and may limit continuation of exercise in the heat.[6] Symptoms are variable and may include weakness, fatigue, thirst, headache, nausea, dizziness, and muscle aches.[21] This mild to moderate heat illness may progress to heat stroke if left untreated or unrecognized in a hot environment, although heat stoke does occur as a fulminant illness without preceding heat exhaustion. *Heat stroke* is traditionally defined as a core temperature above 40°C (104°F) with central nervous system involvement (eg, encephalopathy, seizures, or coma). Heat stroke is generally divided into 2 categories: classic heat stroke resulting from passive exposure to high environmental temperatures and EHS resulting from pathologic

**Table 1.** Categories of heat illness

| *Condition* | *Definition* |
|---|---|
| Hyperthermia | A rise in body temperature above the hypothalamic set point when heat-dissipating mechanisms are impaired (by clothing or insulation, drugs, or disease) or overwhelmed by external (environmental) or internal (metabolic) heat production. |
| Heat edema | Dependent extremity swelling due to interstitial fluid pooling. |
| Heat cramps | Exercise-associated painful involuntary muscle contractions during or immediately after exercise. |
| Heat syncope | Transient loss of consciousness with spontaneous return to normal mentation. |
| Heat exhaustion | Mild to moderate heat illness due to exposure to high environmental heat or strenuous physical exercise; signs and symptoms include intense thirst, weakness, discomfort, anxiety, dizziness, syncope; core temperature may be normal or slightly elevated >37°C (98.6°F) but <40°C (104°F). |
| Heat stroke | Severe heat illness characterized by a core temperature >40°C (104°F) and central nervous system abnormalities such as altered mental status (encephalopathy), seizure, or coma resulting from passive exposure to environmental heat (classic heat stroke) or strenuous exercise (exertional heat stroke). |

(nonphysiologic) hyperthermia during strenuous exercise (Table 1).[22]

### Heat dissipation and pathophysiology

Heat loss is controlled by peripheral centers in the skin and organs and the central nervous system via the hypothalamus, with a greater cooling response to temperature elevation via central sensors.[23] A temperature gradient exists between the body core and skin that promotes heat dissipation when core temperature is higher than surface temperature. A rise in blood temperature by less than 1°C triggers hypothalamic thermoregulation to increase blood flow to the skin by up to 8 $L \cdot min^{-1}$ via sympathetic cutaneous vasodilation, with sixfold blood flow increases to the forearms and the arteriovenous anastomotic microvascular structures deep to the glabrous skin areas, with their unique intrinsic heat transfer capabilities.[24,25] As blood is shunted to the periphery to facilitate heat loss, renal and splanchnic perfusion is reduced by 30%.[24]

However, when the core temperature increases during exercise and skin temperature also rises as a result of the environment or internal heat production, heat dissipation is reduced. Similarly, when the body's metabolic heat production outpaces heat transfer, core temperature rises, and heat illness can occur.[26] Heat stroke occurs when internal core temperatures rise above a critical level, leading to a cascade of cellular and systemic responses. These responses include thermoregulatory dysfunction, an acute phase response, and a heat shock protein response. The acute phase response to heat stress involves an inflammatory reaction of interleukins, cytokines, and proteins that progresses in a sequence similar to that seen in sepsis. It is theorized that an exaggerated acute phase and inflammatory response mark the progression from heat stress to heat stroke, possibly incited by the hypoperfused gastrointestinal tract.[22] Increased mucosal permeability from inflammatory mediators allows endotoxins from the gut to enter the systemic circulation. This combination of endotoxemia and cascade of inflammatory cytokines leads to alterations in the microcirculation, further endothelial and tissue injury, and impaired thermoregulation, thus precipitating heat stroke and hypotension. An overlapping hypothesis presupposes that at a similar threshold temperature, the expression of protective heat-shock proteins is altered, decreasing their ability to prevent thermal denaturation of structural proteins and enzymes that start to fail at a cellular level, with ensuing end organ dysfunction.[22,27] At critical levels of hyperthermia, heat causes direct tissue injury and death via apoptosis or necrosis, with the severity of injury dictated by both the level and duration of thermal stress.[28,29] This complex constellation of overlapping events leads to thermoregulatory failure, heat stroke, and circulatory shock.

### Prevention and planning

The proverb that "an ounce of prevention is worth a pound of cure" is especially apt in light of the potentially fatal nature of heat illness. Deliberate strategies for prevention should be included when planning for activities with a credible risk. Structured risk assessments can be built and validated for population-level use,[30,31] or the practitioner considering a particular scenario should consider the risk incurred by the individual participant's factors including physiology, the environment, and the planned athletic activity.[32]

## INDIVIDUAL FACTORS

Any condition that limits heat loss through the skin may lead to heat retention, including hypohydrosis, extensive scars, and diminished cardiopulmonary reserve at the extremes of age. Small studies have linked acute sunburn with impaired sweating, which persisted for 7 d, considerably longer than the associated pain and erythema.[33,34] Impaired sweating is a risk factor for heat accumulation, but otherwise the risks of sunburn are of indeterminate clinical significance.

Certain drugs can predispose individuals to heat injury by 2 primary pathways, increased heat production resulting from drug actions and compromised function of thermoregulatory centers (Table 2).[35,36] Moderate caffeine intake appears to have no detrimental effect.[18] A large prospective study of military

**Table 2.** Medications and drugs that may contribute to heat illness

| |
|---|
| Alcohol |
| Alpha adrenergics |
| Amphetamines |
| Anticholinergics |
| Antihistamines |
| Antipsychotics |
| Benzodiazepines |
| Beta blockers |
| Calcium channel blockers |
| Clopidogrel |
| Cocaine |
| Diuretics |
| Laxatives |
| Neuroleptics |
| Phenothiazines |
| Thyroid agonists |
| Tricyclic antidepressants |

recruits found a significantly increased risk of heat illness among those who were obese or overweight compared with fitter individuals.[37]

Heat acclimatization, as induced by 1 to 2 h of heat-exposed exertion per day over 10 to 14 d, results in reproducible adaptations that increase the body's ability to tolerate and divest heat.[38–40] These adaptations may persist for up to a month.[41,42] Evidence suggests that a bout of heat stroke may acutely reset these thermoregulatory adaptations and cause elevated risk for subsequent heat injury for months after the initial event,[43] although case reports indicate that heat tolerance can be recovered fully.[44,45] Individuals with high levels of cardiopulmonary fitness tolerate more activity in heat-strained conditions and acclimatize to heat more rapidly because they have increased sweat volumes and higher subjective tolerance for activity when hyperthermic.

The most readily modifiable physiologic risk factor is hydration status. Although endurance athletes may comfortably tolerate weight losses of 3 to 4% during events,[46,47] fluid losses that result in a 2 to 3% decrease in body weight correlate with greater core temperatures at a given work load in the heat.[39,48,49] Dehydration has been found to increase physiologic strain, decrease sweat rates, increase perceived exertion, and increased core temperatures.[23,50,51]

Hyperhydration before activity has not been shown to have a significant effect on heat tolerance, nor has active body cooling before activity.[52] One investigation on the effect of sex as a risk factor on thermal recovery was confounded by body mass index differences, such that no conclusion could be reached.[53] The luteal phase of the menstrual cycle, which is associated with increased core temperatures, does not appear to induce heat intolerance in women on oral contraceptive pills.[54] The physiology of pediatric and elderly populations differs enough from healthy adults to warrant special considerations that are outside this panel's scope but are discussed at length elsewhere.[55–57]

***Recommendations***. Screen for significant pre-existing medical conditions (1B). Minimize use of medications that could limit the thermoregulatory response (1C). Recognize that an overweight body habitus is associated with greater risk of heat illness (1B). Promote regular aerobic activity before heat exposure (1C). Allow for acclimatization with 1 to 2 h per d of heat-exposed exertion for at least 8 days (1C). Ensure euhydration before activity (1B). Ensure ongoing rehydration with a "drink to thirst" approach sufficient to prevent >2% loss of body weight (1B). Consider history of heat injury as a reversible risk factor for recurrence (1C).

## ENVIRONMENTAL CONSIDERATIONS

The body and the environment exchange heat through several mechanisms: conduction (heat transfer from the body to the surrounding environment along a temperature gradient by direct contact), evaporation (heat transfer from the body to sweat, resulting in transition of water from the liquid to vapor phase), thermal radiation (infrared rays given off by any mass as a function of the temperature of that mass), or convection (transfer of heat from the body to free fluids or gas moving across the skin surface).

As the environmental temperature increases, the body will eventually incur a net heat gain through conductive, convective, and radiative processes, leaving evaporation as the only cooling mechanism. The vaporization of 1.7 mL of sweat consumes 1 kcal of heat[58]; however, evaporative cooling is less effective in highly humid environments, which have a lower water vapor pressure difference between the sweat on the skin and the water in the surrounding air. The wet-bulb globe temperature index (WBGT) is a composite index of temperature, humidity, and solar radiation that expresses the total thermal strain that an individual experiences. A series of WBGT values can be designated as cautionary warnings and triggers to activate guidelines for rehydration, active cooling, and limitations (or even cancellation) of physical activity.[34] An alternative to the WBGT that is more readily available is the heat index, which is a measure of the contribution that high temperature and high humidity (expressed as either relative humidity or dew point temperature) make in reducing the body's ability to cool itself. Although the wet bulb globe temperature is a metric likely not readily available to individual medical practitioners, its current use by military,[59] occupational,[60] and civilian groups[26,55] makes it the standard when discussing environmental thermal strain and choosing activity levels for ambient conditions. Guidelines that correlate the heat index with the risk of heat injury and outline parameters for limiting physical activity are readily available.[61]

***Recommendation.*** WBGT should be used for the assessment of heat risk (1A).

## ACTIVITY CONSIDERATIONS

The metabolic thermal output of an activity is the product of its intensity and duration. The accumulation of heat by the body is tempered in some circumstances by an activity that can enhance heat transfer with the environment (eg, water convection on a swimmer or wind past a cyclist). Occupational,[60,62] military,[59] and medical[24] guidelines recommend breaks in proportion to metabolic demand and ambient conditions, but there are few studies examining how to optimize the dosing of breaks.

***Recommendation.*** Consider which mechanisms of heat accumulation or dissipation are dominant during an activity, and consider heat loss as a key feature of breaks (1C).

### CLOTHING AND EQUIPMENT

Clothing or other equipment worn during an activity may limit or enhance the body's thermoregulatory efficiency. Of particular importance is equipment that occludes regions of skin, resulting in compromise of evaporative, convective, radiative, or conductive heat transfer. For example, the American football uniform prevents full heat exchange across much of the torso and head and can therefore contribute to heat accumulation,[63] similar to military helmets and body armor.[64] Preventing heat exchange may be protective, as in the case of firefighting gear that prevents heat in a superheated environment from entering the body by conduction or radiation. Sports medicine guidelines and military occupational guidelines have set examples of systematic reductions in clothing and equipment based on WBGT thresholds.[26,65]

***Recommendation***. Clothing and equipment for a given activity should be evaluated and modified as needed to optimize evaporative, convective, conductive, and radiative heat exchange or isolation (1C).

## Field treatment

Optimal field management of heat illness may be challenging because of resource limitations or extreme settings. The ideal treatment, as emphasized in the previous section, is prevention via avoiding high-exertion activities in exposed or hot areas. The method and aggressiveness of cooling in the field depend on the type of heat illness encountered (Table 3). Regardless of the underlying cause, removal from the heat and rapid cooling is critical because the extent of morbidity is directly related to both to the degree and duration of hyperthermia.[8,37,66–69] All treatment in the field is first directed to stabilization of the patient's airway, breathing, and circulation before proceeding to more specific cooling therapy. If no life-threatening complications exist, the implementation of on-site cooling before evacuation should be implemented (Figure 1).[26] In transitioning patient care to emergency medical service providers, it is important to communicate any cooling techniques begun in the field and to emphasize continued cooling of the patient by best available means en route to the destination.

### MINOR HEAT ILLNESS TREATMENT

There is scant evidence supporting treatments of minor and moderate heat illness. Most treatments are anecdotal but effective and generalizable from the evidence-based treatment for more severe forms of heat illness (Table 3).

**Table 3.** Heat illness treatments

| *Severity of heat-related illness* | *Diagnosis* | *Treatment* |
|---|---|---|
| Mild | Heat cramps | Oral isotonic or hypertonic fluid replacement |
| | Heat edema | Extremity elevation<br>Compression stockings |
| Moderate | Heat syncope | Remove from heat source<br>Passive cooling<br>Oral isotonic or hypertonic fluid hydration |
| | Heat exhaustion | Remove from heat source<br>Evaporative, convective, or conductive cooling<br>Oral or intravenous isotonic or hypertonic fluid hydration |
| Severe | Heat stroke | Remove from heat source<br>Supportive care of airway, breathing, and circulation<br>Cold water immersion<br>Whole-body conductive cooling<br>Intravenous hydration[a]<br>*Evacuation*[b] |

[a] Intravenous hydration with isotonic (0.9% sodium chloride) or hypertonic (D5NS) fluids, with 3% sodium chloride indicated if concern for exercise-associated hyponatremia as cause of encephalopathy.

[b] Initiate emergency medical services if unable to rapidly cool patient, prolonged encephalopathy, or concern of multiorgan dysfunction.

Heat cramps, which are historically described as generalized,[16] differ from the focal exercise-associated muscle cramps seen in endurance athletes. Heat cramps are relieved with oral salt solutions or electrolyte replacement that may be isotonic or hypertonic,[16] compared with exercise-associated muscle cramps that occur with neuromuscular fatigue and are relieved with passive stretching.[70] Heat edema is reversed by extremity elevation or wearing of compression stockings. Diuretics are ineffective and may worsen volume depletion.[71]

Heat syncope by definition is self-limiting. After consideration of other medical causes of syncope or resultant trauma from a fall, treatment consists of ensuring replacement of vascular volume with isotonic oral fluids and rest in a cool environment.[19] Individuals at risk for heat syncope should move often and flex their larger leg muscles to prevent peripheral pooling of blood from cutaneous vasodilation. An individual with heat syncope is likely underacclimatized to the heat, and caution is warranted before immediate return to regular activity.

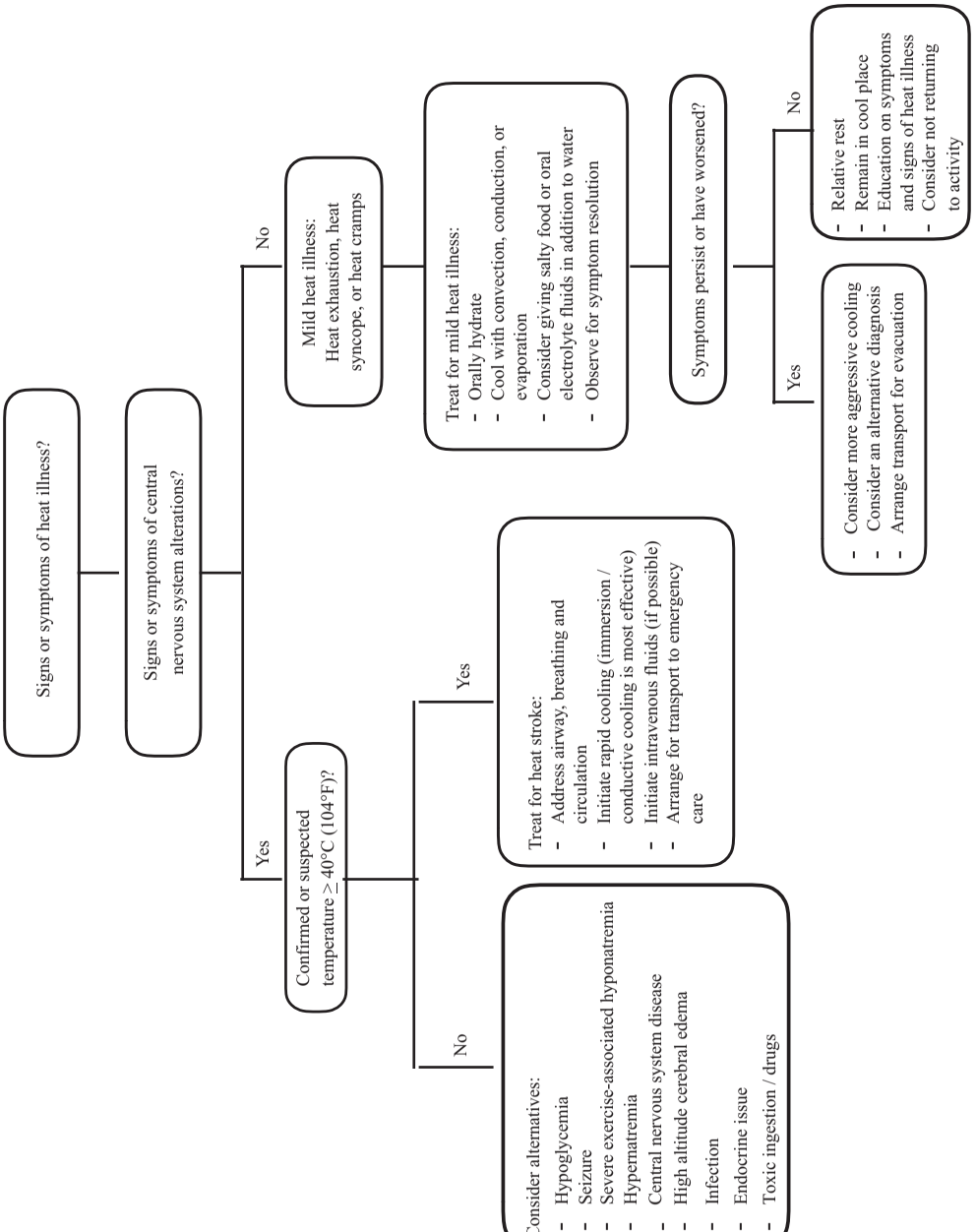


**Figure 1.** Heat illness treatment algorithm.

Heat exhaustion, like heat stroke, results from a combination of both cardiovascular and thermal strain, and various forms of rest and whole-body cooling are dictated by severity of symptoms. Mild cases generally resolve with removing the patient from the hot environment, cessation of physical activity, and rehydration with oral isotonic fluids. Severe heat exhaustion typically has more pronounced volume depletion and may require intravenous replacement of fluids as well as conductive and convective cooling. Because heat exhaustion can lead to cessation of physical activity and collapse,[6] it is important to actively reverse the process of heat exhaustion, which can progress to heat stroke without proper cooling techniques. Case reports have linked heat exhaustion or acute heat stress to precipitating electrocardiogram changes, symptomatic arrhythmias, and cardiac arrest with features of underlying Brugada syndrome.[72,73]

***Recommendation***. Heat syncope patients whose event is recurrent and inconsistent with exercise-associated collapse or other clear explanation should be referred for further cardiology diagnostics (2C).

## TEMPERATURE MEASUREMENT

When possible, obtaining an accurate body temperature is an important diagnostic step in differentiating heat stroke from less severe heat illness. Rectal temperature is widely considered the standard field measurement,[25,67] because it is a reliable and practical measure of core temperature that is more accurate than temporal, axillary, oral, or aural thermometry.[74,75] Esophageal and ingestible thermistors have been validated and provide a more accurate measurement of core temperature but are impractical in the wilderness setting. Rectal temperature measurement carries implicit challenges in maintaining patient privacy and hygiene, so initial assessment and aggressive cooling should be implemented based on the clinical suspicion, regardless of the degree of hyperthermia or mode of measurement.

***Recommendations***. When available, rectal temperature should be considered the most accurate measurement of core hyperthermia compared to axillary, oral, or aural thermometry (1B). In a hyperthermic individual with an altered sensorium, the initiation of empiric cooling for heat stroke should not be delayed by a measurement value that may be below the diagnostic threshold of 40°C (1B).

## PASSIVE COOLING

Simple measures can be easily taken to reduce the patient's exposure to heat. Moving the victim into the shade can externally decrease the ambient temperature; however, this is most effective when temperatures are <20°C (68°F).[67] Conduction of heat from the ground can be decreased by placing the victim on cool ground, if available, or on an insulating barrier such as sleeping pad or sleeping bag. Loosening or removing any tight-fitting clothing to optimize air circulation aids in convective heat exchange.[76]

***Recommendation***. Passive cooling measures should be used to minimize thermal strain and maximize heat loss (1C).

## HYDRATION

Euhydration is an important factor in reducing hyperthermia.[76,77] Body water losses through increased sweat rates, vomiting, diarrhea, or insufficient oral intake increase the risk of potential heat injury resulting from poor hydration status. Dehydration predisposes patients to hyperthermia by decreasing sweat rates and increases thermal strain at a given temperature.[50,77–79] Oral and intravenous hydration have been shown to be equally effective in replenishing water deficiencies related to heat stress.[77,80]

***Recommendation***. Dehydration should be minimized in heat illness (1C).

Optimizing hydration in heat stroke decreases both the cardiovascular and thermal strain. In a heat stroke victim with altered mental status and risk of seizure, the intravenous route minimizes aspiration risk and subsequent airway compromise. Few data exist on the optimal intravenous fluid type and amount relating specifically to heat illness. Because those with EHS may be volume depleted from insensible fluid losses, the reasonable choices of replenishment are 1 to 2 L of isotonic (0.9% normal saline or normal saline with 5% dextrose) fluids. Because heat stroke can occur in both euhydrated and dehydrated individuals, care should be taken to not overhydrate patients (especially those with coronary comorbidity) because this may increase the risk of pulmonary edema.[79] Any effort to provide hydration in suspected heat stroke should not delay rapid whole-body cooling.[82] If intravenous hydration is provided, field monitoring of blood pressure, heart rate, lightening of urine color, and increase in urine output can help guide patient response and fluid status.

***Recommendation.*** Intravenous fluids should be used for rehydration in EHS (1B).

Symptomatic exercise-associated hyponatremia may present similarly to heat exhaustion,[21] and the presence of altered mental status (eg, obtundation, coma, or seizures) without other explanation, such as hypoglycemia or trauma, in the absence of hyperthermia may indicate severe exercise-associated hyponatremia. This is a critical illness that ideally should be confirmed with serum sodium measurement, but in the absence of point-of-care testing the patient should

empirically be resuscitated with up to 3, 100 mL 3% sodium chloride boluses given every 10 min, or until resolution of altered mental status, with rapid transfer to a medical facility.[83]

## COLD WATER IMMERSION THERAPY

Cold water immersion therapy is the optimal field treatment to achieve rapid temperature reduction below critical levels in heat stroke. Immersion is a conductive method of cooling that takes advantage of water's high thermal conductivity, which is 24 times greater than that of air,[84] and the high thermal gradient that exists between cold water and skin,[85] which translates into a greater capacity for heat transfer. The colder the water, the faster the rate of cooling.[86] The theoretical concern that cold-water immersion causes peripheral vasoconstriction and shivering that slow cooling, or may even increase the core temperature, is a prevalent misconception, possibly stemming from a misinterpretation of the "Currie response."[87] This 18th century observation found an increase in the core temperature of shivering normothermic individuals by 0.1 to 0.2°C. Although shivering has been observed in immersions lasting longer than 10 min in healthy volunteers,[88,89] such shivering may be less problematic in actual heat stroke patients with failing thermoregulation.[90] In addition, the hindrance of cooling EHS by heat-generating shivering has been physiologically refuted.[86,91] Cold-water immersion is achieved by removing insulating clothes and equipment and submersing the patient's trunk and extremities in a bath of cold water or tub of ice water. Alternatively, water may be applied onto a patient covered in crushed ice and lying on a plastic sheet or tarp with its sides folded upright to keep the slurry in place ("tarp taco").[92] Ice water cooling has been shown to be twice as rapid in reducing core temperature as covering the body in soaked towels to enhance evaporative cooling (0.20°C·min$^{-1}$ vs 0.11°C·min$^{-1}$).[66]

In the field, using a natural body of water such as a stream, pond, river, or lake may be another treatment option. Special care should be taken to protect against currents and to ensure the head does not go underwater and the airway is protected; the patient should never be left alone owing to risk of aspiration and drowning. In lieu of a cold-water source, repeated dousing with cold water or snow, if available, is encouraged. Multiple military studies on immersion cooling of comparatively young and healthy EHS patients boast a 0% fatality rate,[93] strongly supporting that rapid treatment with this cooling modality has the best outcomes.

***Recommendation.*** Cold water immersion is the optimal cooling method for heat stroke (1A).

## EVAPORATIVE COOLING

If immersion or conductive cooling is unavailable, evaporative cooling measures should be initiated by loosening or removing clothing and dousing the patient with cold water to maximize the water−vapor skin interface.[94] Convection is then facilitated with air movement by fanning. Cooling by evaporation plus convection has been studied predominantly in patients with non-EHS,[95] with mean cooling times of 40 to 68 min.[91,96] Limited studies on traditional evaporative cooling have been done with EHS or heat exhaustion, with reported cooling rates half as fast as immersion cooling.[97]

***Recommendation.*** Evaporative or convective cooling can be considered as adjunct cooling methods if cold water immersion is unavailable (1C).

## CHEMICAL COLD PACKS/ICE PACKS

There is a traditional advocacy for the use of ice packs or chemical cold packs strategically applied to the skin covering the neck, axillae, and groin to cool blood flow passing in the major vessels as an adjunctive cooling measure.[98] Limited studies show no benefit in heat reduction with ice packs or chemical cold packs applied to these areas.[99,100] Ice packs have been found to have greater cooling capacity than chemical cold packs,[101] and if used, are most efficacious when wet and covering the entire body (to optimize conductive cooling).[99] A small translational study applied chemical cold packs to the glabrous skin of the palms, soles, and cheeks and found twice the cooling rate over traditional major vascular locations,[102] using the high-capacity blood flow of the subcutaneous arteriovenous anastomoses.

***Recommendations.*** Ice packs should be applied to cover the entire body (1C). If chemical cold packs are used, they should be applied to the cheeks, palms, and soles rather than the skin covering the major vessels (1C).

## ANTIPYRETICS

As clinicians, we generally treat elevated temperatures with antipyretics. This class of medications, such as ibuprofen and aspirin, works by inhibiting prostaglandin formation, and acetaminophen lowers the thermoregulatory setpoint.[103] Although this may be elevated in infectious causes of hyperthermia, this is not the case in exercise-induced hyperthermia. Antipyretic drugs are ineffectual and should be avoided.[104,105]

***Recommendation.*** Antipyretics should be avoided in heat illness (2B).

## Hospital treatment

Generally, patients with heat stroke should be transported to a medical facility capable of critical care management of

patients with multiple organ failure. Exceptions to this guideline have included soldiers or athletes treated in the field with ice-water immersion *immediately* at the onset of EHS with complete resolution of symptoms and subsequent observation in a medical station or infirmary.[106,107] In a hospital setting, the primary goals of treatment for heat stroke are rapidly lowering core body temperature and supporting organ system function[22] because patients may develop multiple organ failure with shock, acute respiratory failure, acute kidney injury, disseminated intravascular coagulopathy, and intestinal ischemia. Depending on the patient's clinical status, supportive treatment may include administering supplemental oxygen, performing intubation and mechanical ventilation, establishing adequate intravascular access, restoring intravascular volume with intravenous isotonic crystalloid solution, placing a bladder catheter to monitor urine output, and initiating vasopressors to support blood pressure (after adequate volume resuscitation).

The evidence on different cooling methods has involved a heterogeneous range of subjects experiencing EHS or classic heat stroke. Of the studies comparing different cooling methods, those involving randomized trials generally have been performed on healthy volunteers with exercise-induced hyperthermia and have enrolled relatively few subjects. The remaining studies on treating heat stroke patients have for the most part been case series reports or nonrandomized comparisons of treatment methods, with considerable variations in the baseline characteristics of subjects from one study to the next. Such heterogeneity and variation have reduced the comparative conclusions that can be drawn. Despite this limitation, the historical record has promoted 2 methods of cooling in a hospital setting: 1) conductive cooling via cold water immersion of the patient; and 2) evaporative and convective cooling via the application of sprayed water and forced air currents over the body.

## CONDUCTIVE COOLING

Cold water immersion is safe and effective for young, athletic patients with EHS. A cooling protocol used for over 15 y involving an ice-water slurry has been applied effectively with no fatalities or adverse effects in hundreds of civilian and military individuals.[18,106,108] Agitation, intolerance, or combativeness may occur in encephalopathic heat stroke patients, and benefits of immersive cooling should be balanced with the theoretical concerns of impaired access to an immersed patient who may require advanced cardiac monitoring or resuscitation, especially among older patients.[90,94,109] Cold-water immersion may be considered in non-EHS, although this may not be practical for the typically older patients with multiple comorbidities in the critical care environment.[90,110] In the absence of cold-water immersion, wetted ice packs covering the entire body can cool through conduction.[99]

***Recommendations.*** Cold water immersion should be considered for EHS in the hospital setting (1A). Cold water immersion can be considered for treatment of classic heat stroke patients (1C).

## EVAPORATIVE AND CONVECTIVE COOLING

Evaporative cooling in elderly patients may offer several theoretical advantages, such as greater patient comfort and less agitation as well as easier access to patients who may need advanced monitoring or resuscitative procedures. In general, studies on evaporative and convective cooling have involved classic heat stroke patients and experimental volunteers with exercise-induced hyperthermia but not patients with actual EHS. The larger studies using a specially constructed device, termed a body cooling unit, have produced cooling rates ranging from 0.04 to 0.11°C·min$^{-1}$, with an average cooling of time of 68 to 78 min and 10% mortality.[94,95] No direct comparisons between the body cooling unit with cold water immersion are available, but extrapolation of cooling rates suggests evaporative and convective cooling is an order of magnitude less efficacious. Because classic heat stroke patients are more likely to be older, obese, and with medical conditions such as diabetes, high blood pressure, and heart disease, the evidence suggests that the evaporative plus convective cooling technique by wetting and fanning the skin has a passable hospital-based role in the treatment of classic heat stroke but cools more slowly than conductive cooling and is not indicated in EHS.

***Recommendation.*** Evaporative and convective cooling may be considered in classic heat stroke in the hospital setting, but cooling rates with this method are inferior to those with conductive cooling. Evaporative and convective cooling is not indicated in EHS, unless effective conductive cooling is not available (1C).

## TARGET COOLING TEMPERATURES

The target cooling temperatures of EHS and exercise-induced hyperthermia to less than 39°C by ice water immersion have been well tolerated, with no fatalities, adverse outcomes, or core temperature "afterdrop" resulting in hypothermia.[18,106,108,111] Practitioners should also be cautious of falsely elevated rectal temperature measurements in the recovery phase resulting from the insulating effect of body mass.[112]

***Recommendation***. Heat stroke patients should be cooled to a target temperature of no less than 39°C (1B).

## ADJUNCTIVE COOLING TREATMENTS

If intravenous fluids are available, it is beneficial to use cold fluids (4°C) whenever possible. These can decrease core temperature at a twofold rate compared with room temperature fluids but provide insufficient cooling as a primary treatment for heat stroke. More invasive techniques of body cavity lavage with cold isotonic fluid have been reported but have not been adequately studied.[113,114] Intravascular cooling catheters are suggested to decrease morbidity when added to evaporative and convective cooling.[115]

***Recommendations.*** Cold intravenous fluids should be given for adjunctive cooling in heat stroke (1C). Intravascular cooling catheters or cold water lavage are not recommended primary treatments for heat stroke (2C).

## PHARMACOLOGIC TREATMENT

No pharmacologic agent has been shown to be helpful as a treatment for heat stroke. Dantrolene has been used for treatment of malignant hyperthermia. It acts by impairing calcium release from the sarcoplasmic reticulum, thereby reducing the muscular rigidity and hypertonicity typical of this condition. A well-designed randomized clinical trial of dantrolene vs placebo in classic heat stroke found no difference in cooling rates or outcome, concluding that this pharmacologic treatment should not be used in heat stroke patients.[116]

***Recommendation.*** Dantrolene should be avoided for treatment of heat stroke patients (2B).

## Conclusion

This article provides evidence-based guidelines for the prevention, recognition, and treatment of heat illness. Most of the available data are based on case series or extrapolation of results stemming from exercise-associated hyperthermia, which is an accepted research model, because randomized controlled trials for treatments of EHS are ethically challenging to justify. These guidelines apply the strength of the evidence to 2 distinct populations of heat stroke patients, and although the patient with EHS is more likely to be found in the wilderness environment, the medical provider should be aware of all therapeutic modalities and their inherent risks and benefits. We recommend that patients with heat stroke be cooled by conductive means by whole-body ice water or cold-water immersion (the preferential method in EHS). Evaporative and convective cooling of classic heat stroke may be augmented with the addition of ice packs over the entire body to promote conductive cooling. Future areas of research should include direct comparisons of available cooling modalities in controlled models, as well as further evaluation of endovascular catheters and hospital-based systems for optimum cooling of critical patients.

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## References

1. Robine JM, Cheung SL, Le Roy S, Van Oyen H, Griffiths C, Michel JP, et al. Death toll exceeded 70,000 in Europe during the summer of 2003. *C R Biol*. 2008;331(2):171–8.
2. Xu J. QuickStats: Number of heat-related deaths, by sex—national vital statistics system, United States, 1999–2010. *MMWR Morb Mortal Wkly Rep*. 2012;61(36):729.
3. Gilchrist J, Haileyesus T, Murphy M, Comstock RD, Collins C, Yard E. Heat illness among high school athletes—United States, 2005–2009. *MMWR Morb Mortal Wkly Rep*. 2010;59(32):1009–13.
4. Centers of Disease Control and Prevention. Heat-related illnesses and deaths—United States, 1994–1995. *MMWR Morb Mortal Wkly Rep*. 1995;44(25):465–8.
5. Austin MG, Berry JW. Observations on one hundred cases of heatstroke. *J Am Med Assoc*. 1956;161(16):1525–9.
6. Adolph EF. Tolerance to heat and dehydration in several species of mammals. *Am J Physiol*. 1947;151(2):564–75.
7. Overgaard J, Suit HD. Time-temperature relationship in hyperthermic treatment of malignant and normal tissue in vivo. *Cancer Res*. 1979;39(8):3248–53.
8. Vicario SJ, Okabajue R, Haltom T. Rapid cooling in classic heatstroke: effect on mortality rates. *Am J Emerg Med*. 1986;4(5):394–8.
9. Lipman GS, Eifling KP, Ellis MA, Gaudio FG, Otten EM, Grissom CK. Wilderness Medical Society practice guidelines for the prevention and treatment of heat-related illness. *Wilderness Environ Med*. 2013;24(4):351–61.
10. Lipman GS, Eifling KP, Ellis MA, Gaudio FG, Otten EM, Grissom CK. Wilderness Medical Society practice guidelines for the prevention and treatment of heat-related illness: 2014 update. *Wilderness Environ Med*. 2014;25(4 Suppl):S55–65.

11. Noakes TD, Myburgh KH, du Plessis J, Lang L, Lambert M, van der Riet C, et al. Metabolic rate, not percent dehydration, predicts rectal temperature in marathon runners. *Med Sci Sports Exerc*. 1991;23(4):443–9.
12. Byrne C, Lee JK, Chew SA, Lim CL, Tan EY. Continuous thermoregulatory responses to mass-participation distance running in heat. *Med Sci Sports Exerc*. 2006;38 (5):803–10.
13. Veltmeijer MT, Eijsvogels TM, Thijssen DH, Hopman MT. Incidence and predictors of exertional hyperthermia after a 15-km road race in cool environmental conditions. *J Sci Med Sport*. 2015;18(3):333–7.
14. Lipman GS, Eifling KP, Ellis MA, Gaudio FG, Otten EM, Grissom CK. Keeping a broad perspective: reply regarding the Wilderness Medical Society practice guidelines for the prevention and treatment of heat-related illness. *Wilderness Environ Med*. 2014;25(2):251–2.
15. Nelson DA, Deuster PA, O'Connor FG, Kurina LM. Timing and predictors of mild and severe heat illness among new military enlistees. *Med Sci Sports Exerc*. 2018;50(8):1603–12.
16. Talbott JH, Michelsen J. Heat cramps. A clinical and chemical study. *J Clin Invest*. 1933;12(3):533–49.
17. Schwellnus MP. Cause of exercise associated muscle cramps (EAMC)—altered neuromuscular control, dehydration or electrolyte depletion? *Br J Sports Med*. 2009;43(6):401–8.
18. Costrini AM, Pitt HA, Gustafson AB, Uddin DE. Cardiovascular and metabolic manifestations of heat stroke and severe heat exhaustion. *Am J Med*. 1979;66(2):296–302.
19. Asplund CA, O'Connor FG, Noakes TD. Exercise-associated collapse: an evidence-based review and primer for clinicians. *Br J Sports Med*. 2011;45(14):1157–62.
20. Casa DJ, DeMartini JK, Bergeron MF, Csillan D, Eichner ER, Lopez RM, et al. National Athletic Trainers' Association Position Statement: exertional heat illnesses. *J Athl Train*. 2015;50(9):986–1000.
21. Backer HD, Shopes E, Collins SL, Barkan H. Exertional heat illness and hyponatremia in hikers. *Am J Emerg Med*. 1999;17(6):532–9.
22. Bouchama A, Knochel JP. Heat stroke. *N Engl J Med*. 2002;346(25):1978–88.
23. Sawka MN, Wenger CB. *Physiological Responses to Acute Exercise-Heat Stress*. Indianapolis, IN: Benchmark Press; 1988.
24. Rowell LB. Cardiovascular aspects of human thermoregulation. *Circ Res*. 1983;52(4):367–79.
25. Heller HC, Grahn DA. Enhancing thermal exchange in humans and practical applications. *Disrupt Sci Technol*. 2012;1(1):11–9.
26. Armstrong LE, Casa DJ, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc*. 2007;39(3):556–72.
27. Leon LR, Helwig BG. Heat stroke: role of the systemic inflammatory response. *J Appl Physiol (1985)*. 2010;109 (6):1980–8.
28. Sakaguchi Y, Stephens LC, Makino M, Kaneko T, Strebel FR, Danhauser LL, et al. Apoptosis in tumors and normal tissues induced by whole body hyperthermia in rats. *Cancer Res*. 1995;55(22):5459–64.
29. Buckley IK. A light and electron microscopic study of thermally injured cultured cells. *Lab Invest*. 1972;26 (2):201–9.
30. Eberman LE, Cleary MA. Development of a heat-illness screening instrument using the Delphi panel technique. *J Athl Train*. 2011;46(2):176–84.
31. Toloo GS, Fitzgerald G, Aitken P, Verrall K, Tong S. Are heat warning systems effective? *Environ Health*. 2013;12:27.
32. Pryor RR, Bennett BL, O'Connor FG, Young JM, Asplund CA. Medical evaluation for exposure extremes: heat. *Wilderness Environ Med*. 2015;26(4 suppl):S69–75.
33. Pandolf KB, Gange RW, Latzka WA, Blank IH, Kraning II KK, Gonzalez RR. Human thermoregulatory responses during heat exposure after artificially induced sunburn. *Am J Physiol*. 1992;262(4 Pt 2):R610–6.
34. Pandolf KB, Gange RW, Latzka WA, Blank IH, Young AJ, Sawka MN. Human thermoregulatory responses during cold water immersion after artificially induced sunburn. *Am J Physiol*. 1992;262(4 Pt 2):R617–23.
35. Glazer JL. Management of heatstroke and heat exhaustion. *Am Fam Physician*. 2005;71(11):2133–40.
36. Bruning RS, Dahmus JD, Kenney WL, Alexander LM. Aspirin and clopidogrel alter core temperature and skin blood flow during heat stress. *Med Sci Sports Exerc*. 2013;45(4):674–82.
37. Bedno SA, Li Y, Han W, Cowan DN, Scott CT, Cavicchia MA, et al. Exertional heat illness among overweight US army recruits in basic training. *Aviat Space Environ Med*. 2010;81(2):107–11.
38. Brazaitis M, Skurvydas A. Heat acclimation does not reduce the impact of hyperthermia on central fatigue. *Eur J Appl Physiol*. 2010;109(4):771–8.
39. Cheung SS, McLellan TM. Heat acclimation, aerobic fitness, and hydration effects on tolerance during uncompensable heat stress. *J Appl Physiol (1985)*. 1998;84 (5):1731–9.
40. Garrett AT, Goosens NG, Rehrer NJ, Patterson MJ, Cotter JD. Induction and decay of short-term heat acclimation. *Eur J Appl Physiol*. 2009;107(6):659–70.
41. Weller AS, Linnane DM, Jonkman AG, Daanen HA. Quantification of the decay and re-induction of heat acclimation in dry-heat following 12 and 26 days without exposure to heat stress. *Eur J Appl Physiol*. 2007;102 (1):57–66.
42. Daanen HA, Jonkman AG, Layden JD, Linnane DM, Weller AS. Optimising the acquisition and retention of heat acclimation. *Intl J Sports Med*. 2011;32(11):822–8.
43. Armstrong LE, De Luca JP, Hubbard RW. Time course of recovery and heat acclimation ability of prior exertional heatstroke patients. *Med Sci Sports Exerc*. 1990;22(1):36–48.
44. Kazman JB, Heled Y, Lisman PJ, Druyan A, Deuster PA, O'Connor FG. Exertional heat illness: the role of heat tolerance testing. *Curr Sports Med Rep*. 2013;12(2):101–5.
45. Johnson EC, Kolkhorst FW, Richburg A, Schmitz A, Martinez J, Armstrong LE. Specific exercise heat stress

protocol for a triathlete's return from exertional heat stroke. *Curr Sports Med Rep*. 2013;12(2):106–9.
46. Sharwood KA, Collins M, Goedecke JH, Wilson G, Noakes TD. Weight changes, medical complications, and performance during an Ironman triathlon. *Br J Sports Med*. 2004;38(6):718–24.
47. Wharam PC, Speedy DB, Noakes TD, Thompson JM, Reid SA, Holtzhausen LM. NSAID use increases the risk of developing hyponatremia during an Ironman triathlon. *Med Sci Sports Exerc*. 2006;38(4):618–22.
48. Maughan RJ, Watson P, Shirreffs SM. Heat and cold: what does the environment do to the marathon runner? *Sports Med*. 2007;37(4-5):396–9.
49. Wall BA, Watson G, Peiffer JJ, Abbiss CR, Siegel R, Laursen PB. Current hydration guidelines are erroneous: dehydration does not impair exercise performance in the heat. *Br J Sports Med*. 2015;49(16):1077–83.
50. Sawka MN, Latzka WA, Matott RP, Montain SJ. Hydration effects on temperature regulation. *Int J Sports Med*. 1998;19(Suppl 2):S108–10.
51. Sawka MN, Young AJ, Latzka WA, Neufer PD, Quigley MD, Pandolf KB. Human tolerance to heat strain during exercise: influence of hydration. *J Appl Physiol (1985)*. 1992;73(1):368–75.
52. Duffield R, Steinbacher G, Fairchild TJ. The use of mixed-method, part-body pre-cooling procedures for team-sport athletes training in the heat. *J Strength Cond Res*. 2009;23(9):2524–32.
53. Lemire B, Gagnon D, Jay O, Dorman L, DuCharme MB, Kenny GP. Influence of adiposity on cooling efficiency in hyperthermic individuals. *Eur J Appl Physiol*. 2008;104(1):67–74.
54. Tenaglia SA, McLellan TM, Klentrou PP. Influence of menstrual cycle and oral contraceptives on tolerance to uncompensable heat stress. *Eur J Appl Physiol Occup Physiol*. 1999;80(2):76–83.
55. Bergeron MF, Devore C, Rice SG. Policy statement—Climatic heat stress and exercising children and adolescents. *Pediatrics*. 2011;128(3):e741–e7.
56. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiol Rev*. 2002;24(2):190–202.
57. Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic factors in heat wave related deaths: a meta-analysis. *Arch Intern Med*. 2007;167(20):2170–6.
58. Nelson N, Eichna LW, Horvath SM, Shelley WB, Hatch TF. Thermal exchanges of man at high temperatures. *Am J Physiol*. 1947;151(2):626–52.
59. United States Department of the Navy, Bureau of Medicine and Surgery. *Manual of Naval Preventive Medicine (NAVMED P-5010-3)*. Washington, DC: Department of the Navy, US Department of Defense; 2009.
60. Occupational Health and Safety Administration. *OSHA Technical Manual (TED1-00-015)*. Washington, DC: Occupational Health and Safety Administration, US Department of Labor; 1999.
61. National Climactic Data Center. *Heat Index Charts*. Asheville, NC: National Oceanic and Atmospheric Administration, National Climactic Data Center; 2000.
62. Jackson LL, Rosenberg HR. Preventing heat-related illness among agricultural workers. *J Agromedicine*. 2010;15(3):200–15.
63. Armstrong LE, Johnson EC, Casa DJ, Ganio MS, McDermott BP, Yamamoto LM, et al. The American football uniform: uncompensable heat stress and hyperthermic exhaustion. *J Athl Train*. 2010;45(2):117–27.
64. Porter AM. Heat illness and soldiers. *Mil Med*. 1993;158(9):606–9.
65. Biery Jr JC, Blivin SJ, Pyne SW. Training in ACSM black flag heat stress conditions: how US marines do it. *Curr Sports Med Rep*. 2010;9(3):148–54.
66. Armstrong LE, Crago AE, Adams R, Roberts WO, Maresh CM. Whole-body cooling of hyperthermic runners: comparison of two field therapies. *Am J Emerg Med*. 1996;14(4):355–8.
67. Hadad E, Moran DS, Epstein Y. Cooling heat stroke patients by available field measures. *Intensive Care Med*. 2004;30(2):338.
68. Hadad E, Rav-Acha M, Heled Y, Epstein Y, Moran DS. Heat stroke: a review of cooling methods. *Sports Med*. 2004;34(8):501–11.
69. Shapiro Y, Seidman DS. Field and clinical observations of exertional heat stroke patients. *Med Sci Sports Exerc*. 1990;22(1):6–14.
70. Schwellnus MP, Derman EW, Noakes TD. Aetiology of skeletal muscle 'cramps' during exercise: a novel hypothesis. *J Sports Sci*. 1997;15(3):277–85.
71. Lugo-Amador NM, Rothenhaus T, Moyer P. Heat-related illness. *Emerg Med Clin North Am*. 2004;22(2):315–27. viii.
72. Canpolat U, Bayazit Y, Aytemir K. Brugada syndrome unmasked by heat exhaustion. *Ann Noninvasive Electrocardiol*. 2017;22(1).
73. Molina Borao I, Calvo Galiano N, Urmeneta Ulloa J, Rivero Fernandez E, Oloriz Sanjuan T, Asso Abadia A. Heat wave: a trigger of electrical storm in a patient with Brugada syndrome. *Rev Esp Cardiol (Engl Ed.)*. 2016;69(12):1228–30.
74. Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National Athletic Trainers' Association position statement: exertional heat illnesses. *J Athl Train*. 2002;37(3):329–43.
75. Casa DJ, Becker SM, Ganio MS, Brown CM, Yeargin SW, Roti MW, et al. Validity of devices that assess body temperature during outdoor exercise in the heat. *J Athl Train*. 2007;42(3):333–42.
76. Gonzalez-Alonso J, Calbet JA, Nielsen B. Metabolic and thermodynamic responses to dehydration-induced reductions in muscle blood flow in exercising humans. *J Physiol*. 1999;520(Pt 2):577–89.
77. Casa DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff RV, Rich BS, et al. National Athletic Trainers' Association position statement: fluid replacement for athletes. *J Athl Train*. 2000;35(2):212–24.

78. Lopez RM, Casa DJ, Jensen KA, DeMartini JK, Pagnotta KD, Ruiz RC, et al. Examining the influence of hydration status on physiological responses and running speed during trail running in the heat with controlled exercise intensity. *J Strength Cond Res*. 2011;25(11):2944–54.
79. Sawka MN. Physiological consequences of hypohydration: exercise performance and thermoregulation. *Med Sci Sports Exerc*. 1992;24(6):657–70.
80. Castellani JW, Maresh CM, Armstrong LE, Kenefick RW, Riebe D, Echegaray M, et al. Intravenous vs. oral rehydration: effects on subsequent exercise-heat stress. *J Appl Physiol (1985)*. 1997;82(3):799–806.
81. Epstein Y, Shani Y, Moran DS, Shapiro Y. Exertional heat stroke—the prevention of a medical emergency. *J Basic Clin Physiol Pharmacol*. 2000;11(4):395–401.
82. Hostler D, Reis SE, Bednez JC, Kerin S, Suyama J. Comparison of active cooling devices with passive cooling for rehabilitation of firefighters performing exercise in thermal protective clothing: a report from the Fireground Rehab Evaluation (FIRE) trial. *Prehosp Emerg Care*. 2010;14(3):300–9.
83. Hew-Butler T, Rosner MH, Fowkes-Godek S, Dugas JP, Hoffman MD, Lewis DP, et al. Statement of the Third International Exercise-Associated Hyponatremia Consensus Development Conference, Carlsbad, California, 2015. *Clin J Sport Med*. 2015;25(4):303–20.
84. McArdle WD, Magel JR, Lesmes GR, Pechar GS. Metabolic and cardiovascular adjustment to work in air and water at 18, 25, and 33 degrees C. *J Appl Physiol*. 1976;40(1):85–90.
85. Noakes TD. Body cooling as a method for reducing hyperthermia. *S Afr Med J*. 1986;70(6):373–4.
86. Proulx CI, Ducharme MB, Kenny GP. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol (1985)*. 2003;94(4):1317–23.
87. Cooper KE. Physiology of hypothermia. *Br J Anaesth*. 1959;31(3):96–105.
88. Proulx CI, Ducharme MB, Kenny GP. Safe cooling limits from exercise-induced hyperthermia. *Eur J Appl Physiol*. 2006;96(4):434–45.
89. Wyndham CH, Strydom NB, Cooke HM, Maritz JS, Morrison JF, Fleming PW, et al. Methods of cooling subjects with hyperpyrexia. *J Appl Physiol*. 1959;14:771–6.
90. Ferris EB, Blankenhorn MA, Robinson HW, Cullen GE. Heat stroke: clinical and chemical observations on 44 cases. *J Clin Invest*. 1938;17(3):249–62.
91. Casa DJ, McDermott BP, Lee EC, Yeargin SW, Armstrong LE, Maresh CM. Cold water immersion: the gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev*. 2007;35(3):141–9.
92. O'Connor JP. Simple and effective method to lower body core temperatures of hyperthermic patients. *Am J Emerg Med*. 2017;35(6):881–4.
93. Costrini A. Emergency treatment of exertional heatstroke and comparison of whole body cooling techniques. *Med Sci Sports Exerc*. 1990;22(1):15–8.
94. Khogali M, Weiner JS. Heat stroke: report on 18 cases. *Lancet*. 1980;2(8189):276–8.
95. Khogali M, al Khawashi M. Heat stroke during the Makkah pilgrimage. *Saudi Med J*. 1981;2:85–93.
96. Al-Aska AK, Abu-Aisha H, Yaqub B, Al-Harthi SS, Sallam A. Simplified cooling bed for heatstroke. *Lancet*. 1987;1(8529):381.
97. Hee-Nee P, Rupeng M, Lee VJ, Chua WC, Seet B. Treatment of exertional heat injuries with portable body cooling unit in a mass endurance event. *Am J Emerg Med*. 2010;28(2):246–8.
98. Platt M, Vicario S. *Rosen's Emergency Medicine*. 7th ed. Philadelphia, PA: Mosby; 2009.
99. Kielblock AJ, Van Rensburg JP, Franz RM. Body cooling as a method for reducing hyperthermia. An evaluation of techniques. *S Afr Med J*. 1986;69(6):378–80.
100. Richards D, Richards R, Schofield PJ, Ross V, Sutton JR. Management of heat exhaustion in Sydney's the Sun City-to-Surf run runners. *Med J Aust*. 1979;2(9):457–61.
101. Phan S, Lissoway J, Lipman GS. Chemical cold packs may provide insufficient enthalpy change for treatment of hyperthermia. *Wilderness Environ Med*. 2013;24(1):37–41.
102. Lissoway JB, Lipman GS, Grahn DA, Cao VH, Shaheen M, Phan S, et al. Novel application of chemical cold packs for treatment of exercise-induced hyperthermia: a randomized controlled trial. *Wilderness Environ Med*. 2015;26(2):173–9.
103. Saper CB, Breder CD. Endogenous pyrogens in the CNS: role in the febrile response. *Prog Brain Res*. 1992;93:419–28. discussion 428–9.
104. Downey JA, Darling RC. Effect of salicylates on elevation of body temperature during exercise. *J Appl Physiol*. 1962;17:323–5.
105. Johnson SC, Ruhling RO. Aspirin in exercise-induced hyperthermia. Evidence for and against its role. *Sports Med*. 1985;2(1):1–7.
106. Beller GA, Boyd 3rd AE. Heat stroke: a report of 13 consecutive cases without mortality despite severe hyperpyrexia and neurologic dysfunction. *Mil Med*. 1975;140(7):464–7.
107. Demartini JK, Casa DJ, Stearns R, Belval L, Crago A, Davis R, et al. Effectiveness of cold water immersion in the treatment of exertional heat stroke at the Falmouth Road Race. *Med Sci Sports Exerc*. 2015;47(2):240–5.
108. O'Donnell Jr TF. Acute heat stroke. Epidemiologic, biochemical, renal, and coagulation studies. *JAMA*. 1975;234(8):824–8.
109. Bouchama A, Dehbi M, Chaves-Carballo E. Cooling and hemodynamic management in heatstroke: practical recommendations. *Crit Care*. 2007;11(3):R54.
110. Hart GR, Anderson RJ, Crumpler CP, Shulkin A, Reed G, Knochel JP. Epidemic classical heat stroke: clinical characteristics and course of 28 patients. *Medicine (Baltimore)*. 1982;61(3):189–97.
111. Gagnon D, Lemire BB, Casa DJ, Kenny GP. Cold-water immersion and the treatment of hyperthermia: using 38.6°C

as a safe rectal temperature cooling limit. *J Athl Train*. 2010;45(5):439–44.
112. Newsham KR, Saunders JE, Nordin ES. Comparison of rectal and tympanic thermometry during exercise. *South Med J*. 2002;95(8):804–10.
113. Smith JE. Cooling methods used in the treatment of exertional heat illness. *Br J Sports Med*. 2005;39(8):503–7. discussion 507.
114. Horowitz BZ. The golden hour in heat stroke: use of iced peritoneal lavage. *Am J Emerg Med*. 1989;7(6):616–9.
115. Yokobori S, Koido Y, Shishido H, Hifumi T, Kawakita K, Okazaki T, et al. Feasibility and safety of intravascular temperature management for severe heat stroke: a prospective multicenter pilot study. *Crit Care Med*. 2018;46(7):e670–6.
116. Bouchama A, Cafege A, Devol EB, Labdi O, el-Assil K, Seraj M. Ineffectiveness of dantrolene sodium in the treatment of heatstroke. *Crit Care Med*. 1991;19(2):176–80.

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WILDERNESS MEDICAL SOCIETY CLINICAL PRACTICE GUIDELINES

# Wilderness Medical Society Clinical Practice Guidelines for the Treatment and Prevention of Drowning: 2019 Update

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The Wilderness Medical Society convened a panel to review available evidence supporting practices for acute management and treatment of drowning in out-of-hospital and emergency medical care settings. Literature about definitions and terminology, epidemiology, rescue, resuscitation, acute clinical management, disposition, and drowning prevention was reviewed. The panel graded available evidence supporting practices according to the American College of Chest Physicians criteria and then made recommendations based on that evidence. Recommendations were based on the panel's collective clinical experience and judgment when published evidence was lacking. This is the first update to the original practice guidelines published in 2016.

*Keywords:* submersion, immersion, cold water submersion, hypothermia

## Introduction

Approximately 360,000 deaths globally are attributed to drowning every year.[1] Drowning often affects young victims and can have dire personal, emotional, and financial consequences for patients, families, and society. The goal of these practice guidelines is to reduce the burden of drowning through improvements in treatment and prevention. We present accepted drowning terminology as part of a review and evaluation of literature regarding acute care for the drowning patient, in both out-of-hospital and emergency medical care settings, with particular focus on the wilderness context. The authors relied upon the experience and knowledge of a panel of wilderness and emergency medicine practitioners to make recommendations where little or unreliable evidence is available.[2] This is the first update of the original publication from 2016.[3]

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## Methods

The authors of this update reviewed each section of the original document to determine relevance and need for updating. Articles were identified through PubMed, MEDLINE, and Google Scholar using a keyword search appropriate to each topic. Randomized controlled trials, observational studies, case series, and review articles were reviewed and evidence assessed. Abstracts for which the full article could not be obtained were excluded. If no relevant studies were identified, recommendations were based on the panel's clinical experience and judgment. Recommendations were graded using the American College of Chest Physicians classification scheme (see online Supplemental Table 1), in accordance with prior versions of the Wilderness Medical Society Practice Guidelines.[4]

## Epidemiology

The highest-risk age group for drowning worldwide is children ages 1 to 4 y, primarily owing to unintentional falls into water; the next highest-risk group is adolescents and

young adults in natural bodies of water. In the United States, there was on average 3536 drowning deaths per year from 2005 to 2014, plus an additional 679 boating-related deaths, 75% of which were from drowning.[5,6] More than 90% of the world's drowning deaths occur in low- and middle-income countries.[1] In the context of low- and middle-income countries, natural sources of water are often ubiquitous and used for transportation, cleaning, food, and hydration and lack barriers. Based on World Health Organization and Centers for Disease Control and Prevention systems for classifying drowning statistics, these numbers exclude deaths occurring during floods and other natural disasters. In 2010, there were 12,900 emergency department (ED) visits in the United States for drowning, with 20.3% of patients admitted to the hospital. Drowning deaths were 48% more likely to occur on weekends compared to weekdays. Fifty-three percent of all male and 26% of all female drowning deaths occurred in natural bodies of water.[5]

The burden of drowning is underreported because most studies address the issue of fatal drowning. In the United States, a conservative estimate is that for every fatal drowning, another 5 persons seek emergency care for nonfatal drowning.[5] Internationally, the burden of nonfatal drowning is more difficult to estimate because many patients may not present to an emergency medical system or hospital, where data collection typically occurs.[5,7,8] In Bangladesh, a large population-based study showed fatal and nonfatal drowning rates of 15.8 per 100,000 and 318.4 per 100,00 compared to 1.17 per 100,000 and 10 per 100,000 in the United States.[9,10] Risk factors for nonfatal drowning are similar to those for fatal drowning.[9,11–15]

## Terminology

The standard definition for drowning, as defined by the World Congress on Drowning in 2002, is "the process of experiencing respiratory impairment due to submersion or immersion in liquid." Inspired by the Utstein Style for reporting cardiac arrest data, the standard definition allows for only 3 outcomes after drowning: 1) morbidity; 2) no morbidity; and 3) mortality. This definition is based on the understanding that "respiratory impairment occurs as the person's airway goes below the surface of the liquid (submersion) or water splashes over the face (immersion)."[16] However, the inclusion of both submersion and immersion in this definition may cause confusion with the large body of work on survival and rescue related specifically to cold water immersion, which focuses more on hypothermia than on drowning. For the purposes of these guidelines, which could include cold water conditions, a further distinction is necessary. "Immersion" refers to situations in which airways are above water, whereas "submersion" refers to situations in which airways are under water. Thus immersion (in cold water) may lead to hypothermia, and submersion at any water temperature may lead to drowning. The following modifiers should *not* be used in association with drowning: near, wet, dry, active, passive, saltwater, freshwater, or secondary. Sufficient data related to human drowning pathophysiology show that none of these modifiers is valid because the final common pathway is hypoxemia and eventual cardiopulmonary arrest.[2,16,17] By understanding and using the standard definition for drowning and abstaining from using incorrect terminology, communication among medical practitioners, data collection agencies, researchers, and policymakers has become more consistent. Accurate communication better reflects the true incidence, prevalence, and sequelae of drowning and should improve clinical dialogue and management.[18–20]

## Rescue of the Drowning Patient

### REACHING THE PATIENT

Rescuer safety is paramount during rescue operations; in the aquatic environment, specific skills, training, and physical capabilities are required. The physical characteristics of aquatic environments vary widely, with a spectrum including pools, lakes, rivers, ocean, swift river water, and ice scenarios, each requiring different sets of equipment and training for technical rescue. Few studies objectively measure effectiveness of in-water rescue techniques. Much of the literature on this topic is based on experiences and policies of the writers or organizational authorities. There is a high prevalence of fatal and nonfatal drowning of untrained persons attempting to perform in-water rescues, with 1 study revealing 114 rescuer deaths during a 3-y period in Turkey alone.[21–23] Hazardous water conditions that led to the initial person drowning often persist and place the well-intentioned rescuer at risk for becoming an additional drowning patient.[24] Rescue by untrained persons should be attempted without entering hazardous conditions by reaching out to the drowning patient with a paddle or branch; throwing a rope, buoy, cooler, or any floating object; or rowing a boat, canoe, or paddleboard to the patient. Trained rescue personnel should operate according to their level of training, expertise, equipment, and comfort level. Entering the water to perform a rescue should be attempted only by persons with specific training to operate in that dangerous environment. Few studies have been conducted on the effectiveness of different water safety devices (eg, rescue tubes, rescue cans, throw bags, life rings), but what has been demonstrated is that proper and effective use of these devices requires basic knowledge of their function combined with regular practice.[25]

***Recommendation.*** Persons without formal water rescue training should attempt rescues from a safe location by reaching, throwing, or rowing to the drowning patient. Persons with formal water rescue training should perform in-water rescues according to their level of training and with personal protective and safety equipment. There is insufficient evidence to recommend specific rescue devices. If specialized rescue equipment is available, participants should be familiar with the location and purpose of this equipment, and designated rescue personnel with proper training should be tasked with its use in the event of a water rescue. **Recommendation Grade:** 1C[26–28]

## PATIENTS IN SUBMERGED VEHICLES

Death from entrapment and drowning in submerged vehicles is often not classified as a drowning death, confounding attempts to accurately track the epidemiology of this type of drowning.[29] Studies suggest that 10% of drowning deaths may be due to entrapment in submerged vehicles and that in the case of inland flooding as much as 10% of motor vehicle crashes result in a drowning death.[30–33] There is a small body of medical and rescue literature on the topic of vehicle submersions.[31,34–39] A formal review of educational and public service information identified "three probable significant contributors to [the] high fatality rate [of drowning in submerged vehicles]: 1) 'authorities' provide an inadequate description of vehicle sinking characteristics; 2) contradictory and inadequate advice is often provided; and 3) a poor public perception of how to escape."[34] Several sources recommend questionable escape practices without supporting evidence for efficacy. These practices include allowing the passenger compartment to fill with water so that it will be easier to open doors, waiting until the vehicle sinks to the bottom of a body of water to maintain orientation, relying on kicking out the windshield or opening doors after the vehicle has fully sunk, and relying on breathing trapped air in the passenger compartment. In a formal survey, more than half of the general public identify an option that involves staying in a vehicle while it sinks to the bottom as being the safest option when trapped in a submerging vehicle; this advice often appears in the popular media.[38] Research data derived from 35 vehicle submersions conducted in diverse locations and seasons suggest that this advice is erroneous. Evidence suggests the best time to escape from a submerging vehicle is immediately during the initial floating phase, ideally during the initial 30 s to 2 min after water entry when most vehicles remain partially above the surface.[38] An algorithm, using the acronym SWOC, has been developed to advise those entrapped in water how to sequence escape actions. The SWOC algorithm recommends the following sequencing of actions: Seatbelts off, Window open, Out immediately, Children first.[39] In 2008, a US-based proprietary out-of-hospital emergency medical dispatcher system added an addendum to its standardized protocols that instructed emergency medical dispatchers not to persist in getting a location for a caller in a submerging vehicle. Instead, it recommends that a caller exit the vehicle immediately if it is submerging, before using precious time to determine location, and using the SWOC protocol.[40,41]

***Recommendation.*** The safest time to escape from a submerging vehicle is immediately after it enters the water, during the initial floating phase. If the vehicle remains floating, persons should climb out and remain on top of the vehicle. If it is sinking, they should move away from the vehicle and toward safety after exiting. **Recommendation Grade:** 2C

## IN-WATER RESUSCITATION

The primary physiologic insult in a drowning patient is cerebral hypoxia; its rapid reversal is the primary objective of drowning resuscitation. For the purpose of these guidelines, in-water resuscitation (IWR) is defined as an attempt to provide ventilations to a drowning patient who is still in the water. This does not apply to chest compressions. It is impossible to perform adequate chest compressions while the victim and rescuer are in the water, and so they should not be attempted.[42] Successful use of IWR was first described in 1976, with a manikin-based feasibility study reported in 1980; however, the first clinical study to show a positive patient outcome was not published until 2004.[43–45]

Available outcome data for IWR are based on a single retrospective analysis of lifeguard rescues in Brazil and show significant improvement in survival and neurologic outcome in persons receiving IWR. These rescues were performed by trained, professional lifeguards in the ocean environment. Lifeguards would frequently tow the patient beyond breaking waves and perform mouth-to-mouth ventilations while awaiting helicopter pickup.[45] Subsequent studies, primarily using manikins, evaluated ease of performing this task in controlled aquatic environments and found that IWR increases overall rescue time, subjective rescue difficulty, number of submersions, and water aspiration.[46,47] A single study comparing lifeguards to lay rescuers when using IWR found that lifeguards showed improved rescue times and decreased estimated pulmonary aspiration.[48] Consensus statements from the International Lifesaving Federation, United States Lifesaving Association, American Red Cross, and the Young Men's Christian Association recommend IWR by trained rescuers when a patient is rescued in shallow water or in deep water when a flotation device is present.[49,50]

Rescuer safety and prevention of communicable diseases are of utmost importance, so consideration should be given to the use of barrier devices during IWR. Food and Drug Administration—approved, IWR-specific devices are available that use a self-purging mechanical one-way valve instead of the paper valve on standard CPR masks.[51,52]

***Recommendation.*** IWR should only be considered by a rescuer with adequate training, ability, and equipment to safely and effectively perform the skill in the aquatic environment. The aquatic conditions must be sufficiently safe for the rescuer to perform IWR, and the point of extrication from the water must be sufficiently distant to warrant an attempt of this technically difficult task. If conditions are too hazardous to safely perform the task, rapid extrication is indicated without a delay for IWR. Chest compressions should not be attempted in the water; all drowning patients without a pulse should be extricated as quickly and safely as possible so that early, effective chest compressions and ventilations can be initiated. **Recommendation Grade:** 1C

## Initial Resuscitation

### HYPOTHERMIA

Water is thermally neutral at approximately 33°C (91°F). Because most patients drown in water at a lower temperature than this, concomitant hypothermia is common.[30] The main physiologic problem with drowning is brain hypoxia. Current practice suggests that the brain can withstand longer periods of hypoxia if the body is cooler than the normal physiologic range. On one hand, leaving a patient moderately cool, or warming them to a moderately cool degree, could be beneficial or at least innocuous. On the other hand, moderate to severe hypothermia should be corrected, with the understanding that warming may be operationally difficult in some drowning situations. Beyond initiation of basic warming measures, the details of hypothermia treatment, including augmented advanced life support measures, are beyond the scope of these guidelines. Readers are encouraged to review the most current version of the Wilderness Medical Society Practice Guidelines for the Out-of-hospital Evaluation and Treatment of Accidental Hypothermia.[53]

***Recommendation.*** Suspect and treat hypothermia. **Recommendation Grade:** 1C

### CARDIOPULMONARY RESUSCITATION AND PRIORITIZATION OF AIRWAY

Because of the central role of hypoxemia in the pathophysiology of drowning, initial resuscitation should focus on establishing and maintaining a patent airway and providing oxygen. Recent updates to cardiopulmonary resuscitation (CPR) algorithms, specifically for the lay rescuer, include recommendations for compression-only CPR and prioritization of compressions before airway maneuvers.[54,55] Compression-only CPR is likely to be of little to no benefit in drowning resuscitation, and its use is limited to untrained bystanders. Bystander CPR for infants and children includes compressions and ventilations, regardless of which is started first. Professional rescuer CPR should emphasize prioritization of airway and breathing before initiation of chest compressions. If the airway is overlooked in initial resuscitation, ongoing hypoxemia leads to decreased survival and worse neurologic outcomes. Incorrect application of rescue breaths can delay care and cause gastric insufflation and pulmonary aspiration. For lay responders or persons without current training in rescue breathing, compression-only CPR is still the preferred method of resuscitation. All persons who may respond to a drowning person (eg, parents, trip leaders, lifeguards) should take CPR classes that include training on proper use of chest compressions and rescue breathing.

***Recommendation.*** Supplying oxygen to the brain is critical to successful resuscitation of the drowning patient. Establishing an airway and providing oxygen are priorities in initial resuscitation. For the patient in cardiac arrest, provide positive pressure ventilations in addition to chest compressions using the traditional Airway-Breathing-Circulation model of resuscitation. If an advanced airway is available and properly placed, provide breaths at specified time intervals (every 6 to 8 s) while continuous compressions are administered. For lay people without training in rescue breathing, compression-only CPR is a preferred alternative to no intervention. **Recommendation Grade:** 1C

### OXYGENATION

Few large-scale studies have evaluated different airway adjuncts applied to drowning patients. Although ideal rescue breathing includes supplemental oxygen and a positive pressure delivery device, any amount of oxygen delivery (eg, mouth-to-mouth, bag-valve-mask [BVM] with ambient air) is better than none if supplemental oxygen is not available. Manikin studies of supraglottic airways have shown that lifeguards can successfully insert them, but there is concern that this does not replicate real world usage.[56,57] Additional concern is that because of pulmonary edema from drowning, certain supraglottic airway devices may perform poorly for oxygenation based on leak pressures.[58,59] If the supraglottic airway fails to achieve

adequate chest rise, a BVM or other method to oxygenate and ventilate the patient should be used.

Recent resuscitation data have brought into question the benefit of providing high oxygen concentrations in the acute setting of out-of-hospital cardiac arrest and stroke, primarily based on data correlating hyperoxemia after return of spontaneous circulation (ROSC) with increased mortality. Most of these data focus on the period after ROSC in the intensive care unit setting; no studies focus specifically on cardiac arrest associated with drowning or other primary respiratory events. A single retrospective case-control study involving arterial blood analysis during CPR provides support for using high levels of supplemental oxygen. This study showed a significant increase in survival to hospital discharge with increasing levels of arterial oxygenation in all cardiac arrest patients, even at levels that would be considered hyperoxemic.[60]

***Recommendation.*** When resuscitating a drowning patient, oxygen should initially be delivered at the highest concentration available. For the patient in respiratory distress or arrest, positive pressure is preferred over passive ventilation. If multiple modalities are available, the method that most effectively delivers the highest concentration of oxygen should be used. If a modality or device fails, BVM or mouth-to-mouth ventilation should be attempted. **Recommendation Grade:** 1C

## AUTOMATED EXTERNAL DEFIBRILLATOR

Although cerebral hypoxia is the primary cause of morbidity in the drowning patient, hypoxic myocardial injury might also occur. Drowning patients initially typically experience sinus tachycardia, followed by bradycardia, pulseless electrical activity, and then asystole, owing to the hypoxic nature of the event.[61] In drowning patients, ventricular fibrillation (VF) is rare, occurring in less than 10% of patients; thus, reversal of hypoxemia with ventilations and compressions should not be delayed in an attempt to apply an automated external defibrillator (AED).[61–67] Once resuscitation is established, early application of an AED might be beneficial, given the possibility of VF as the cause or result of drowning. In the drowning patient, if global myocardial hypoxia persists, attempts at defibrillation may be unsuccessful without concomitant oxygenation and ventilation.

Experimental animal models have shown that as long as AED pads are placed firmly on a patient's chest and a rescuer is not in direct contact with that patient, use of an AED in a wet environment does not pose increased risk to the patient or rescuers.[68–70] AEDs have been tested and noted to correctly detect simulated arrhythmias and deliver shocks on moving boats.[71]

***Recommendation.*** VF is rare in drowning, so incorporation of an AED in the initial minutes of drowning resuscitation should not interfere with oxygenation and ventilation. If available, an AED should be used during resuscitation of a drowning patient; its use is not contraindicated in a wet environment. **Recommendation Grade:** 1A

## HEIMLICH MANEUVER

Drowning involves water obstructing the airway and causing cerebral hypoxia; in some cases, small amounts of water are aspirated into the lungs. This can cause atelectasis, direct cellular injury, and pulmonary edema. Even after unconsciousness, reflex swallowing of water from the hypopharynx into the stomach may occur. Dr Henry Heimlich advocated use of abdominal thrusts in initial treatment of the drowning patient, claiming that aspirated water must first be cleared from the airway to allow proper ventilations.[72–74] In the 30 y since his original report, concern has been raised about this recommendation, resulting in an Institute of Medicine report and a systematic literature review by the American Red Cross.[75,76] All of these investigations failed to identify quality data to support use of the Heimlich maneuver before providing ventilations. Its use during initial resuscitation delays delivery of ventilations and prolongs hypoxemia.[75]

***Recommendation.*** Owing to the possibility of delaying ventilations, the Heimlich maneuver is not recommended for resuscitation of the drowning patient. **Recommendation Grade:** 1B

## CERVICAL SPINE PRECAUTIONS

Recent discussions and research in the field of out-of-hospital medicine have brought in to question the utility, safety, and clinical benefit of what has been called routine spine immobilization. The most current published review of this topic specific to austere environments is the Wilderness Medical Society Clinical Practice Guidelines for Spinal Cord Protection: 2019 Update.[77] We recommend reviewing the updated guidelines for current evidence on the utility of this procedure.

Retrospective studies of drowning patients found the incidence of cervical spine injuries was low (0.5–5%) and that most injuries were related to diving from a height. In patients without obvious signs of trauma or a known fall or diving event, the risk of spine injury is low.[78,79] In these patients, treatment maneuvers focused on restricting spine motion may distract rescuers from the critical role of oxygenation and ventilation.

***Recommendation.*** The most current Wilderness Medical Society Practice Guidelines concerning the field treatment of possible spinal injuries should be reviewed when developing or reviewing agency protocols. Drowning patients who display evidence of spine injury, such as focal neurologic deficit, have a history of high-risk activity, or exhibit altered mental status are considered to be at a higher risk for spine injury. This does not include patients with altered mental status who were witnessed to have no trauma as an inciting event. Treatment considerations for this population should be carried out in accordance with the most current version of Wilderness Medical Society Clinical Practice Guidelines for Spinal Cord Protection. **Recommendation Grade:** 1C

## Postresuscitation Management

### OXYGENATION/VENTILATION

#### *Mechanical ventilation*

No literature is available comparing out-of-hospital or in-hospital mechanical ventilation strategies for the drowning patient. Current practice recommends a lung protective ventilation strategy similar to that used for patients with acute respiratory distress syndrome (ARDS), on the premise that the lung injury pattern after drowning is similar.[16,80,81] This includes mechanical ventilation starting with a tidal volume ($V_T$) of 6 to 8 $mL \cdot kg^{-1}$, augmentation of $V_T$ and respiratory rate to maintain plateau pressure $<30$ mm Hg, and augmentation of positive end expiratory pressure and fraction of inspired oxygen ($F_IO_2$) to maintain partial pressure of arterial oxygen ($P_aO_2$) at 55 to 80 mm Hg.[82]

***Recommendation.*** Mechanical ventilation for the drowning patient should follow ARDS protocols. **Recommendation Grade:** 1C

#### *Noninvasive positive pressure ventilation*

Noninvasive positive pressure ventilation (NIPPV) has been used successfully in the out-of-hospital setting. There are case reports describing its successful use in drowning.[83–86] Similar to invasive ventilation, the addition of airway pressure to prevent atelectasis and support respiratory muscle use while preventing hypoxemia can be achieved with NIPPV. However, caution should be used with NIPPV in the drowning patient with altered mental status because there may be increased risk of vomiting and aspiration. Drowning patients who have mild to moderate hypoxemia and are being treated in out-of-hospital and emergency medical systems using NIPPV might benefit from this therapy. One small retrospective study showed similar neurologic outcomes and correction of hypoxemia and acidosis between patients treated with early endotracheal intubation versus NIPPV after drowning; in addition, patients receiving NIPPV had a lower incidence of infection and decreased hospital and intensive care unit length of stay.[87]

***Recommendation.*** NIPPV may be usd in the alert drowning patient with mild to moderate respiratory symptoms. Caution should be taken with any patient displaying altered mental status and/or active emesis owing to the potential for aspiration. **Recommendation Grade:** 2C

## Diagnostics

### RADIOLOGIC TESTING

Several retrospective ED studies of drowning patients found that the initial chest radiograph did not correlate with arterial blood gas levels, outcome, or disposition.[88–90] A study of admitted drowning patients showed that those who went on to develop acute lung injury or ARDS had abnormal chest radiograph findings within the first few hours, but not necessarily on arrival to the ED.[80] Head computed tomography (CT) has been studied in an attempt to quantify anoxic brain injury in drowning patients. Retrospective studies have found that patients with abnormal initial CT all went on to develop severe brain injury or die, whereas initially normal head CT had no prognostic value.[91]

***Recommendation.*** Initial chest radiograph findings do not correlate with arterial blood gas measurements or outcome; x-rays may be useful in tracking changes in patient condition, but not for determining prognosis if obtained at the time of presentation. A normal initial head CT does not have prognostic value in the drowning patient. Routine use of neuroimaging in the awake and alert drowning patient is not recommended unless dictated by a change in clinical status. **Recommendation Grade:** 1C

### LABORATORY TESTING

Canine studies performed in the 1960s showed clinically significant hemodilution and red blood cell lysis associated with salt, chlorine, and freshwater drowning.[92–94] These studies were based on instilling up to 44 $mL \cdot kg^{-1}$ of fluid into the trachea of anesthetized dogs, far greater than the 1 to 3 $mL \cdot kg^{-1}$ typically aspirated by human drowning patients. Electrolyte abnormalities and hemodilution only occurred in dogs that had 11 $mL \cdot kg^{-1}$ or more instilled. No studies have identified clinically significant electrolyte

or hematologic abnormalities in drowning patients that help guide initial therapy or provide prognostic information. In patients with altered mental status or decreased level of consciousness, laboratory evaluation for alternative causes that might have led to the drowning event, such as hypoglycemia or intoxication, can be helpful. Arterial blood gas analysis in symptomatic patients can be used to help guide respiratory resuscitation.

***Recommendation.*** Routine use of complete blood count or electrolyte testing in the drowning patient is not recommended. Arterial blood gas testing in patients with evidence of hypoxemia or respiratory distress (eg, cyanosis, low oxygen saturation, tachypnea, persistent tachycardia) may be indicated to guide respiratory interventions. For patients whose mental status fails to respond to resuscitation or in whom the initial cause of submersion is unknown, laboratory testing for causes of altered mental status or any inciting event should be considered. **Recommendation Grade:** 1C

## Other Treatments

### ANTIBIOTICS

Although microorganisms present in aspirated water may eventually cause pneumonia, no study to date has shown benefit from empiric administration of antibiotics in drowning patients. This is in part because microorganisms found in drowning-associated pneumonia are atypical bacteria or fungi and often are resistant to standard empiric treatments.[95–97] Aspiration of even small volumes of water can produce abnormalities on chest radiograph that can mimic pneumonia. The trauma of the drowning event and hypoxemia can cause leukocytosis from stress demargination as well as fever from inflammation and irritation caused by water in the airways, making it difficult to differentiate inflammatory from infectious pneumonitis.[98] The decision to administer antibiotics should be made after initial resuscitation and ideally be based on expectorated sputum or endotracheal aspirate bacterial culture, blood cultures, or urinary antigen tests.[95–97] Because these tests are not available in the wilderness setting, treatment should be initiated for symptoms consistent with pulmonary infection (eg, fever, increased sputum, abnormal lung auscultation) that continue after initial resuscitation and treatment phases.

***Recommendation.*** There is no evidence to support empiric antibiotic therapy in the initial treatment of drowning patients. After initial resuscitation, if pneumonia is present, treatment should be guided by expectorated sputum or endotracheal aspirate bacterial culture, blood cultures, or urinary antigen tests. In the absence of these tests, decision to treat should be based on clinical examination focusing on physical evidence of pulmonary or systemic infection (eg, fever, increased sputum, abnormal lung auscultation). **Recommendation Grade:** 1A

### CORTICOSTEROIDS

Corticosteroids were historically used in drowning patients to facilitate pulmonary recovery and surfactant production. However, there is not sufficient evidence to support empiric corticosteroid administration for drowning patients.[99]

***Recommendation.*** Given limited data, corticosteroids should not be routinely administered specifically for treatment of drowning patients. **Recommendation Grade:** 1C

### THERAPEUTIC HYPOTHERMIA

Mild therapeutic hypothermia (TH) has been shown to decrease cerebral oxygen utilization and improve neurologically intact survival in patients with witnessed VF cardiac arrest.[81] Current American Heart Association/International Liaison Committee on Resuscitation guidelines recommend targeted temperature management for adults after cardiac arrest, at a temperature between 32 and 34°C for at least 24 h.[100] Many institutions have extrapolated these data to include non-VF causes of cardiac arrest.

The 2002 World Congress on Drowning provided a consensus statement recommending TH of 32 to 34°C (90−93°F) for patients achieving ROSC after cardiac arrest due to drowning.[101] Our literature search yielded multiple case reports and retrospective reviews supporting neurologically intact survival in hypothermic patients, but several older studies showed no benefit.[102–114] There is no prospective study comparing TH to normothermia after ROSC in drowning patients. There might be benefit to discontinuing rewarming interventions after a hypothermic drowning patient has reached TH temperature range, but this has been insufficiently studied to support an evidence-based recommendation.

***Recommendation.*** Although current literature recommend targeted temperature management in postcardiac arrest care, there is insufficient evidence to either support or discourage induction or maintenance of TH in drowning patients. **Recommendation Grade:** 2C

## Disposition in the Wilderness

### DECISION TO EVACUATE

If a patient survives a drowning event in the wilderness, objective physical examination findings may assist in the decision to evacuate the patient to advanced medical care. A single large retrospective study of nearly 42,000 ocean lifeguard rescues serves as the primary evidence for on-scene decision-making.[115] This study found that patients who experienced a drowning event but had no symptoms other than mild cough and who did not have abnormal lung sounds had 0% mortality. As symptoms worsened and abnormal lung sounds appeared, mortality increased. Hypotension (systolic blood pressure $<90$ mm Hg or mean arterial pressure $<60$ mm Hg) accounted for the next largest increase in mortality (Table 1). In a retrospective study of children who experienced nonfatal drowning, any clinical deterioration occurred within the first 4 h in patients presenting with mild symptoms and Glasgow Coma Scale score $\geq 13$.[88] These findings are similar to those from another retrospective study of pediatric patients in which new symptom development after arrival to the hospital occurred within 4.5 h in all but 1 patient; the 1 outlier developed symptoms in 7 h and had a good outcome.[116] Additional recent emergency department studies are discussed in the *Disposition in Emergency Department* section of these guidelines. These studies revealed similar results in the fact that clinical decompensation, if present, occurred in the first few hours of observation.[26]

***Recommendation:***

1. Any patient with abnormal lung sounds, severe cough, frothy sputum, foamy material in the airway, depressed mentation, or hypotension warrants immediate evacuation to advanced medical care if risks of evacuation do not outweigh potential benefit.
2. Any patient who is asymptomatic (other than a mild cough) and displays normal lung auscultation may be considered for release from the scene. Ideally, another individual should be with them for the next 4 to 6 h to monitor for symptom development or the patient should be advised to seek medical assistance if symptoms develop.
3. If evacuation is difficult or may compromise the overall expedition, patients with mild symptoms and normal mentation should be observed for 4 to 6 h. Any evidence of decompensation warrants prompt evacuation if the risks of evacuation do not outweigh the potential benefit.
4. If evacuation of a mildly symptomatic patient has begun and the patient becomes asymptomatic for 4 to 6 h, canceling further evacuation and continuing previous activity may be appropriate.

**Recommendation Grade:** 1C

### CEASING WATER-BASED RESCUE AND RESUSCITATION EFFORTS

A wilderness search and rescue team can range from a small group of untrained participants with no equipment to a highly trained team with extensive resources. In the wilderness setting, available resources, risk to rescuers, and team safety must be considered when deciding how long to search for a submerged patient. Although each drowning episode has unique patient and environmental factors, the most important predictor of outcome is duration of submersion.[67,117,118] Available evidence shows that prognosis is poor with submersion times greater than 30 min, regardless of water temperature.[119] There are also case reports of survival with good neurologic outcome despite prolonged submersion, predominantly in children aged $\leq 6$ y in water $<6°C$ (43°F) and with use of advanced treatment modalities, such as extracorporeal membrane oxygenation.[120–125] For the purpose of these guidelines, recommendations are based on available evidence relevant to a typical drowning patient and on the probability of neurologically intact survival in specific conditions. A literature review of 43 cases serves as the evidence for water-based rescue.[126] The report concludes that there is minimal chance of neurologically intact survival with submersion time $>30$ min in water $>6°C$ (43°F) or $>90$ min in water

**Table 1**
Out-of-hospital management and classification of drowning patients

| *Grade* | *Pulmonary exam* | *Cardiac exam* | *Mortality (%)* |
|---|---|---|---|
| 0 | Normal auscultation, without cough | Radial pulses | 0 |
| 1 | Normal auscultation, with cough | Radial pulses | 0 |
| 2 | Rales, small foam in airway | Radial pulses | 0.6 |
| 3 | Acute pulmonary edema | Radial pulses | 5.2 |
| 4 | Acute pulmonary edema | Hypotension | 19 |
| 5 | Respiratory arrest | Hypotension | 44 |
| 6 | Cardiopulmonary arrest | | 93 |

Adapted from Semprsott et al.[25]

<6°C (43°F). It is important to note that "submersion time" was defined as beginning upon arrival of emergency services personnel; total submersion time is often unknown.

If a drowning patient is removed from the water and resuscitation takes place, it might be necessary to decide when to cease resuscitation efforts if no signs of life return. Based primarily on retrospective studies, submersion times of >10 min appear to correlate with increased mortality or survival with severe neurologic dysfunction.[67,118,127] In addition, more than 25 min of resuscitation or prolonged time to advanced medical care also correlate with negative outcomes, but without the statistical significance of submersion time. In a Dutch retrospective review of 160 hypothermic drowning patients under the age of 16 y, 98 children received CPR for more than 30 min, with only 11 surviving to discharge, all of whom were neurologically devastated.[119,127–129]

***Recommendation:***

1. Based on resources, it might be reasonable to cease rescue and resuscitation efforts when there is a known submersion time of greater than 30 min in water >6°C (43°F), or greater than 90 min in water <6°C (43°F), or after 25 min of continuous cardiopulmonary resuscitation.
2. If at any point during search and rescue efforts the safety of the rescue team becomes threatened, rescue efforts should be ceased.
3. If resources are available and recovery team safety is maintained, body recovery efforts may continue beyond the search and rescue period with the understanding that resuscitation attempts will likely be futile.

**Recommendation Grade:** 1C

## Disposition in the Emergency Department

Although many studies have addressed prognostic factors for neurologic survival at hospital discharge, only a few have addressed the question of which patients can be safely discharged from the ED. The first, a prospective study of primarily pediatric patients, included follow-up phone interviews with 33 patients who were either released on the scene or discharged from the ED within 1 to 6 h of arrival and found that none of these patients experienced delayed effects.[130] A retrospective review of 48 pediatric drowning patients who presented to a single ED with Glasgow Coma Scale score ≥13 studied whether factors predicting safe ED discharge could be identified.[88] Initial chest radiograph did not correlate with severity of disease, and all patients who deteriorated did so within 4 h of ED arrival. The authors concluded that patients could be safely discharged home if normalized and if there was no deterioration in respiratory function after 4 to 6 h of observation in the ED. A retrospective review of hospitalized pediatric patients found that in all patients who were initially asymptomatic, but who went on to develop symptoms during their stay, these symptoms developed within 4.5 h in all but 1 patient and did so within 7 h in the final patient.[116] In the 2 y preceding this current guideline update, 3 more pertinent retrospective studies investigating safe discharge of pediatrics patients were published.[90,131,132] The findings of these articles are in line with the aforementioned studies in that patients who initially presented as normal or with minimal symptoms, with normal mentation, and with no need for airway support generally could be safely discharged. Patients in this group who had a clinical decline did so within the first few hours and had subsequent safe discharge. One of the studies derived and validated a clinical score to assist in determining which patients may be safely discharged after 8 h of ED observation. The study found that the presence of 4 or more of the following factors predicted safe discharge: normal mentation, normal respiratory rate, absence of dyspnea, absence of need for airway support, and absence of hypotension.[132]

***Recommendation.*** After an observation period of 4 to 6 h, it is reasonable to discharge a drowning patient with normal mental status in whom respiratory function is normalized and no further deterioration in respiratory function has been observed. **Recommendation Grade:** 2C

## Prevention

Prevention has the potential to save far more lives than rescue or treatment of a drowning person. A comprehensive prevention program includes participant screening for medical diseases that increase risk of drowning, swimming ability, use of safety devices, and use of safe practices when in and around water.

### PARTICIPANT SCREENING

Retrospective studies have linked coronary artery disease, prolonged QT syndrome, autism, and seizure disorders with higher than normal rates of drowning and drowning deaths.[62,133–140] Preparticipation screening should focus on uncovering any medical or physical condition that may potentially impair decision making, physical abilities, and thus swimming ability. These include a history of spontaneous syncope, exertional syncope, and family history of sudden cardiac death. There remains no reliable screening tool for evaluation of cardiac conduction disorders, but screening electrocardiogram and family history of sudden cardiac death can help clinicians differentiate which

patients might benefit from further evaluation or genetic testing if indicated.

***Recommendation.*** All patients with coronary artery disease, prolonged QT syndrome or other ion channel disorder, autism, seizure disorders, or other medical and physical impairments should be counseled about the increased risk of drowning and about steps to mitigate the risk, such as buddy swimming and rescue devices, should they choose to participate in water activities. Given the extremely high rate of drowning in patients with epilepsy, patients should be counseled to never swim without direct supervision. **Recommendation Grade:** 2C

## SWIMMING ABILITY

Common sense dictates that an individual who is a competent swimmer and has the neurocognitive ability to make appropriate decisions about water safety has a decreased likelihood of drowning. However, the best ages to learn technique and specific swimming skills that reduce a person's chance of drowning are not well established. Most literature evaluates infant and pediatric populations for the effects of swimming and the effects of infant survival lessons on drowning and mortality.[26,141] There is concern that by providing swim lessons to young children, parents may develop a false sense of security in their child's swimming ability, which might lead to increased drowning incidents.[27,28,142]

The American Academy of Pediatrics has always maintained that children should learn to swim at some point in their life. Previous recommendations were against formal swim lessons for all children age 4 y and under. The most recent review by the American Academy of Pediatrics acknowledges a lack of evidence surrounding pediatric swimming lessons and so does not formally recommend for or against lessons for children under age 4 y.[141]

There is considerable debate regarding the definition of "swimming" or "survival-swimming" and what constitutes the most protective approach to swim instruction. Although the ability to swim farther distances can be perceived as increased swim ability, for the purpose of swimming as a tool for drowning prevention, the distance of 25 m (82 ft) has been adopted by international lifesaving agencies and a large population-based study in Bangladesh.[143,144]

Despite the lack of definitive evidence showing clear benefit to formal swim lessons, panel members agree that familiarity with and, more importantly, confidence in an aquatic environment would be beneficial in the event of accidental immersion or submersion. In addition, unique aquatic environments, such as whitewater, should be approached only after focused instruction on swimming techniques specific to that environment.

***Recommendation.*** All persons who participate in activities conducted in or around water should have, at a minimum, enough experience and physical capability to maintain their head above water, tread water, and make forward progress for a distance of 25 m (82 ft). **Recommendation Grade:** 2C

## PERSONAL FLOTATION DEVICES

Within the category of personal flotation devices, devices such as lifejackets, manually or automated inflation systems, and neoprene wetsuits are available. Currently, lifejackets are the only devices with injury prevention data available and will, therefore, be used as the prototypical model for this category. In 2017, according to United States Coast Guard data, drowning was the cause of death in more than 76% of fatal boating accidents.[5] In addition, 85% of these fatalities were not wearing lifejackets. Three other retrospective studies have found an association between lifejacket use and decreased mortality in boating accidents.[145–147] One of these studies compared drowning deaths before and after increased lifejacket regulations, revealing improved survival rates after regulations went into effect. These data suggest that activities in and around water, especially while boating, should include lifejacket use.[145]

***Recommendation.*** Properly fitted lifejackets that meet local regulatory specifications should be worn by participants when boating or engaging in any water sports for which lifejackets are recommended. **Recommendation Grade:** 1C

## ALCOHOL USE

Alcohol is a known contributing factor to drowning deaths. Data obtained primarily from telephone studies likely underrepresents the true burden of alcohol in drowning causation. In 2017, alcohol was a leading factor in boating-related deaths.[5] A 2004 review found that 30 to 70% of drowning fatalities have a measurable blood alcohol level, with 10 to 30% of deaths being directly attributed to alcohol use.[148]

***Recommendation.*** Alcohol and other intoxicating substances should be avoided before and during water activities. **Recommendation Grade:** 1C

## LIFEGUARDS

There are no specific peer-reviewed studies on the utility of lifeguards on expeditions or wilderness trips.[149] A 2001 Centers for Disease Control and Prevention working group report recommends the presence of lifeguards for drowning prevention in open water settings. In 2017, the

United States Lifesaving Association reported over 8 million preventative actions and over 75,000 water rescues covering a population of almost 386 million beachgoers. There were 17 reported drowning deaths at guarded beaches compared with 131 deaths at beaches without lifeguards.[150] Among nationally recognized lifeguard certifying agencies (Ellis & Associates, American Red Cross, Starfish Aquatics Institute, and National Aquatic Safety Company) there are no specific guidelines or recommendations for the number of lifeguards per number of participants in an event or at an aquatic facility.

***Recommendation.*** Despite a lack of definitive evidence, all groups operating in or near aquatic environments, regardless of size, should consider water safety during planning and execution of excursions. This includes contingencies for prevention, rescue, and treatment of drowning persons. In high-risk environments or large groups, consider including personnel with technical rescue training and appropriate rescue equipment. **Recommendation Grade:** 1C

## Special Situations

### COLD WATER SURVIVAL

No single recommendation can address all possible scenarios in a water setting. An unintentional fall into a swift moving river, deep offshore ocean, inland waterways, backyard swimming pool, or through ice into static or moving water are all treated according to the skill level, preparation, and equipment available to patient and rescuer. Immediate attention must always be given to self-rescue and extricating oneself from a hazardous environment. After immersion in cold water, a person has a limited amount of time before fatigue and incapacitation render self-rescue impossible. Likelihood of survival is increased by having appropriate gear and training and by dressing for water temperature, not just air temperature, in the event of immersion.

Extensive controlled trials of cold-water survival are lacking, and the available literature is not generalizable to all scenarios. For example, presence of a lifejacket, sea state, weather, physical fitness, clothing, and mental preparedness all contribute to survivability in cold water. Whitewater is different from still water or the ocean in polar regions. A single large literature review serves as the source for recommendations about cold water survival under ideal conditions and must be interpreted according to the level of training, preparation, and situation presented to the patient.[151]

After immersion, the most important decisions a person must make are: 1) assessment of the presence of any potential immediate threats to life and 2) whether to swim to safety or await rescue. Should a person choose to await rescue, preventing loss of body heat becomes paramount. By positioning the body to protect major areas of heat loss, a patient may lengthen immersion survival time. A position that has been proven in a laboratory setting to decrease heat loss is the heat escape lessening position. The goal of this position is to decrease heat loss from areas such as the arm pits, groin, and, to a lesser extent, neck. This position is achieved by pressing the arms against the sides of the chest and squeezing the legs together. If possible, additional protection may be obtained by flexing the hips and knees and shrugging the shoulders. In some cases, it may be possible to pull the knees to the chest with the hands. Some individuals will be unstable in this position; in this case the arms can simply be folded across the chest. In the event of group immersion, the huddle formation has been recommended to lessen heat loss, assist injured or weak persons, and improve group morale. Although this position has been shown to decrease cooling in participating individuals in a controlled environment, the effort needed to assist debilitated individuals in an actual emergency may result in increased heat loss (Figures 1 and 2).[152]

Swimming or treading water should be limited to minimize heat loss. Life jackets should be worn to aid insulation and flotation. If possible, the ideal location to await rescue is out of the water, even if only partially, to reduce heat loss and delay onset of hypothermia. Prolonged cold-water exposure eventually results in motor disabilities, which can appear within 10 min of immersion, making advanced maneuvers difficult. For this reason, it may be beneficial to affix one's body or clothing to a floating object using rope, or freezing clothing to the ice surface if exit is not possible. Prolonged immersion will also eventually lead to cognitive disabilities, rendering decision-making difficult.

Should a person decide to swim to safety, some important physiologic changes may occur. The initial cold shock, which lasts seconds to a few minutes, may prompt gasping and hyperventilation and can have a disorienting effect, making self-rescue attempts difficult. Upon immersion in cold water, if no immediate life threats are present, a person should focus on remaining calm and controlling breathing by taking slow, deep breaths. Once a person is able to obtain his or her bearings, he or she may have far less than 10 m of effective swimming, and up to 1 h of consciousness, before succumbing to hypothermia. All of these statements assume the person is wearing an appropriate lifejacket. Further detailed discussion of the science behind cold water immersion is available in chapter 8 of *Wilderness Medicine* (7th edition).[30]


**Figure 1.** Heat escape lessening position (used with permission from www.Boat-Ed.com).

***Recommendations:***

1. Upon falling into cold water, distance oneself from any immediate life threats (eg, fire, sinking vehicle, white-water, hazardous waves, rocks). Then, remain calm and focused and control breathing by taking slow deep breaths.
2. Consider physical capabilities, location, resources, and chances of rescue to determine whether to swim to safety.
3. If a decision is made to swim to safety, this should be done as soon as possible before physical capabilities deteriorate from the effects of cold stress.
4. If a decision is made to await rescue, an attempt should be made to remove as much of the body from the water as possible. All clothing should remain on, unless it hampers buoyancy. Most clothing does not compromise buoyancy and will not pull one down, although the water within the garment may impede movement. If the person remains immersed and has a flotation garment on, the heat escape lessening position should be maintained if possible. In a group, the huddle position may be used.
5. If prolonged rescue is expected, it might be beneficial to attach oneself to a buoyant object or to a surface out of the water to improve the chance for survival.

**Recommendation Grade:** 2C

**Figure 2.** Huddle formation (used with permission from www.Boat-Ed.com).

## Conclusions

Drowning is a process with outcomes ranging from no morbidity to severe morbidity to death. The most important aspect of treatment is to reverse cerebral hypoxia by providing oxygen to the brain. Drowning prevention can be effective and should be thoroughly deployed.

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## Supplementary materials

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## References

1. World Health Organization. Preventing drowning: an implementation guide. *Geneva*. 2017.
2. van Beeck EF, Branche CM, Szpilman D, Modell JH. Bierens JJ. A new definition of drowning: towards documentation and prevention of a global public health problem. *Bull World Health Organ*. 2005;83(11):853−6.
3. Schmidt AC, Sempsrott JR, Hawkins SC, Arastu AS, Cushing TA, Auerbach PS. Wilderness Medical Society practice guidelines for the prevention and treatment of drowning. *Wilderness Environ Med.* 2016;27(2):236−51.
4. Guyatt G, Gutterman D, Baumann MH, Addrizzo-Harris D, Hylek EM, Phillips B, et al. Grading strength of recommendations and quality of evidence in clinical guidelines: report from an American college of chest physicians task force. *Chest.* 2006;129:174−81.
5. Centers for Disease Control and Prevention (CDC). Unintentional drowning: get the facts. Available at: https://www.cdc.gov/homeandrecreationalsafety/water-safety/waterinjuries-factsheet.html. Accessed November 7, 2017.
6. United States Coast Guard. 2017 recreational boating statistics. Available at: http://uscgboating.org/library/accident-statistics/Recreational-Boating-Statistics-2017.pdf. Accessed November 7, 2018.
7. Alonge O, Agrawal P, Talab A, Rahman QS, Rahman AF, Arifeen SE, et al. Fatal and non-fatal injury outcomes: results from a purposively sampled census of seven rural subdistricts in Bangladesh. *Lancet Glob Health*. 2017;5(8):e818−27.
8. Abdullah SA, Flora MS. Risk factors for nonfatal drowning in children in rural Bangladesh: a community-based case-control study. *WHO South East Asia J Public Health*. 2013;2(2):88−95.
9. Felton H, Myers J, Liu G, Davis DW. Unintentional, non-fatal drowning of children: US trends and racial/ethnic disparities. *BMJ Open*. 2015;5(12):e008444.
10. Rahman A, Alonge O, Bhuiyan AA, Agrawal P, Salam SS, Talab A, et al. Epidemiology of drowning in Bangladesh: an update. *Int J Environ Res Public Health*. 2017;14(5):488.
11. Reijnen G, van de Westeringh M, Buster MC, Vos PJE, Reijnders ULJ. Epidemiological aspects of drowning and non-fatal drowning in the waters of Amsterdam. *J Forensic Legal Med*. 2018;58:78−81.
12. Byard RW. Drowning and near drowning in rivers. *Forensic Sci Med Pathol*. 2017;13(3):396.
13. Matthews BL, Andrew E, Andronaco R, Cox S, Smith K. Epidemiology of fatal and non-fatal drowning patients attended by paramedics in Victoria, Australia. *Int J Inj Control Saf Promot*. 2017;24(3):303−10.
14. Irwin CC, Irwin RL, Ryan TD, Drayer J. The legacy of fear: is fear impacting fatal and non-fatal drowning of African American children? *J Black Stud*. 2011;42(4):561−76.
15. Ma WJ, Nie SP, Xu HF, Xu YJ, Song XL, Guo QZ, et al. An analysis of risk factors of non-fatal drowning among children in rural areas of Guangdong province, China: a case-control study. *BMC Public Health*. 2010;10:156.
16. Szpilman D, Bierens JJ, Handley AJ, Orlowski JP. Drowning. *N Engl J Med*. 2012;366:2102−10.
17. Idris AH, Berg RA, Bierens J, Bossaert L, Branche CM, Gabrielli A, et al. Recommended guidelines for uniform reporting of data from drowning: The "Utstein Style". *Circulation.* 2003;108:2565−74.
18. Hawkins S, Semprott J, Schmidt A. 'Drowning' in a sea of misinformation. *Emergency Medicine News.* 2017;39(8):39−40.
19. Schmidt A, Semprott J, Hawkins S. Special report: the myth of dry drowning remains at large. *Emergency Medicine News*. 2018;40(6):22.
20. Szpilman D, Sempsrott J, Webber J, Hawkins SC, Barcala-Furelos R, Schmidt A, et al. 'Dry drowning' and other myths. *Cleve Clin J Med.* 2018;85(7):529−35.
21. Franklin RC, Pearn JH. Drowning for love: the aquatic victim-instead-of-rescuer syndrome: Drowning fatalities involving those attempting to rescue a child. *J Paediatr Child Health*. 2011;47(1−2):44−7.
22. Turgut A. A study on multiple drowning syndromes. *Int J Inj Control Saf Promot*. 2012;19:63−7.
23. Turgut A, Turgut T. A study on rescuer drowning and multiple drowning incidents. *J Saf Res*. 2012;43(2):129−32.
24. Moran K, Stanley T. Bystander perceptions of their capacity to respond in a drowning emergency. *Int J Aquatic Res Educ*. 2013;7(4):290−300.
25. Pearn J, Franklin R. "Flinging the squalor" lifeline rescues for drowning prevention. *Int J Aquatic Res Educ*. 2009:315−21.
26. Brenner RA, Taneja GS, Haynie DL, Trumble AC, Qian C, Klinger RM, et al. Association between swimming lessons and drowning in childhood: a case-control study. *Arch Pediatr Adolesc Med*. 2009;163(3):203−10.

27. Morrongiello BA, Sandomierski M, Schwebel DC, Hagel B. Are parents just treading water? The impact of participation in swim lessons on parents' judgments of children's drowning risk, swimming ability, and supervision needs. *Accid Anal Prev*. 2013;50:1169–75.
28. Morrongiello BA, Sandomierski M, Spence JR. Changes over swim lessons in parents' perceptions of children's supervision needs in drowning risk situations: "his swimming has improved so now he can keep himself safe". *Health Psychol*. 2014;33(7):608–15.
29. Semprsott J, Schmidt A, Hawkins S, Cushing T. Submersion injuries and drowning. In: Auerbach P, ed. *Wilderness Medicine*. 7th ed. Philadelphia: Elsevier; 2017:1530–49.
30. Giesbrecht G, Steinman A. Immersion into cold water. In: Auerbach P, ed. *Wilderness Medicine*. 7th ed. Philadelphia: Elsevier; 2017:162–97.
31. Wintemute GJ, Kraus JF, Teret SP, Wright MA. Death resulting from motor vehicle immersions: the nature of the injuries, personal and environmental contributing factors, and potential interventions. *Am J Public Health*. 1990;80:1068–70.
32. Yale JD, Cole TB, Garrison HG, Runyan CW, Ruback JK. Motor vehicle-related drowning deaths associated with inland flooding after Hurricane Floyd: a field investigation. *Traffic Inj Prev*. 2003;4:279–84.
33. Smith GS, Brenner RA. The changing risks of drowning for adolescents in the US and effective control strategies. *Adolesc Med*. 1995;6(2):153–70.
34. Lunetta P, Penttila A, Sajantila A. Drowning in Finland: "external cause" and "injury" codes. *Inj Prev*. 2002;8(4):342–4.
35. French J, Ing R, Von Allmen S, Wood R. Mortality from flash floods: a review of national weather service reports, 1969–81. *Public Health Rep*. 1983;98(6):584–8.
36. Agocs MM, Trent RB, Russell DM. Activities associated with drownings in imperial county, CA, 1980–90: implications for prevention. *Public Health Rep*. 1994;109(2):290–5.
37. Lobeto A. Engine company operations: vehicle accidents in water. *Fire Eng*. 2003;156.
38. McDonald G, Giesbrecht G. Vehicle submersion: a review of the problem, associated risks, and survival information. *Aviat Space Environ Med*. 2013;84(5):498–510.
39. Giesbrecht GG, McDonald GK. My car is sinking: automobile submersion, lessons in vehicle escape. *Aviat Space Environ Med*. 2010;81(8):779–84.
40. Priority Dispatch Corporation. Medical priority dispatch system ProQA, v5.1.1.23. Current v13.1; last. update. January 12, 2018.
41. Giesbrecht GG. The evidence base for a new "vehicle in floodwater" emergency dispatch protocol. *Ann Emerg Dispatch Response*. 2016;4(2):7–11.
42. Orlowski JP, Szpilman D. Drowning. Rescue, resuscitation, and reanimation. *Pediatr Clin North Am*. 2001;48(3):627–46.
43. Ghaphery JL. In-water resuscitation. *JAMA*. 1981;245(8):821.
44. March NF, Matthews RC. New techniques in external cardiac compressions. *Aquatic cardiopulmonary resuscitation JAMA*. 1980;244(11):1229–32.
45. Szpilman D, Soares M. In-water resuscitation—is it worthwhile? *Resuscitation*. 2004;63(1):25–31.
46. Perkins GD. In-water resuscitation: A pilot evaluation. *Resuscitation*. 2005;65(3):321–4.
47. Winkler BE, Eff AM, Eff S, Ehrmann U, Koch A, Kähler W, et al. Efficacy of ventilation and ventilation adjuncts during in-water-resuscitation—a randomized cross-over trial. *Resuscitation*. 2013;84:1137–42.
48. Winkler BE, Eff AM, Eff S, Eff S, Koch A, Kaehler W, et al. Effectiveness and safety of in-water resuscitation performed by lifeguards and laypersons: a crossover manikin study. *Prehosp Emerg Care*. 2013;17:409–15.
49. The United States Lifeguard Standards Coalition. United States lifeguard standards. Available at: http://www.lifeguardstandards.org/. Updated 2011. Accessed November 10, 2018.
50. International Life Saving Federation. Medical position statement: in water resuscitation. Available at: http://www.ilsf.org/about/position-statements. Updated 2001. Accessed November 15, 2018.
51. Water Safety Products. BigEasy rescue breathing mask kit. Available at: http://www.watersafety.com/store/lifeguard-equipment/bigeasy-rescue-breathing-mask-kit.html. Updated 2015. Accessed November 20, 2018.
52. The Lifeguard Store. Seal rite mask kit. Available at: https://thelifeguardstore.com/seal-rite-mask-kit-22961.html. Accessed November 10, 2018.
53. Zafren K, Giesbrecht GG, Danzl DF, Brugger H, Sagalyn EB, Walpoth B, et al. Wilderness medical society practice guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia: 2014 update. *Wilderness Environ Med*. 2014;25(4 Suppl):S66–85.
54. Truhlář A, Deakin CD, Soar J, Khalifa GE, Alfonzo A, Bierens JJ, et al. European Resuscitation Council guidelines for resuscitation 2015: section 4. cardiac arrest in special circumstances. *Resuscitation*. 2015;95:148–201.
55. Lavonas EJ, Drennan IR, Gabrielli A, Heffner AC, Hoyte CO, Orkin AM, et al. Part 10: Special circumstances of resuscitation: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2015;132(18 Suppl 2):S501–18.
56. Adelborg K, Al-Mashhadi RH, Nielsen LH, Dalgas C, Mortensen MB, Lofgren B. A randomised crossover comparison of manikin ventilation through Soft Seal, i-gel and AuraOnce supraglottic airway devices by surf lifeguards. *Anaesthesia*. 2014;69(4):343–7.
57. McKenna M, Davies M. Supraglottic airway use by lifeguards. *Anaesthesia*. 2014;69(8):928.
58. Baker P, Webber J. Should supraglottic airway devices be used by lifeguards at all? *Anaesthesia*. 2014;69(8):928–9.
59. Baker PA, Webber JB. Failure to ventilate with supraglottic airways after drowning. *Anaesth Intensive Care*. 2011;39:675–7.

60. Spindelboeck W, Schindler O, Moser A, Hausler F, Wallner S, Strasser C, et al. Increasing arterial oxygen partial pressure during cardiopulmonary resuscitation is associated with improved rates of hospital admission. *Resuscitation.* 2013;84(6):770–5.
61. Eich C, Bräuer A, Timmermann A, Schwarz SK, Russo SG, Neubert K, et al. Outcome of 12 drowned children with attempted resuscitation on cardiopulmonary bypass: an analysis of variables based on the "Utstein Style for drowning". *Resuscitation.* 2007;75(1):42–52.
62. Papadodima SA, Sakelliadis EI, Kotretsos PS, Athanaselis SA, Spiliopoulou CA. Cardiovascular disease and drowning: autopsy and laboratory findings. *Hell J Cardiol.* 2007;48(4):198–205.
63. Grmec S, Strnad M, Podgorsek D. Comparison of the characteristics and outcome among patients suffering from out-of-hospital primary cardiac arrest and drowning victims in cardiac arrest. *Int J Emerg Med.* 2009;2(1):7–12.
64. Ballesteros MA, Gutierrez-Cuadra M, Munoz P, Minambres E. Prognostic factors and outcome after drowning in an adult population. *Acta Anaesthesiol Scand.* 2009;53(7):935–40.
65. Nitta M, Kitamura T, Iwami T, Nadkarni VM, Berg RA, Topjian AA, et al. Out-of-hospital cardiac arrest due to drowning among children and adults from the Utstein Osaka project. *Resuscitation.* 2013;84(11):1568–73.
66. Claesson A, Lindqvist J, Herlitz J. Cardiac arrest due to drowning—changes over time and factors of importance for survival. *Resuscitation.* 2014;85(5):644–8.
67. Suominen P, Baillie C, Korpela R, Rautanen S, Ranta S, Olkkola KT. Impact of age, submersion time and water temperature on outcome in near-drowning. *Resuscitation.* 2002;52(3):247–54.
68. Lyster T, Jorgenson D, Morgan C. The safe use of automated external defibrillators in a wet environment. *Prehosp Emerg Care.* 2003;7(3):307–11.
69. Schratter A, Weihs W, Holzer M, Janata A, Behringer W, Losert UM, et al. External cardiac defibrillation during wet-surface cooling in pigs. *Am J Emerg Med.* 2007;25(4):420–4.
70. Klock-Frezot JC, Ohley WJ, Schock RB, Cote M, Schofield L. Successful defibrillation in water: a preliminary study. *Conf Proc IEEE Eng Med Biol Soc.* 2006;1:4028–30.
71. de Vries W, Bierens JJ, Maas MW. Moderate sea states do not influence the application of an AED in rigid inflatable boats. *Resuscitation.* 2006;70(2):247–53.
72. Heimlich HJ, Spletzer EG. Drowning. *N Engl J Med.* 1993;329(1):65.
73. Heimlich HJ, Patrick EA. Using the Heimlich maneuver to save near-drowning victims. *Postgrad Med.* 1988;84(2):62–7, 71.
74. Heimlich HJ. Subdiaphragmatic pressure to expel water from the lungs of drowning persons. *Ann Emerg Med.* 1981;10:476–80.
75. Rosen P, Stoto M, Harley J. The use of the Heimlich maneuver in near drowning: Institute of Medicine report. *J Emerg Med.* 1995;13(9):397–405.
76. Francesco P, Fielding R, Wernicki PG, Markenson D. Sub-diaphragmatic thrusts and drowned persons. *Int J Aquatic Res Educ.* 2010;4:81–92.
77. Hawkins SC, Williams J, Bennett BL, Islas A, Kayser DW, Quinn R. Wilderness Medical Society clinical practice guidelines for spinal cord protection: 2019 update. *Wilderness Environ Med.* In press.
78. Watson RS, Cummings P, Quan L, Bratton S, Weiss NS. Cervical spine injuries among submersion victims. *J Trauma.* 2001;51(4):658–62.
79. Hwang V, Shofer FS, Durbin DR, Baren JM. Prevalence of traumatic injuries in drowning and near drowning in children and adolescents. *Arch Pediatr Adolesc Med.* 2003;157(1):50–3.
80. Gregorakos L, Markou N, Psalida V, Kanakaki M, Alexopoulou A, Sotiriou E, et al. Near-drowning: clinical course of lung injury in adults. *Lung.* 2009;187(2):93–7.
81. Topjian AA, Berg RA, Bierens JJ, Branche CM, Clark RS, Friberg H, et al. Brain resuscitation in the drowning victim. *Neurocrit Care.* 2012;17(3):441–67.
82. ARDS Clinical Network. Mechanical ventilation protocol summary. Available at: http://www.ardsnet.org/. Updated 2008. Accessed November 2, 2018.
83. Thompson J, Petrie DA, Ackroyd-Stolarz S, Bardua DJ. Out-of-hospital continuous positive airway pressure ventilation versus usual care in acute respiratory failure: a randomized controlled trial. *Ann Emerg Med.* 2008;52(3):232–41.
84. Dottorini M, Eslami A, Baglioni S, Fiorenzano G, Todisco T. Nasal-continuous positive airway pressure in the treatment of near-drowning in freshwater. *Chest.* 1996;110(4):1122–4.
85. Nava S, Schreiber A, Domenighetti G. Noninvasive ventilation for patients with acute lung injury or acute respiratory distress syndrome. *Respir Care.* 2011;56(10):1583–8.
86. Ruggeri P, Calcaterra S, Bottari A, Girbino G, Fodale V. Successful management of acute respiratory failure with noninvasive mechanical ventilation after drowning, in an epileptic-patient. *Respir Med Case Rep.* 2016;17:90–2.
87. Michelet P, Bouzana F, Charmensat O, Tiger F, Durand-Gasselin J, Hraiech S, et al. Acute respiratory failure after drowning: a retrospective multicenter survey. *Eur J Emerg Med.* 2017;24(4):295–300.
88. Causey AL, Tilelli JA, Swanson ME. Predicting discharge in uncomplicated near-drowning. *Am J Emerg Med.* 2000;18(1):9–11.
89. Modell JH, Graves SA, Ketover A. Clinical course of 91 consecutive near-drowning victims. *Chest.* 1976;70(2):231–8.
90. Brennan CE, Hong TKF, Wang VJ. Predictors of safe discharge for pediatric drowning patients in the emergency department. *Am J Emerg Med.* 2018;36(9):1619–23.
91. Rafaat KT, Spear RM, Kuelbs C, Parsapour K, Peterson B. Cranial computed tomographic findings in a large group of children with drowning: diagnostic, prognostic, and forensic implications. *Pediatr Crit Care Med.* 2008;9(6):567–72.

92. Modell JH, Davis JH. Electrolyte changes in human drowning victims. *Anesthesiology.* 1969;30(4):414–20.
93. Modell JH, Moya F. Effects of volume of aspirated fluid during chlorinated fresh water drowning. *Anesthesiology.* 1966;27(5):662–72.
94. Modell JH, Moya F, Newby EJ, Ruiz BC, Showers AV. The effects of fluid volume in seawater drowning. *Ann Intern Med.* 1967;67(1):68–80.
95. Wood C. Towards evidence based emergency medicine: best BETs from the Manchester royal infirmary. BET 1: prophylactic antibiotics in near-drowning. *Emerg Med J.* 2010;27(5):393–4.
96. Ender PT, Dolan MJ. Pneumonia associated with near-drowning. *Clin Infect Dis.* 1997;25(4):896–907.
97. Tadié JM, Heming N, Serve E, Weiss N, Day N, Imbert A, et al. Drowning associated pneumonia: a descriptive cohort. *Resuscitation.* 2012;83:399–401.
98. van Berkel M, Bierens JJ, Lie RL, de Rooy TP, Kool LJ, van de Velde EA, et al. Pulmonary oedema, pneumonia and mortality in submersion victims; a retrospective study in 125 patients. *Intensive Care Med.* 1996;22(2):101–7.
99. Foex BA, Boyd R. Towards evidence based emergency medicine: best BETs from the Manchester royal infirmary. Corticosteroids in the management of near-drowning. *Emerg Med J.* 2001;18(6):465–6.
100. Callaway CW, Donnino MW, Fink EL, Geocadin RG, Golan E, Kern KB, et al. Part 8: post-cardiac arrest care: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation.* 2015;132(18 Suppl 2):S465–82.
101. World Congress on Drowning. Recommendations of the World Congress on Drowning. Available at: http://www.ilsf.org/drowning-prevention/report. Updated 2002. Accessed November 10, 2018.
102. Batra RK, Paddle JJ. Therapeutic hypothermia in drowning induced hypoxic brain injury: a case report. *Cases J.* 2009;2:9103.
103. Varon J, Marik PE. Complete neurological recovery following delayed initiation of hypothermia in a victim of warm water near-drowning. *Resuscitation.* 2006;68(3):421–3.
104. Williamson JP, Illing R, Gertler P, Braude S. Near-drowning treated with therapeutic hypothermia. *Med J Aust.* 2004;181(9):500–1.
105. de Pont AC, de Jager CP, van den Bergh WM, Schultz MJ. Recovery from near drowning and postanoxic status epilepticus with controlled hypothermia. *Neth J Med.* 2011;69(4):196–7.
106. Rudolph SS, Barnung S. Survival after drowning with cardiac arrest and mild hypothermia. *ISRN Cardiol.* 2011;2011:895625.
107. Choi SP, Youn CS, Park KN, Wee JH, Park JH, Oh SH, et al. Therapeutic hypothermia in adult cardiac arrest because of drowning. *Acta Anaesthesiol Scand.* 2012;56(1):116–23.
108. Kawati R, Covaciu L, Rubertsson S. Hypothermia after drowning in paediatric patients. *Resuscitation.* 2009;80(11):1325–6.
109. Mizobuchi M, Nakamura S, Muranishi H, Utsunomiya M, Funatsu A, Kobayashi T, et al. Hypothermia with extracorporeal membrane oxygenation for sudden cardiac death and submersion. *Am J Emerg Med.* 2010;28(1):115.e1–e4.
110. Baldursdottir S, Sigvaldason K, Karason S, Valsson F, Sigurdsson GH. Induced hypothermia in comatose survivors of asphyxia: a case series of 14 consecutive cases. *Acta Anaesthesiol Scand.* 2010;54(7):821–6.
111. Oude Lansink-Hartgring A, Ismael F. Controlled hypothermia and recovery from postanoxic encephalopathy in near-drowning victim. *Neth J Med.* 2011;69(7):351.
112. Guenther U, Varelmann D, Putensen C, Wrigge H. Extended therapeutic hypothermia for several days during extracorporeal membrane-oxygenation after drowning and cardiac arrest two cases of survival with no neurological sequelae. *Resuscitation.* 2009;80(3):379–81.
113. Hein OV, Triltsch A, von Buch C, Kox WJ, Spies C. Mild hypothermia after near drowning in twin toddlers. *Crit Care.* 2004;8(5):R353–7.
114. Bohn DJ, Biggar WD, Smith CR, Conn AW, Barker GA. Influence of hypothermia, barbiturate therapy, and intracranial pressure monitoring on morbidity and mortality after near-drowning. *Crit Care Med.* 1986;14(6):529–34.
115. Szpilman D. Near-drowning and drowning classification: a proposal to stratify mortality based on the analysis of 1,831 cases. *Chest.* 1997;112(3), 66–5.
116. Noonan L, Howrey R, Ginsburg CM. Freshwater submersion injuries in children: a retrospective review of seventy-five hospitalized patients. *Pediatrics.* 1996;98(3 Pt 1):368–71.
117. Quan L, Mack CD, Schiff MA. Association of water temperature and submersion duration and drowning outcome. *Resuscitation.* 2014;85(6):790–4.
118. Suominen PK, Vahatalo R. Neurologic long term outcome after drowning in children. *Scand J Trauma Resusc Emerg Med.* 2012;20:55.
119. Kieboom JK, Verkade HJ, Burgerhof JG, Bierens JJ, Rheenen PF, Kneyber MC, et al. Outcome after resuscitation beyond 30 minutes in drowned children with cardiac arrest and hypothermia: Dutch nationwide retrospective cohort study. *BMJ.* 2015;350:h418.
120. Orlowski JP. How much resuscitation is enough resuscitation? *Pediatrics.* 1992;90(6):997–8.
121. Modell JH, Idris AH, Pineda JA, Silverstein JH. Survival after prolonged submersion in freshwater in Florida. *Chest.* 2004;125(5):1948–51.
122. Hasibeder WR. Drowning. *Curr Opin Anaesthesiol.* 2003;16(2):139–45.
123. Martin TG. Neardrowning and cold water immersion. *Ann Emerg Med.* 1984;13(4):263–73.
124. Gilbert M, Busund R, Skagseth A, Nilsen PA, Solbo JP. Resuscitation from accidental hypothermia of 13.7 degrees C with circulatory arrest. *Lancet.* 2000;355(9201):375–6.
125. Wanscher M, Agersnap L, Ravn J, Yndgaard S, Nielsen JF, Danielsen ER, et al. Outcome of accidental hypothermia with or without circulatory arrest: experience from the

Danish Praesto fjord boating accident. *Resuscitation*. 2012;83(9):1078–84.
126. Tipton MJ, Golden FS. A proposed decision-making guide for the search, rescue and resuscitation of submersion (head under) victims based on expert opinion. *Resuscitation*. 2011;82(7):819–24.
127. Quan L, Kinder D. Pediatric submersions: prehospital predictors of outcome. *Pediatrics*. 1992;90(6):909–13.
128. Youn CS, Choi SP, Yim HW, Park KN. Out-of-hospital cardiac arrest due to drowning: an Utstein Style report of 10 years of experience from St. Mary's hospital. *Resuscitation*. 2009;80(7):778–83.
129. Claesson A, Svensson L, Silfverstolpe J, Herlitz J. Characteristics and outcome among patients suffering out-of-hospital cardiac arrest due to drowning. *Resuscitation*. 2008;76(3):381–7.
130. Pratt FD, Haynes BE. Incidence of "secondary drowning" after saltwater submersion. *Ann Emerg Med*. 1986;15(9):1084–7.
131. Cantu RM, Pruitt CM, Samuy N, Wu CL. Predictors of emergency department discharge following pediatric drowning. *Am J Emerg Med*. 2018;36(3):446–9.
132. Shenoi RP, Allahabadi S, Rubalcava DM, Camp EA. The pediatric submersion score predicts children at low risk for injury following submersions. *Acad Emerg Med*. 2017;24(12):1491–500.
133. Ackerman MJ, Tester DJ, Porter CJ, Edwards WD. Molecular diagnosis of the inherited long-QT syndrome in a woman who died after near-drowning. *N Engl J Med*. 1999;341(15):1121–5.
134. Tester DJ, Medeiros-Domingo A, Will ML, Ackerman MJ. Unexplained drownings and the cardiac channelopathies: a molecular autopsy series. *Mayo Clin Proc*. 2011;86(10):941–7.
135. Bell GS, Gaitatzis A, Bell CL, Johnson AL, Sander JW. Drowning in people with epilepsy: how great is the risk? *Neurology*. 2008;71(8):578–82.
136. Albertella L, Crawford J, Skinner JR. Presentation and outcome of water-related events in children with long QT syndrome. *Arch Dis Child*. 2011;96:704–7.
137. SoRelle R. Genetic drowning trigger. *Circulation*. 2000;101(3):E36.
138. Choi G, Kopplin LJ, Tester DJ, Will ML, Haglund CM, Ackerman MJ. Spectrum and frequency of cardiac channel defects in swimming-triggered arrhythmia syndromes. *Circulation*. 2004;110(15):2119–24.
139. Lunetta P, Levo A, Laitinen PJ, Fodstad H, Kontula K, Sajantila A. Molecular screening of selected long QT syndrome (LQTS) mutations in 165 consecutive bodies found in water. *Int J Legal Med*. 2003;117(2):115–7.
140. Tester DJ, Kopplin LJ, Creighton W, Burke AP, Ackerman MJ. Pathogenesis of unexplained drowning: new insights from a molecular autopsy. *Mayo Clin Proc*. 2005;80(5):596–600.
141. Weiss J. American Academy of Pediatrics Committee on Injury, Violence. *Prevention of drowning Pediatrics*. 2010;126(1):e253–62.
142. Moran K, Stanley T. Parental perceptions of toddler water safety, swimming ability and swimming lessons. *Int J Inj Control Saf Promot*. 2006;13(3):139–43.
143. Mecrow TS, Linnan M, Rahman A, Scarr J, Mashreky SR, Talab A, et al. Does teaching children to swim increase exposure to water or risk-taking when in the water? Emerging evidence from Bangladesh. *Inj Prev*. 2015;21(3):185–8.
144. Australian Council for the Teaching of Swimming and Water Safety. Audit of national water safety programs. Available at: http://www.watersafety.com.au/Reports.aspx. Updated 2013. Accessed November 20, 2014.
145. Bugeja L, Cassell E, Brodie LR, Walter SJ. Effectiveness of the 2005 compulsory personal flotation device (PFD) wearing regulations in reducing drowning deaths among recreational boaters in Victoria, Australia. *Inj Prev*. 2014;20(6):387–92.
146. Cummings P, Mueller BA, Quan L. Association between wearing a personal floatation device and death by drowning among recreational boaters: a matched cohort analysis of United States Coast Guard data. *Inj Prev*. 2011;17(3):156–9.
147. O'Connor PJ, O'Connor N. Causes and prevention of boating fatalities. *Accid Anal Prev*. 2005;37(4):689–98.
148. Driscoll TR, Harrison JA, Steenkamp M. Review of the role of alcohol in drowning associated with recreational aquatic activity. *Inj Prev*. 2004;10(2):107–13.
149. Branche CM, Stewart S. Lifeguard effectiveness: a report of the working group. Centers for Disease Control and Prevention, National Center for Injury. *Prev Control*. 2001.
150. United States Lifesaving Association. 2017 national lifesaving statistics. Available at: http://arc.usla.org/Statistics/public.asp. Updated 2013. Accessed November 20, 2018.
151. Ducharme MB, Lounsbury DS. Self-rescue swimming in cold water: the latest advice. *Appl Physiol Nutr Metab*. 2007;32(4):799–807.
152. Hayward JS, Eckerson JD, Collis ML. Effect of behavioral variables on cooling rate of man in cold water. *J Appl Physiol*. 1975;38(6):1073–7.

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WILDERNESS MEDICAL SOCIETY CLINICAL PRACTICE GUIDELINES

# Wilderness Medical Society Clinical Practice Guidelines for Water Disinfection for Wilderness, International Travel, and Austere Situations

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To provide guidance to clinicians, the Wilderness Medical Society convened experts to develop evidence-based guidelines for water disinfection in situations where the potability of available water is not ensured, including wilderness and international travel, areas affected by disaster, and other areas without adequate sanitation. The guidelines present the available methods for reducing or eliminating microbiologic contamination of water for individuals, groups, or households; evaluation of their effectiveness; and practical considerations. The evidence evaluation includes both laboratory and clinical publications. The panel graded the recommendations based on the quality of supporting evidence and the balance between benefits and risks or burdens, according to the criteria published by the American College of Chest Physicians.

*Keywords:* drinking water, water purification, water microbiology, disaster planning, pasteurization, halogens

## Introduction

Safe and efficient treatment of drinking water is among the major public health advances of the last century. Without treatment, waterborne diseases can spread rapidly, resulting in large-scale disease and death.[1,2] In industrialized nations, the population generally is protected from waterborne disease by sophisticated water supply systems that disinfect water and provide continuous monitoring. In contrast, travelers to wilderness and recreational areas anywhere in the world and to underdeveloped regions of some countries may be confronted with untreated or contaminated water that poses a risk of acquiring enteric disease. In addition, disaster situations, such as the 2017 hurricanes that affected Houston, Texas, and Puerto Rico, may result in a breakdown of municipal water systems, exposing victims to nonpotable water. These situations necessitate knowledge of how to disinfect water at the point-of-use, prior to drinking.

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Methods of water treatment that can be applied in the field include the use of heat, ultraviolet light, clarification, filtration, and chemical disinfection. The choices for the wilderness hiker or international traveler are increasing as new technology is applied to field applications. Different microorganisms have varying susceptibilities to these methods. The risk of waterborne illness depends on the number and type of organisms consumed, host factors, and the efficacy of the treatment system.

## Methods

To develop these guidelines, specialists with expertise in wilderness medicine, travel medicine, public health, and microbiology were chosen on the basis of their clinical or research experience. Relevant articles were identified through the PubMed database using the following keywords or phrases: water disinfection, waterborne illness, wilderness water, water filtration, emergency or disaster drinking water treatment. This was supplemented by a hand search of articles from references in the initial PubMed search. Conclusions from review articles were cited in an effort to provide background information and to augment reference selection.

The evidence base for water disinfection has substantial differences from other clinical guidelines. Most of the literature concerning the effectiveness of specific disinfectants and methods against various waterborne microorganisms is laboratory based. Evidence on the benefits of disinfection is either population-based public health research of disease outbreaks or randomized household trials of water disinfection that are influenced by compliance and hygiene. Therefore, the evidence grade is a combination of laboratory, population, and household- or community-level studies.

The authors used a consensus approach to develop recommendations for the disinfection of water. Water treatment techniques and recommendations were not evaluated for the removal of chemicals or toxins. Evidence grades were assigned according to methodology stipulated by the American College of Chest Physicians for grading of evidence and recommendations[3] (online Supplementary Table 1). These recommendations are graded on the basis of the totality of supporting evidence and balance between the benefits and risks or burdens for each modality.

## Etiology and Risk of Waterborne Infection

### WILDERNESS SETTINGS

Millions of people enter wilderness areas each year and drink surface water. Even in developed countries with low rates of diarrheal illness, regular waterborne disease outbreaks indicate that the microbiologic quality of the water, especially surface water, is not ensured.[4–7] Public health agencies regularly report outbreaks of disease associated with surface water from backcountry and parks as well as from campground water systems. The environment and activity upstream from the travelers' surface water source defines the risk. Side streams draining springs, snowmelt, and glaciers where there is no human or animal activity are lower risk. In contrast, upstream usage by humans, farm animals, or wildlife pose a major risk. Cattle excrete pathogenic strains of *Escherichia coli* and *Salmonella* and have been found in multiple studies to be the major animal species contributing to waterborne disease in North America.[8,9] Giardiasis is a zoonotic infection with numerous host species, including farm animals, deer and other wild ungulates, beavers, and even household animals; however, the extent of transmission to humans is less defined.[10]

Nonalpine wilderness areas in the United States may have streams and rivers that are contaminated with animal waste, including farm animal runoff, or may be contaminated with incompletely treated sewage from towns and urban areas. In many countries, wilderness areas are cooccupied by local populations and domesticated animals that pollute water sources. Because it is very difficult to exclude animal and human activity in the watershed, the Centers for Disease Control recommend treating surface water before ingestion as a precaution to protect health.

### INTERNATIONAL TRAVEL

Substantial progress has been made in the past 20 years toward the goal of safe drinking water and sanitation worldwide, particularly in Asia and Latin America[11]; however, 780 million people (11% of world population) still lack a safe water source, and 2.5 billion people lack access to improved sanitation. Africa and Oceania are the regions with the greatest need for improvement. More than 890 million persons still practice open defecation, the largest number being in India and Africa.[11–13] Studies in underdeveloped regions around the world show high levels of microbes in the environment and water sources.[14–18] Contamination of tap water commonly occurs because of antiquated and inadequately monitored waste disposal, water treatment, and distribution systems.[19,20]

In both developed and developing countries, after natural disasters such as hurricanes, tsunamis, and earthquakes, one of the most immediate public health problems is a lack of potable water. Wilderness visitors and international travelers have no reliable resources to evaluate local water system quality. Less information is available for remote surface water sources. Appearance, smell, and taste are not reliable indicators to estimate water safety.

Infectious agents with the potential for waterborne transmission include bacteria, viruses, protozoa, and nonprotozoan parasites. The list of microbial agents is similar to the list of microorganisms that can cause travelers' diarrhea, most of which can be waterborne as well as foodborne. Although the primary reason for disinfecting drinking water is to destroy microorganisms from animal and human biologic wastes, water may also be contaminated with toxins and chemical pollutants from industrial sources or from the environment. *Escherichia coli* and *Vibrio cholerae* may be capable of surviving indefinitely in tropical water. Enteric bacterial and viral pathogens survive in temperate water generally only several days; however, some species such as *E coli* O157: H7 can survive 12 weeks at 25°C.[21] Most enteric organisms, including *Shigella* spp, *Salmonella enterica* serotype Typhi, hepatitis A, and *Cryptosporidium* spp, can retain viability for long periods in cold water and can even survive for weeks when frozen in water.

The risk of waterborne illness depends on the number of organisms consumed, which is in turn determined by the volume of water, concentration of organisms, and treatment system efficiency.[22,23] Additional factors include virulence of the organism and defenses of the host. Microorganisms with a small infectious dose (eg, *Giardia, Cryptosporidium*, *Shigella* spp, hepatitis A, enterohemorrhagic *E coli,* and

norovirus—the leading viral disease risk in water contaminated with human waste) may cause illness even from inadvertent drinking during water-based recreational activities.[10] Most diarrhea among travelers is probably foodborne; however, the capacity for waterborne transmission should not be underestimated. Because long-lasting immunity does not develop for most enteric pathogens, reinfection may occur.

The combined roles of safe water, hygiene, and adequate sanitation in reducing diarrhea and other diseases are clear and well documented. The World Health Organization (WHO) estimates that 94% of diarrheal cases globally are preventable through modifications to the environment, including access to safe water.[1] Recent studies of simple water interventions in households of developing countries clearly document improved microbiological quality of water, a 30 to 60% reduced incidence of diarrheal illness, enhanced childhood survival, and reduction of parasitic diseases, many of which are independent of other measures to improve sanitation.[24]

General recommendations for drinking water disinfection:

- Treat water when traveling in developing countries. **Evidence grade: 1A**
- Treat water in wilderness areas with nearby agricultural use, animal grazing, or upstream human activity. **Evidence grade: 1A**
- Treat water in wilderness settings without evidence of domestic animal and little to no wildlife or human activity. **Evidence grade: 2B**
- Treat water in disaster situations affecting municipal or private drinking water sources. **Evidence grade: 1A**

## Water Treatment Methods

Multiple techniques for improving the microbiologic quality of water are available to individuals and small groups while hiking or traveling. Bottled water may be a convenient and popular solution but creates ecologic problems. Furthermore, in underdeveloped countries, the quality of bottled water may not meet the standards of developed countries and may contain pathogenic microbes.[25]

The term *disinfection*, the desired result of field water treatment, is used here to indicate the removal or destruction of harmful microorganisms, which reduces the risk of illness. This is sometimes used interchangeably with *purification*, but the latter term more accurately indicates the removal of organic or inorganic chemicals and particulate matter to improve color, taste, and odor. Unless specifically designed to remove chemical contaminants, disinfection techniques may not make water safe from chemical exposures. *Potable* implies drinkable water, but it technically means that a water source, on average, over a period of time, contains a minimal microbial hazard so that the statistical likelihood of illness is acceptably low. All standards, including water regulations in the United States, acknowledge the impracticality of trying to eliminate all microorganisms from drinking water. Generally, the goal is a 3 to 5 log reduction (99.9—99.999%), allowing a small risk of enteric infection. Newer standards from the US Environmental Protection Agency (US EPA) and the WHO set target goals to reduce some organisms to zero; however, all enforceable standards allow a small risk for enteric infection.[26]

## Product Testing and Rating

Filters are rated by their ability to retain particles of a certain size, which is described by 2 terms. *Absolute* rating means that 100% of a certain size of particle is retained by the filter (ie, filtered-out). *Nominal* rating indicates that >90% of a given particle size will be retained. Filter efficiency is generally determined with hard particles (beads of known diameter), but microorganisms are soft and compressible under pressure. The US EPA and NSF International are the primary agencies that set standards for disinfection products and protocols for testing to meet these standards.

The US EPA does not endorse, test, or approve mechanical filters; it merely assigns registration numbers that distinguish between 2 types of filters: those that use mechanical means only and those that use a chemical designated as a pesticide. Portable water treatment device claims for microbiologic reduction are based on consensus performance standards that serve as a guideline for testing.[27] Testing is done or contracted by the manufacturer; the US EPA neither tests nor specifies laboratories. Testing must be done with bacteria (*Klebsiella*), viruses (poliovirus and rotavirus), and protozoa (*Cryptosporidium* has replaced *Giardia*). A 3-log reduction (99.9%) is required for protozoan cysts, 4-log reduction (99.99%) for viruses, and 5- to 6-log reduction for bacteria. To be called a microbiologic water purifier, the unit must remove, kill, or inactivate all types of disease-causing microorganisms from the water, including bacteria, viruses, and protozoan cysts, so as to render the processed water safe for drinking. An exception for limited claims may be allowed for units removing specific organisms to serve a definable environmental need, for example, removal of protozoan cysts.[27]

## Clarification Techniques

Clarification refers to techniques that reduce the turbidity or cloudiness of water caused by natural organic and inorganic material. (Turbidity is measured in nephelometric turbidity units [NTU].) These techniques can markedly improve the

appearance and taste of water. They may reduce the number of microorganisms, but not enough to ensure potable water; however, clarifying the water facilitates disinfection by filtration or chemical treatment. Cloudy water can rapidly clog filters designed to remove microorganisms. Moreover, cloudy water requires increased levels of chemical treatment, and the combined effects of the water contaminants plus chemical disinfectants results in unpleasant taste.

*Adsorption*

Granular activated carbon (GAC) is widely used in water treatment. When activated, charcoal's regular array of carbon bonds is disrupted, making it highly reactive for adsorbing dissolved chemicals.[28,29] GAC is the best means to remove toxic organic and inorganic chemicals from water (including disinfection byproducts) and to improve odor and taste.[30,31] Thus, it is widely used in municipal disinfection plants, in household under-sink devices, and in portable water filters. In field water treatment, GAC is best used after chemical disinfection to make water safer and more palatable by removing disinfection byproducts and pesticides, as well as many other organic chemicals and some heavy metals. It removes the taste of chemical disinfectants such as iodine and chlorine.

GAC does not kill microorganisms and is not designed for microbial removal; in fact, bacteria attach to charcoal, where they are resistant to chlorination because the chlorine is adsorbed by the GAC.[30–32]

*Sedimentation*

Sedimentation is the separation of suspended particles such as sand and silt that are large enough to settle rapidly by gravity. Most microorganisms, especially protozoan cysts, also settle eventually, but this takes much longer.[33] Simply allowing the water to sit undisturbed for about 1 h or until sediment has formed on the bottom of the container and then decanting or filtering the clear water from the top through a coffee filter or finely woven cloth will remove many larger particles from the water. A second method of disinfection must then be used to obtain potable water.

*Coagulation–flocculation*

Coagulation–flocculation (C-F) is a technique that has been in use since 2000 BC and remains a routine step in municipal water treatment.[34,35] C-F can remove smaller suspended particles and chemical complexes too small to settle by gravity (colloids). Coagulation is achieved with the addition of a chemical that causes particles to stick together by electrostatic and ionic forces. Flocculation is a physical process that promotes the formation of larger particles by gentle mixing. Alum (an aluminum salt), lime (alkaline chemicals principally containing calcium or magnesium with oxygen), or iron salts are commonly used coagulants. Alum is nontoxic and used in the food industry for pickling. It is readily available in most chemical supply stores and some grocery stores. C-F removes 60 to 98% of microorganisms, heavy metals, and some chemicals and minerals.[36,37] The tendency of microorganisms to clump with small particles or clump together to form larger aggregates enhances their removal by C-F. C-F also has the benefit of reducing the amount of chemical disinfectant needed because turbidity increases demand for disinfectants such as hypochlorite.[37–39]

The amount of alum added in the field, approximately 1 large pinch (1 mL or 1/8 tsp) per 4 L (approximately 1 gal) of water, need not be precise. Stir or shake briskly for 1 min to mix, and then agitate gently and frequently for at least 5 min to assist flocculation. If the water is still cloudy, add more flocculent and repeat mixing. After at least 30 min for settling, pour the water through a fine-woven cloth or paper filter. Although most microorganisms are removed with the floc, a final process of microbiologic filtration or chemical disinfection (below) should be completed to ensure disinfection. Several products combine C-F with halogen disinfection, which allows a single-step process.[40–43]

*Improvisational techniques for clarification*

Many inorganic and organic compounds can be used as a coagulant, including lime (calcium oxide) or potash (from wood ash).[44] In an emergency, bleaching powder, baking powder, or even the fine white ash from a campfire can be used.[45] Other C-F agents used traditionally by native peoples include seed extracts from the nirmali plant in southern India, moringa plants in Sudan, crushed almonds, dried and crushed beans, and rauwaq (a form of bentonite clay).[46]

Adsorbents such as charcoal, clay, and other types of organic matter have been used for water treatment since biblical times.[32] These substances are used as the filter media and also can act as coagulants.[47] Clays can decrease turbidity and microbes in water by about 90% to 95%, but adsorption is not the main action of ceramic or clay filters.

Assessment of supporting evidence:

- Clarification reduces cloudiness, particulate matter, and waterborne microorganisms; improves the taste and esthetics of water; and improves the effectiveness of chemical disinfectants, filtration, and ultraviolet disinfection. However, it does not reliably disinfect if used alone. **Evidence grade: 1A**
- GAC is highly effective at removing taste and odor compounds but is not adequate for microbial removal. **Evidence grade: 1A**

- Sedimentation is effective for removing large particles such as sand and dirt but will not remove suspended or dissolved substances (see C-F). **Evidence grade: 2B**
- C-F removes most microorganisms, but it does not reliably disinfect if used alone. **Evidence grade: 1A**
- Traditional or improvisational C-F techniques (other than alum or those used in municipal disinfection plants) have empiric evidence but do not have robust scientific evidence or practical use guidance and should be used with caution to protect the health of consumers. **Evidence grade: 2C**

## Disinfection Methods

### HEAT

Heat is the oldest and most reliable means of water disinfection. Heat inactivation of microorganisms is a function of time and temperature (exponential function of first-order kinetics). Thus, the thermal death point is reached in a shorter time at higher temperatures, whereas lower temperatures are effective if applied for a longer time. Pasteurization uses this principle to kill food pathogens and spoiling organisms at temperatures well below boiling, generally between 60°C (140°F) and 70°C (158°F). Flash pasteurization occurs within 30 s at 70 to 72°C (158−162°F).[48,49]

All common enteric pathogens are readily inactivated by heat at pasteurization temperatures, although microorganisms vary in heat sensitivity, with protozoan cysts being the most sensitive to heat, bacteria intermediate, and viruses less sensitive (Table 1[50−62]).[50,51] Only bacterial spores are more resistant, but they are not generally enteric pathogens.[52]

As enteric pathogens are killed within seconds by boiling water rapidly at temperatures > 60°C (140°F), the traditional advice to boil water for 10 min to ensure potable water is excessive. The time required to heat water from 55°C (131°F) to a boil works toward disinfection; therefore, any water brought to a rapid boil should be adequately disinfected.[63] Boiling for 1 min is recommended by the US CDC to account for user variability in identifying boiling points and adds a margin of safety. The boiling point decreases with increasing altitude, but this is not significant compared with the time required for thermal death at these temperatures (Table 2).

#### *Improvisational techniques*

In wilderness or travel environments, the main limitation for using heat is availability of fuel. Although attaining boiling temperature is not necessary to kill microorganisms, boiling is the only easily recognizable endpoint without use of a thermometer. Based on microbiologic testing, hot tap water has been proposed as a means of heat disinfection.[64,65]

Most water from hot water taps measured in countries outside the United States measured 55 to 60°C (131 to 140°F).[51] As a rule of thumb, water too hot to touch fell within the pasteurization range, but tolerance to touch is too variable to be reliable.[66]

If no reliable method of water treatment is available, tap water that has been kept hot in a tank for at least 30 min and is too hot to keep a finger immersed for 5 s (estimated 55 to 65°C; 131 to 149°F) is a reasonable alternative. However, this improvisational measure is less useful for hotels that use on-demand water heaters without a hot water tank. Travelers with access to electricity can boil water with either a

**Table 1.** Heat inactivation of microorganisms

| *Organism* | *Lethal temperature/Time* | *Reference* |
|---|---|---|
| Protozoan cysts, including *Giardia, Entamoeba histolytica* | 50°C (122°F) for 10 min<br>55°C (131°F) for 5 min<br>100°C (212°F) immediately | 53−55 |
| *Cryptosporidium oocysts* | 55°C (131°F) warmed over 20 min<br>64°C (148°F) within 2 min | 50,56 |
| Parasitic eggs, larvae, and cercariae | 50°C−55°C (122−131°F) | 57 |
| Common bacterial enteric pathogens (*E coli*, *Salmonella*, *Campylobacter*, *Shigella*) | 55°C (131°F) for 30 min or 65°C (149°F) for less than 1 min (standard pasteurization temperatures) | 48,51 |
| Viruses | 56°C−60°C (133−140°F) in less than 20−40 min | 52,58,59 |
| Hepatitis A virus | 98°C (208°F) for 1 min<br>75°C (167°F) for less than 0.5 min<br>85°C (185°F) for 1 min or less (in various food products) | 60−62 |

**Table 2.** Boiling temperatures at various altitudes

| *Altitude (ft)* | *Altitude (m)* | *Boiling point* |
|---|---|---|
| 5000 | 1524 | 95°C (203°F) |
| 10,000 | 3048 | 90°C (194°F) |
| 14,000 | 4267 | 86°C (187°F) |
| 19,000 | 5791 | 81°C (178°F) |

small electric heating coil or a lightweight electric beverage warmer brought from home. In austere and desperate situations with hot, sunny climate, pasteurization temperature can be achieved with a solar oven or simple reflectors[67,68] (see the Solar UV Disinfection [UV−SODIS] section).

Assessment of supporting evidence:

- Bringing water to boil (100°C/212°F) will kill pathogenic microorganisms. **Evidence grade: 1A**
- Bringing water at 5000 m (16,000 ft) elevation to boil (83°C/181°F) will kill pathogenic organisms. **Evidence grade: 1B**
- Tap water that has been tanked for 30 min or longer and is too hot to touch (60°C) has a significantly reduced number of pathogenic microorganisms, but this cannot be relied on as the sole means of disinfection. Such water may contain increased amounts of lead or other chemicals from the water heater and piping. **Evidence grade: 2B**
- Pasteurization temperatures can be achieved with a solar oven. **Evidence grade: 2B**

## ULTRAVIOLET LIGHT

Ultraviolet (UV) radiation and UV lamp disinfection systems are widely used to disinfect drinking water at the community and household levels. At sufficient doses, all waterborne enteric pathogens are inactivated by UV radiation (UVR). UVC light in the range of 200 to 280 nm is the most effective. The germicidal effect of UV light is the result of action on the nucleic acids of microorganisms and depends on light intensity and exposure time. In sufficient doses of energy, all waterborne enteric pathogens are inactivated by UVR.[69] The UV waves must strike the organism, so the water must be free of particles that could act as a shield.[70] The UV waves do not alter the water, but they also do not provide any residual disinfecting power.[71] Bacteria and protozoan parasites generally require lower doses than do enteric viruses and bacterial spores. However, all viruses, including hepatitis A and norovirus, are susceptible, with relatively minor differences, and follow similar kinetics. The vegetative cells of bacteria are significantly more susceptible to UVR than are bacterial spores or viruses. *Giardia* and *Cryptosporidium* are susceptible to practical doses of UVR and may be more sensitive because of their relatively large size.[72−74] Both large high-volume units and portable, lightweight battery-operated units are available for disinfection of small quantities of water.

### *Improvisational technique: UV-SODIS*

UV irradiation by sunlight can substantially improve the microbiologic quality of water and reduce diarrheal illness in developing countries.[75−85] The optimal procedure for the SODIS technique is to use transparent bottles (eg, clear plastic beverage bottles), preferably lying on a dark surface and exposed to sunlight for a minimum of 4 h with intermittent agitation.[86] UV and thermal inactivation are strongly synergistic for the solar disinfection of drinking water.[67,87,88]

Assessment of supporting evidence:

- UV light is an effective means of water disinfection. **Evidence grade: 1A**
- Full sunlight exposure of clear water in a clear plastic bottle for at least 4 h significantly reduces and possibly eliminates microorganism contamination (**Evidence grade: 1B**); however, studies evaluating this technique for reduction of childhood diarrhea show mixed results. **Evidence grade: 2B**

## FILTRATION

Filters are appealing because of their simplicity and suitability for commercial production. Portable water treatment products are the third highest intended purchase of outdoor equipment, after backpacks and tents.[89] Filtration is a standard step in municipal water treatment and widely used in the food and beverage industry and in many other industrial processes. Many different types of media, from sand to vegetable products to fabric have been used for water filtration throughout history in various parts of the world.[90] Filters have the advantages of being simple and requiring no holding time. They do not add any unpleasant taste and may improve taste and appearance of water. All filters eventually clog from suspended particulate matter (present even in clear streams), requiring cleaning or replacement of the filter. As a filter clogs, it requires increasing pressure to drive the water through it, which can force microorganisms through the filter or damage the filter. A crack or eroded channel in a filter will allow passage of unfiltered water. Bacteria can grow on filter media and potentially result in some bacteria in filtered water, but pathogenic bacteria and illness have not been demonstrated.[91] Silver is often incorporated into the filter media to prevent this growth, but it is not totally effective.

The primary determinant of a microorganism's susceptibility to filtration is its size (Table 3; Figure 1). Portable filters for water treatment can be divided into microfilters with pore sizes down to 0.1 μm, ultrafilters that can remove particles as small as 0.01 μm, nanofilters with pore sizes as small as 0.001 μm or less, and reverse osmosis filters with pore sizes of 0.0001 μm or less.[69] All filters require pressure to drive the water through the filter element. The smaller the pore size, the more pressure required. Waterborne pathogens often adhere to larger particles or clump together, making them easier to remove by physical processes. Therefore, observed reductions are often greater than expected based on their individual sizes.

**Table 3.** Microorganism susceptibility to filtration

| *Organism* | *Approximate size (μm)* | *Recommended filter rating (μm)* |
|---|---|---|
| Viruses[a] | 0.03 | Ultrafilter, nanofilter, reverse osmosis |
| *Escherichia coli* | 0.5 by 3–8 | 0.2–0.4 (microfilter) |
| *Campylobacter* | 0.2–0.4 by 1.5–3.5 | |
| *V cholerae* | 0.5 by 1.5–3.0 | |
| *Cryptosporidium* oocyst | 2–6 | 1 (microfilter) |
| *Giardia* cyst | 6–10 by 8–15 | 3–5 (microfilter) |
| *Entamoeba histolytica* cyst | 5–30 (average 10) | |
| Nematode eggs | 30–40 by 50–80 | 20 (microfilter) |
| Schistosome cercariae | 50 by 100 | Coffee filter or fine cloth, or double thickness |
| *Dracunculus* larvae | 20 by 500 | closely woven cloth |

[a] Microfilters (includes most filters with pore size of 0.1–0.2 μm) can filter bacteria and protozoan cysts, but are not effective for virus removal unless designed to rely on electrostatic trapping of viruses. Hollow fiber filters with 0.02 μm pores and reverse osmosis filters are capable of filtering viruses.

Most portable filters are microfilters that can readily remove protozoan cysts and bacteria but may not remove all viruses, which are much smaller than the pore size of most field filters.[92,93] Viruses often clump together and to other larger particles or organisms, resulting in an aggregate large enough to be trapped by the filter; in addition, electrochemical attraction may cause viruses to adhere to the filter surface.[47,94,95] Through these mechanisms, mechanical filters using ceramic elements with a pore size of 0.2 μm can reduce viral loads by 2 to 3 logs (99–99.9%), but they are not adequate for complete removal of viruses.[96] Ultrafiltration membranes are required for complete microbial removal, including viruses; they can also remove colloids and some dissolved solids.[97]

Recently, hollow-fiber technology has been adapted for field use; this technology uses bundles of tube fibers whose pore size can be engineered to achieve ultrafiltration with viral removal.[98] The large surface area allows these hollow-fiber filters to have relatively high flow rates at low pressure. Small group and individual gravity or hand pump filters are available through several vendors.

Some filters on the market combine the porous filter material with other substances to help the disinfection process. This may include activated charcoal, iodine, silver, and other substances. Iodine molecules can be bound in a resin engineered into field products, but the effectiveness of the resin is highly dependent on the product design and function. Most companies have abandoned iodine resin–containing portable hand-pump filters due to excess iodine or viral breakthrough in the effluent. Only one drink-through bottle remains on the US market, but other products may still be available outside the United States. (GAC was discussed earlier, and silver is addressed later.)

Several factors influence the decision of which filter to buy: 1) flow volume sufficient for the number of persons relying on the filter; 2) whether the filter functional claims

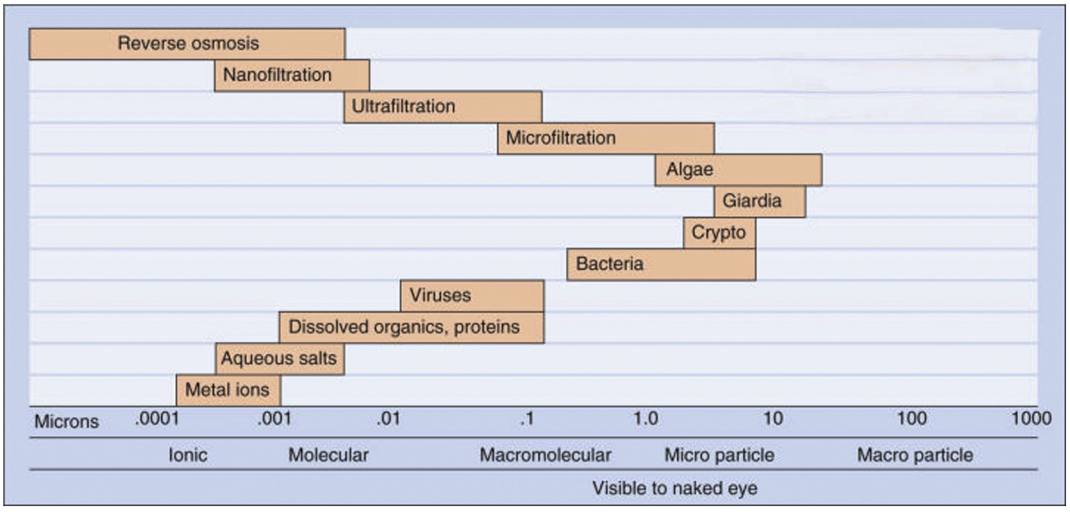


**Figure 1. Levels of filtration and susceptibility of common microbial pathogens and other contaminants.** Adapted from Backer H. Water disinfection for international travelers. In: Keystone JS, Kozarsky PE, Connor BA, eds. *Travel Medicine*. 4th ed. Philadelphia, PA: Elsevier; 2019:31–41. Copyright 2019, reprinted with permission from Elsevier.

matches the microbiologic demands that will be put on the filter; 3) the preferred means of operation (eg, hand pump or gravity); and 4) cost.

*Improvisational filtration techniques*

Filtration using simple, available products, such as rice hull ash filters, crushed charcoal, sponges, and various fabrics and paper, have all been used in developing countries and in emergency situations. Typically, bacteria and viruses can be reduced by as much as 50 to 85% and larger parasites by 99%, depending on the media. The effectiveness for decreasing turbidity may be used as an indicator that a filter material will reduce microbiologic contamination.[38,99,100]

Ceramic filters are a common component in portable water pump filters, but they are also a cost-effective means of household disinfection in developing countries. Ceramic clay is widely available and very inexpensive to locally manufacture in the shape of a sink or flower pot that is set into a larger container that collects the filtered water.[101–107]

Biosand filters use a technology that has been used over centuries and is still used widely in municipal plants and at the household and community level.[108–111] Sand filters can be highly effective at removing turbidity (in 1 study, from 6.2 NTU to 0.9 NTU) and improving microbiologic quality (99% efficacy), depending on their design and operation.[112,113] Sand filters are constructed by forming layers of aggregate increasing in size from the top to the bottom. The top layer is very fine sand and the bottom layer consists of large gravel. The container needs an exit port on the bottom. The top layer forms a biolayer that is important for the function of the filter. The optimum depth of a community or household sand filter is 2 m, with diameter determined by the volume of water needed. An emergency sand filter can be made in a 20 L (5.3 gal) bucket, composed of a 10 cm (3.9 in) layer of gravel beneath a 23 cm (9.1 in) layer of sand; a layer of cotton cloth, sandwiched between 2 layers of wire mesh, separates the sand and gravel layers.[38] A sand filter also can be improvised with stacked buckets of successive filter layers with holes in the bottom to allow water passage. Many websites provide design and assembly instructions, but there are no data for comparative function.

Assessments of supporting evidence:

- Filtration is effective as a primary or adjunctive means of water treatment. **Evidence grade: 1A**
- Standard commercially available microfilters with a pore size of 0.2 microns are effective in removing protozoa and bacteria. **Evidence grade: 1A**
- Ultrafiltration with pore size of less than 0.01 is needed to completely remove pathogenic viruses. **Evidence grade: 1A**
- Filters may clog, so users should know how to clean them or consider carrying a backup method of disinfection. **Evidence grade: 1C**
- Biosand filters are a reasonable improvised technique for filtration. **Evidence grade: 1B**

## CHEMICAL DISINFECTION: HALOGENS (IODINE AND CHLORINE)

Worldwide, disinfection with chemicals, chiefly chlorine, is the most commonly used method for improving and maintaining the microbiologic quality of drinking water and can be used by individuals and groups in the field.[114] The germicidal activity of chlorine and other halogens is well established and results from oxidation of essential cellular structures and enzymes.[115,116] Disinfection effectiveness is determined by characteristics of the microorganism, the disinfectant, contact time, and environmental factors. Both chlorine and iodine are widely available worldwide in multiple formulations. The most commonly available form of chlorine is hypochlorite (household bleach [5–8%] or concentrated swimming pool granules or tablets [70%]).

Both chlorine and iodine have been used for water disinfection for more than a century. Hypochlorite, the major chlorine disinfectant, is currently the preferred means of municipal water disinfection worldwide. Both calcium hypochlorite ($Ca[OCl]_2$) and sodium hypochlorite (NaOCl) readily dissociate in water to form hypochlorite, the active disinfectant.

Iodine is also effective in low concentrations for killing bacteria, viruses, and some protozoan cysts; in higher concentrations, it is effective against fungi and even bacterial spores. However, it is a poor algaecide. Elemental iodine ($I_2$) and hypoiodous acid (HOI) are the major germicides in an aqueous solution. Iodine is the only halogen that is a solid at room temperature.

Given adequate concentrations and contact times, both iodine and chlorine are effective disinfectants with similar biocidal activity under most conditions.[117] Taste preference is individual. Of the halogens, iodine reacts least readily with organic compounds and is less affected by pH, indicating that low iodine residuals should be more stable and persistent than corresponding concentrations of chlorine. Despite these advantages, because of its physiologic activity, WHO recommends iodine only for short-term emergency use.

Chlorine is still advocated by the WHO and the CDC as a mainstay of large-scale community, individual household, and emergency use.[118,119] There are extensive data on effectiveness of hypochlorite in remote settings.[69,120–122]

The CDC/WHO safe water system for household disinfection in developing countries provides a dosage of 1.875 or 3.75 mg·L$^{-1}$ of sodium hypochlorite with a contact time of 30 min, which is sufficient to inactivate most bacteria, viruses, and some protozoa that cause waterborne diseases.[123] Another advantage of hypochlorite is the ease of adjusting the dose for large volumes of water.[45,99]

Vegetative bacteria (nonspore forming) are very sensitive to halogens.[116,124] Viruses, including hepatitis A, have intermediate sensitivity, requiring higher concentrations or longer contact times.[125–130] Protozoan cysts are more resistant than enteric bacteria and enteric viruses but some cysts (eg, *Giardia*) can be inactivated by field doses of halogens.[131–135] *Cryptosporidium* oocysts, however, are much more resistant to halogens, and inactivation is not practical with common doses of iodine and chlorine used in field water disinfection.[136,137] Little is known about *Cyclospora*, but it is assumed to be similar to *Cryptosporidium*. Certain parasitic eggs, such as those of *Ascaris*, are also resistant, but these are not commonly spread by water. (All of these resistant cysts and eggs are susceptible to heat or filtration.) Bacterial spores, such as *Bacillus anthracis*, are relatively resistant to halogens. With chlorine, however, spores are not much more resistant than are *Giardia* cysts; furthermore, they do not normally cause waterborne enteric disease. Relative susceptibility between organisms is similar for iodine and chlorine (Table 4).

Understanding factors that influence the disinfection reaction allows flexibility with greater reassurance. The primary factors of the first-order chemical disinfection reaction are concentration and contact time.[133] To achieve microbial inactivation in aqueous solution with a chemical agent, a residual concentration must be present for a specified contact time. Lower concentrations can be used with longer contact times. In field disinfection, this can be used to minimize halogen dose and improve taste or, conversely, to minimize the required contact time.

Cold water slows chemical reactions; the reaction rate can be adjusted by longer contact times or higher concentration of disinfectant chemical. Another important factor in chemical disinfection is the presence of organic and

**Table 4.** Disinfection data for chlorine and iodine to achieve 99.9% kill or inactivation[a] of select microorganisms

| *Organism* | *Concentration (mg·L$^{-1}$)* | *Time (min)* | *pH* | *Temp* | *Disinfection constant (Ct)*[a] | *Reference* |
|---|---|---|---|---|---|---|
| Chlorine | | | | | | |
| *Escherichia coli* | 0.1 | 0.16 | 6.0 | 5°C (41°F) | 0.016 | 116 |
| *Campylobacter* | 0.3 | 0.5 | 6.0–8.0 | 25°C (77°F) | 0.15 | 124 |
| 20 enteric virus | 0.5 | 60 | 7.8 | 2°C (36°F) | 30 | 138 |
| 6 enteric viruses | 0.5 | 4.5 | 6.0–8.0 | 5°C (41°F) | 2.5 | 125 |
| Norovirus | 1 | 10 | 6.0 | 5°C | 10 | 126 |
| | 5 | 20 sec | | | 1.66 | |
| Hepatitis A virus | 0.5 | 1 | 6.0 | 25°C (77°F) | 0.5 | 127 |
| Amebic cysts | 3.5 | 10 | | 25°C (77°F) | 35 | 139 |
| *Giardia* cysts | 2.5 | 60 | 6.0–8.0 | 5°C (41°F) | 150 | 140 |
| *Giardia lamblia* cysts | 0.85 | 90 | 8.0 | 2–3°C (36–37°F) | 77 | 135 |
| *Giardia muris* cysts | 3.05 | 50 | 7.0 | 5°C (41°F) | 153 | 134 |
| *Cryptosporidium* (2 strains) | 20 | 755 | 7.5 | 23°C | 15,300 | 141 |
| | 20 | 501 | 7.5 | 23°C | 10,400 | |
| Iodine | | | | | | |
| *Escherichia coli* | 1.3 | 1 | 6.0–7.0 | 2–5°C (36–41°F) | 1.3 | 31 |
| Hepatitis A‡ | 8 | .4 | 7.0 | 25°C | 3 | 142 |
| Coxsackie virus | 0.5 | 30 | 7.0 | 5°C (41°F) | 15 | 143 |
| Amebic cysts | 3.5 | 10 | | 25°C (77°F) | 35 | 139 |
| *Giardia* cysts | 4 | 15 | 5.0 | 30°C (86°F) | 60[b] | 131 |
| *Giardia* cysts | 4 | 45 | 5.0 | 15°C (59°F) | 170[b] | 131 |
| *Giardia* cysts | 4 | 120 | 5.0 | 5°C (41°F) | 480[b] | 131 |

[a] 99.9% is for comparison of disinfection potency and microorganism susceptibility. The standard for potable water is 99.99% kill for viruses and 99.999% for bacteria. This would be achieved in each example with a higher concentration of disinfectant or a longer contact time.

[b] 100% kill; viability tested only at 15, 30, 45, 60, and 120 min.

inorganic contaminants, mainly nitrogen compounds from decomposition of organisms and their wastes, fecal matter, and urea. These contaminants react, especially with chlorine, to form compounds with little or no disinfecting ability, effectively decreasing the concentration of available halogen.[26,115] Halogen demand is the amount of halogen reacting with impurities. Residual concentration is the amount of active disinfectant remaining after demand of the water is met. Halogen demand is associated with turbidity (cloudiness).[39] Typical recommendations for field treatment double the amount of chlorine or iodine in cloudy water; however, it is preferable to use clarification techniques prior to chemical disinfection in cloudy water to improve efficacy and taste.[144,145]

Because of the difficulty of estimating halogen demand, it is prudent to use 3 to 4 mg·L$^{-1}$ as a target halogen concentration range for clear surface water. Lower concentrations (eg, 2 mg·L$^{-1}$) can be used for back-up treatment of questionable tap water or high-quality well water (Tables 5 and 6).

### *Halogen toxicity*

Chlorine has no known toxicity at the concentrations used for water disinfection. Sodium hypochlorite is not

**Table 5.** Halogen disinfection products and recommended doses

| | *Add to 1 L or qt of water* | |
|---|---|---|
| *Iodination techniques*[a] | *Amount to achieve 4 mg·L$^{-1}$* | *Amount to achieve 8 mg·L$^{-1}$* |
| Iodine tabs[b]<br>Tetraglycine hydroperiodide<br>Emergency drinking water germicidal tablet<br>Potable aqua<br>Globaline | 0.5 tab (or 1 tab in 2 L) | 1 tab |
| 2% iodine solution (tincture) | 0.2 mL<br>5 drops[c] | 0.4 mL<br>10 drops |
| 10% povidone-iodine solution[d] | 0.35 mL<br>8 drops | 0.70 mL<br>16 drops |
| Saturated solution: iodine crystals in water[e] | 13 mL | 26 mL |
| Chlorination techniques[f] | Amount to achieve 2 mg·L$^{-1}$ | Amount to achieve 5 mg·L$^{-1}$ |
| Sodium hypochlorite (household bleach 5%) | 1 drop | 0.1 mL<br>2 drops |
| Sodium hypochlorite (household bleach 8.25%) | 1 drop (in 2 L) | 1 drop |
| 1% bleach (CDC-WHO Safe Water System)[g] | 4–5 drops | 8–10 drops |
| Calcium hypochlorite[h] (Redi Chlor [0.1-g tab]) | Cannot use in small quantities for low concentrations | 0.25 tab |
| Sodium dichloroisocyanurate (NaDCC)[i] (Aquatab, Kintab) | 0.25 tab of 8.5 mg NaDCC (may be impractical) | 0.5 tab (8.5 mg NaDCC) |
| Chlorine plus flocculating agent (Chlor-Floc) | Not practical for small volumes | 0.5 tablet per gal yields 5 mg·L$^{-1}$ |

[a] World Health Organization recommends only for short-term emergency use.

[b] Iodine tablets were developed by the military with the criteria that they will disinfect water, including for *Giardia*, with a short contact (holding) time of 10 min because troops in the field may not wait longer. This high concentration is not necessary for field disinfection of clear water; it is preferable to target 4 mg·L$^{-1}$ and wait longer. Additionally, the recommendation to use 8 mg·L$^{-1}$ for cloudy water will result in poor taste, so it is recommended to clarify the water first.

[c] Measure of a drop varies from 16–24 gtt·mL$^{-1}$, standard 20 gtt·mL$^{-1}$ is used here.

[d] Povidone-iodine solutions release free iodine in levels adequate for disinfection, but scant data are available (see text).

[e] A small amount of elemental iodine goes into solution (no significant iodide is present); the saturated solution is used to disinfect drinking water. Water can be added to the crystals hundreds of times before they are completely dissolved.

[f] Can easily be adapted to large or small quantities of water. Simple field test kits or swimming pool test kits with color strips are widely available to ensure adequate residual chlorine. In usual situations, EPA recommends a target residual of 4 mg·L$^{-1}$. For household use, the CDC recommends <2 mg·L$^{-1}$. Many of the recommended emergency doses exceed this threshold.[97] For treatment of large volumes, see formula to calculate in Lantagne (2008).[20]

[g] Safe water system for long-term routine household point-of-use water disinfection recommends a hypochlorite dose of about 2 mg·L$^{-1}$ in clear water and 4 mg·L$^{-1}$ in slightly turbid water. This results in a low yet effective target residual concentration but requires testing in a particular water source to ensure sufficient residual.

[h] Stable, concentrated (70%), dry source of hypochlorite that is used for chlorination of swimming pools. Multiple products available in various size tablets or granular form. Best formulation for large quantities of water.

[i] Available in different strengths to treat different volumes of water. Check packaging to determine proper dose.

**Table 6.** Recommendations for contact time using halogen disinfection in the field

| *Concentration of halogen* | *Contact time (min) at various water temperatures* | | |
|---|---|---|---|
| | *5°C (41°F)* | *15°C (59°F)* | *30°C (86°F)* |
| 2 ppm | 240 | 180 | 60 |
| 4 ppm | 180 | 60 | 45 |
| 8 ppm | 60 | 30 | 15 |

Concentration and contact time are based on the most resistant organism, which is the *Giardia* cyst. These are well beyond the time needed to kill bacteria and viruses. These contact times have been extended from the usual recommendations in cold water to account for the extended inactivation time required in very cold water and for the uncertainty of residual concentration.

carcinogenic; however, reactions of chlorine with certain organic contaminants yield chlorinated hydrocarbons, chloroform, and other trihalomethanes, which are considered to have carcinogenic potential in animal models. Nevertheless, the risk of severe illness or even death from infectious diseases if disinfection is not used far exceeds any risk from byproducts of chlorine disinfection.[146]

Despite several advantages over chlorine disinfection, iodine has not gained general acceptance because of concern for its physiologic activity. Some older data indicate that iodination of water with a low residual concentration of $\leq 1$ to 2 $mg \cdot L^{-1}$ appears safe, even for long periods of time, in people with normal thyroid function.[147,148] This is not the current recommendation of major agencies. Recently, the European Union stopped the sale of iodine products used for water disinfection. The WHO did not set a guideline value for iodine in drinking water because of a paucity of data and because it is not recommended for long-term disinfection. If the typical wilderness or international traveler disinfected 3 L of water a day using 2 to 4 $mg \cdot L^{-1}$ of iodine, the ingested amount of iodine would be 6 to 12 $mg \cdot d^{-1}$, well above US Institute of Medicine recommended dietary allowance levels. Levels produced by the recommended doses of iodine tablets are even higher (16—32 $mg \cdot d^{-1}$). Therefore, the use of iodine for water disinfection should be limited to short periods of $\leq 1$ mo. Individuals planning to use iodine for prolonged periods should have their thyroid examined and thyroid function tests done to ensure they are initially euthyroid. Certain groups should not use iodine for water treatment: pregnant women (because of concerns of neonatal goiter); those with known hypersensitivity to iodine; persons with a history of thyroid disease, even if controlled on medication; persons with a strong family history of thyroid disease (thyroiditis); and persons from countries with chronic iodine deficiency.[149]

### *Improving halogen taste*

Objectionable taste and smell limit the acceptance of halogens, but taste can be improved by several means. One method is to use the minimum necessary dose with a longer contact time, as in the CDC safe water system. Another method is to use higher doses and remove the taste through chemical reduction of chlorine to chloride and iodine to iodide; these have no color or taste. The best and most readily available agent is ascorbic acid (vitamin C), available in crystalline or powder form. A small pinch in a liter, mixed after the required contact time, will usually suffice. Ascorbic acid is a common ingredient of flavored drink mixes, accounting for their effectiveness in removing the taste of halogens. GAC (see above) adsorbs organic and inorganic chemicals, including iodine and chlorine byproducts, thereby improving odor and taste—the reason for its common inclusion in field filters.

### *Improvisational techniques*

There is no comparable substitute for proven chemical disinfectants, but there are many common substances that contain halogens. Household bleach is available in most parts of the world. The active disinfectant is sodium hypochlorite. Products for disinfection of swimming pools and spas generally contain calcium hypochlorite that provides much higher concentrations than bleach. Hypochlorite is readily released from different products formulated in liquid, powder, granules, and tablets. Iodine is also available in liquid or tablets; a common household source is tincture of iodine or similar topical disinfectants with an iodine concentration of 2 to 8%. These products also contain iodide, which has no disinfecting power but does contribute to iodine toxicity. Colorless iodine solution contains only iodide and should not be used. Povidone-iodine, a topical disinfectant commonly used in medical settings, contains active iodine bound to a neutral polymer of high molecular weight that gives the iodine greater solubility and stability. In dilute aqueous solution, povidone-iodine provides a sustained-release reservoir, releasing free iodine in a concentration of 2 to 10 $mg \cdot L^{-1}$.[150]

## MIXED SPECIES DISINFECTANT (ELECTROLYSIS)

Passing a current through a simple brine salt solution generates free available chlorine and other mixed species disinfectants that have been shown to be effective against bacteria, viruses, *Cryptosporidium*, and bacterial spores.[151,152] The process is well described and can be

used on both large and small scales. The main disinfectant effect is probably attributable to a combination of chlorine dioxide, ozone, superoxides, and hypochlorous acid, giving the resulting solution greater disinfectant ability than a simple solution of sodium hypochlorite. Small units are now available commercially that use salt, water, and a 12-volt direct current (automobile) battery to create 60 mL of a 0.75% chlorine solution over a 5-min operation cycle that will treat up to 200 L of water.

Other common substances, including hydrogen peroxide and citrus juice that have some disinfectant activity, are discussed later.

Assessments of supporting evidence:

- Halogens chlorine and iodine are an effective means of disinfecting water of bacteria, viruses, and *Giardia* in the field or household when using appropriate contact time and halogen concentration. **Evidence grade: 1A**
- Usual field concentrations of iodine and chlorine are not effective for other protozoa including *Cryptosporidium* and *Cyclospora*. **Evidence grade: 2A**
- Extended use of iodine should be weighed against risks of iodine toxicity. **Evidence grade: 1B**
- Simple techniques for improving taste of halogenated water are available for field use. **Evidence grade: 1B**
- Mixed species electrolytic disinfection techniques are effective for water disinfection of microbes that are susceptible to halogens. **Evidence grade: 1B**

## MISCELLANEOUS DISINFECTANTS

### *Chlorine dioxide*

Chlorine dioxide ($ClO_2$), a potent biocide, has been used for many years to disinfect municipal water and in numerous other large-scale applications. Until recently, the benefits of chlorine dioxide have been limited to large-scale applications because standard formulations must be made on-site and are associated with a risk for producing volatile gas. Newer methods enable cost-effective and portable $ClO_2$ generation and distribution for use in an ever-widening array of small-scale applications. $ClO_2$-production tablets contain 6.4% sodium chlorite as the active ingredient. After a tablet is added to water, a series of complex chemical reactions occurs, generating chlorine dioxide. Some of the intermediary chemical compounds may also have antimicrobial activity.

$ClO_2$ has no taste or odor in water. It is capable of inactivating most waterborne pathogens, including *Cryptosporidium parvum* oocysts.[153–155] It is at least as effective a bactericide as chlorine and far superior for virus and parasite inactivation. Several commercial point-of-use applications use $ClO_2$ in liquid or tablet form, but relatively few data are available on product testing these products.[137] A major disadvantage for field use of tablets is the long reaction or contact time required, with upward of 2 to 4 h needed to achieve dependable disinfection. $ClO_2$ does not produce a lasting residual, and water undergoing chlorine dioxide disinfection must be protected from sunlight.

Assessment of supporting evidence:

- Chlorine dioxide is a widely used and potent water disinfectant, including efficacy against the protozoan parasites *Cryptosporidium*. **Evidence grade: 1A**
- Individual use products have limited data demonstrating effective concentration and contact time. **Evidence grade: 2B**

### *Silver*

Silver ion has bactericidal effects in low doses and some attractive features, including absence of color, taste, and odor. Scant data for disinfection of viruses and protozoan cysts indicate limited effect, even at high doses. Moreover, the concentrations are strongly affected by adsorption onto the surface of any container. Silver is physiologically active but not likely to cause a problem in concentrations found in drinking water. The EPA has not approved silver for primary water disinfection in the United States, but silver is approved as a water preservative to prevent bacterial growth in previously treated and stored water. In Europe, silver tablets are sold for field water disinfection. One rational combination product combines silver with hypochlorite for both disinfection and preservation. There is some promise in steady release products and incorporation into nanoparticles.[156]

Assessment of supporting evidence:

- Use of silver in wilderness settings should be limited to water preservation and not as a primary disinfectant. **Evidence grade: 1B**

### *Hydrogen peroxide*

Hydrogen peroxide is a strong oxidizing agent that is widely used as a preservative in food, as a sterilant for medical and food equipment, and in many other applications. Although hydrogen peroxide can sterilize water, it is not widely used as a field water disinfectant, perhaps because high concentrations known to be effective are very caustic, and there is a lack of data for protozoal cysts and quantitative data for dilute solutions. It can be used to remove the taste of hypochlorite and in combination with other processes.[157]

Assessment of supporting evidence:

- Hydrogen peroxide in typical concentration of 3% cannot be used as a primary drinking water disinfectant, and

**Table 7.** Summary of field water disinfection techniques

| | *Bacteria* | *Viruses* | Giardia/*Ameba* | Cryptosporidium | *Nematodes/Cercarea* |
|---|---|---|---|---|---|
| Heat | + | + | + | + | + |
| Filtration | + | +/−[a] | + | + | + |
| Halogens | + | + | + | − | +/−[b] |
| Chlorine dioxide and photocatalytic | + | + | + | + | DNA[b] |

DNA, data not available.

[a] Most filters make no claims for viruses. Ultrafiltration with hollow fiber technology and reverse osmosis is effective.

[b] Eggs are not very susceptible to halogens but have very low risk of waterborne transmission. No data available for photocatalytic disinfection.

effective concentrations are not practical for field use. **Evidence grade: 1B**

### *Citrus and potassium permanganate*

Both citrus juice and potassium permanganate have some demonstrated antibacterial effects in an aqueous solution.[158] However, data are few and not available for effect on cysts. In municipal water disinfection, potassium permanganate is used primarily for reducing contaminants to improve taste and odor.[159] Either substance could be used in an emergency to reduce bacterial and viral contamination or as an adjunct in combination with another technique, but they cannot be recommended as a primary means of water disinfection.

Assessment of supporting evidence:

- Citrus juice and potassium permanganate have limited applications for drinking water disinfection. **Evidence grade: 1C**

### *Nanoparticles: solar photocatalytic disinfection*

Several nanomaterials have been shown to have strong antimicrobial properties and are being evaluated for use in water disinfection and purification.[160,161] The metals are of particular interest for water disinfection applications because they can be activated by UV light to produce potent oxidizers that are excellent disinfectants for microorganisms and can break down complex organic contaminants and even most heavy metals into nontoxic forms. Titanium

**Table 8.** Efficacy and effectiveness of point-of-use technologies for developing world households

| *Treatment process* | *Pathogen* | *Optimal log reduction*[a] | *Expected log reduction*[b] | *Diarrheal disease reduction (%)*[c] |
|---|---|---|---|---|
| Ceramic filters | Bacteria | 6 | 2 | 63 (51−72) for candle filters |
| | Viruses | 4 | 0.5 | 46 (29−59) for bowl filters |
| | Protozoa | 6 | 4 | |
| Free chlorine | Bacteria | 6 | 3 | 37 (25−48) |
| | Viruses | 6 | 3 | |
| | Protozoa | 5 | 3 | |
| Coagulation/Chlorination | Bacteria | 9 | 7 | 31 (18−42) |
| | Viruses | 6 | 2−4.5 | |
| | Protozoa | 5 | 3 | |
| Biosand filtration | Bacteria | 3 | 1 | 47 (21−64) |
| | Viruses | 3 | 0.5 | |
| | Protozoa | 4 | 2 | |
| SODIS | Bacteria | 5.5 | 3 | 31 (26−37) |
| | Viruses | 4 | 2 | |
| | Protozoa | 3 | 1 | |

SODIS, solar disinfection.

Data from multiple studies, analyzed and summarized by Sobsey et al (2008).[165]

Data also from references[47,166−168] and Table 7.8 in WHO (2011).[26]

[a] Skilled operators using optimal conditions and practices (efficacy); log reduction: pretreatment minus posttreatment concentration of organisms (eg, 6 log = 99.999% removal).

[b] Actual field practice by unskilled persons (effectiveness) depends on water quality, quality, and age of filter or materials, following proper procedure, and other factors.

[c] Summary estimates from published data vary with consistency and correct use of technique, integrity of techniques (eg, cracked filter), and other household sanitation measures.

dioxide ($TiO_2$) is the most effective photocatalytic substance identified to date. Recent work demonstrated inactivation of *Cryptosporidium* by titanium dioxide.[161,162] These methods are widely used in industry, but few products have incorporated the technology into individual or small group point of use products.[163,164]

Assessment of supporting evidence:

- New technology using nanoparticles and photocatalytic disinfection is highly promising for translation into point-of-use water disinfection. **Evidence grade: 2A**

## PREFERRED TECHNIQUE

The optimal water treatment technique for an individual or group will depend on the number of persons to be served, space and weight accommodations, quality of source water, personal taste preferences, and fuel availability. Because halogens are not effective for killing *Cryptosporidium* at drinking water concentrations and common microfilters are not reliable for virus removal, optimal protection for all situations may require a 2-step process of 1) filtration or C-F, followed by 2) halogenation. Heat (boiling) is effective as a 1-step process in all situations but will not improve the esthetics of the water. Table 7 summarizes effects of major water disinfection methods on categories of microorganisms. Persons living or working in communities where sanitation and water treatment are lacking are at higher risk than the average international traveler. Sobsey et al reviewed data for point-of-use methods for household disinfection in developing countries[165] (Table 8).

In disaster situations such as floods, hurricanes, and earthquakes, sanitation and water treatment facilities are frequently damaged or inundated, so household or point-of-use water disinfection is advised. Chlorine is the simplest method, similar to household water disinfection where there is no sanitation or improved water sources.[20,99,169] Cloudy water should first be clarified before using hypochlorite.

On long-distance ocean-going boats where water must be desalinated as well as disinfected during the voyage, only reverse osmosis membrane filters are adequate. Water storage also requires consideration. Iodine will work for short periods only (ie, weeks) because it is a poor algaecide. For prolonged storage, water should be chlorinated and kept in a tightly sealed container to reduce the risk of contamination. For daily use, narrow-mouthed jars or containers with water spigots prevent contamination from repeated contact with hands or utensils.[170]

Relatively few studies compare multiple techniques or devices.[28,92,96,168,171–179] For more detailed discussion of disinfection techniques and available devices, see Backer.[180] For reviews of water disinfection techniques and effectiveness and efficacy data, see the following additional references.[69,168,181,182]

## Sanitation

Sanitation and water treatment are inextricably linked. Studies in developing countries have demonstrated a clear benefit of safe drinking water, hygiene, and adequate sanitation in the reduction of diarrheal illness and other infections.[183–188] The benefit is greater when all are applied together, especially with appropriate education.[24,189] Personal hygiene, particularly handwashing, prevents spread of infection from food contamination during preparation of meals.[190,191] Disinfection of dishes and utensils is accomplished by rinsing in water containing enough household bleach to achieve a distinct chlorine odor. Use of halogen solutions or potassium permanganate solutions to soak vegetables and fruits can reduce microbial contamination, especially if the surface is scrubbed to remove dirt or other particulates, but neither method reaches organisms that are embedded in surface crevices or protected by other particulate matter.[192] Travelers to remote villages, wilderness areas, and persons in disaster situations should ensure proper waste disposal to prevent additional contamination of water supplies. Human waste should be buried 20 to 30 cm (8 to 12 in) deep, at least 30 m (100 ft) from any water, and at a location from which water run-off is not likely to wash organisms into nearby water sources. Groups of 3 persons or more should dig a common latrine to avoid numerous individual potholes and inadequate disposal.

## Conclusion

Wilderness and international travelers should carry an effective means of disinfecting water. It is important for disaster and medical relief workers to understand the common methods of water treatment and improvisational methods. It is not possible for travelers to judge the microbiologic quality of water, and it is prudent to assume that even tap water is nonpotable in many locations. Simple and effective field techniques to improve microbiologic water quality are available to travelers. It is important to understand the basic principles and limitations of heat, filtration, and UV and chemical disinfection and then to become familiar with at least one technique appropriate for the destination, water source, and needs of the travelers.

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## Disclaimer

Use of trade names and commercial sources is for identification only and does not imply endorsement by the Centers for Disease Control and Prevention (CDC), the US Department of Health and Human Services (HHS), or the State of California. The findings and conclusions in this report are those of the authors and do not necessarily represent those of CDC or HHS or the State of California.

## Supplementary materials

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## References


1. World Health Organization. Combating waterborne disease at the household level. Geneva, Switzerland. Available at: https://www.who.int/water_sanitation_health/publications/combating-waterborne-disease/en/; 2007. Accessed February 25, 2019.
2. Schoenen D. Role of disinfection in suppressing the spread of pathogens with drinking water: possibilities and limitations. *Water Res*. 2002;36(15):3874–88.
3. Guyatt G, Gutterman D, Baumann MH, Addrizzo-Harris D, Hylek EM, Phillips B, et al. Grading strength of recommendations and quality of evidence in clinical guidelines: report from an american college of chest physicians task force. *Chest*. 2006;129(1):174–81.
4. Yoder J, Roberts V, Craun GF, Hill V, Hicks LA, Alexander NT, et al. Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking—United States, 2005–2006. *MMWR Surveill Summ*. 2008;57(9):39–62.
5. Colford Jr JM, Hilton JF, Wright CC, Arnold BF, Saha S, Wade TJ, et al. The Sonoma water evaluation trial: a randomized drinking water intervention trial to reduce gastrointestinal illness in older adults. *Am J Public Health*. 2009;99(11):1988–95.
6. Reynolds KA, Mena KD, Gerba CP. Risk of waterborne illness via drinking water in the United States. *Rev Environ Contam Toxicol*. 2008;192:117–58.
7. McClung RP, Roth DM, Vigar M, Roberts VA, Kahler AM, Cocley LA, et al. Waterborne disease outbreaks associated with environmental and undetermined exposures to water—-United States, 2013–2014. *MMWR Morb Mortal Wkly Rep*. 2017;66(44):1222–5.
8. Derlet RW, Carlson JR. An analysis of wilderness water in Kings Canyon, Sequoia, and Yosemite national parks for coliform and pathologic bacteria. *Wilderness Environ Med*. 2004;15(4):238–44.
9. Derlet RW, Ger KA, Richards JR, Carlson JR. Risk factors for coliform bacteria in backcountry lakes and streams in the Sierra Nevada mountains: a 5-year study. *Wilderness Environ Med*. 2008;19(2):82–90.
10. Feng Y, Xiao L. Zoonotic potential and molecular epidemiology of *Giardia* species and giardiasis. *Clin Microbiol Rev*. 2011;24(1):110–40.
11. WHO-UNICEF. Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF). Available at: https://www.unicef.org/publications/files/Progress_on_Drinking_Water_Sanitation_and_Hygiene_2017.pdf; 2017. Accessed February 25, 2019.
12. Ngwenya N, Ncube EJ, Parsons J. Recent advances in drinking water disinfection: successes and challenges. *Rev Environ Contam Toxicol*. 2013;222:111–70.
13. WHO-UNICEF. *Progress on Sanitation and Drinking Water–2015 update and MDG assessment*. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF; 2015.
14. Clasen TF, Bastable A. Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *J Water Health*. 2003;1(3):109–15.
15. Gil AI, Lanata CF, Hartinger SM, Mausezahl D, Padilla B, Ochoa TJ, et al. Fecal contamination of food, water, hands, and kitchen utensils at the household level in rural areas of Peru. *J Environ Health*. 2014;76(6):102–6.
16. Kravitz JD, Nyaphisi M, Mandel R, Petersen E. Quantitative bacterial examination of domestic water supplies in the Lesotho Highlands: water quality, sanitation, and village health. *Bull World Health Organ*. 1999;77(10):829–36.
17. Rai SK, Ono K, Yanagida JI, Ishiyama-Imura S, Kurokawa M, Rai CK. A large-scale study of bacterial contamination of drinking water and its public health impact in Nepal. *Nepal Med Coll J*. 2012;14(3):234–40.
18. Haramoto E. Detection of waterborne protozoa, viruses, and bacteria in groundwater and other water samples in the Kathmandu Valley, Nepal. IOP Conference Series. *Earth Environ Sci*. 2018;120:1–7.
19. Wright J, Gundry S, Conroy R. Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Tropical Med Int Health*. 2004;9(1):106–17.
20. Lantagne D. Sodium hypochlorite dosage for household and emergency water treatment. *J Am Water Works Assoc*. 2008;100(8):106–19.
21. Wang G, Doyle M. Survival of enterohemorrhagic *Escherichia coli* O157:H7 in water. *J Food Prot*. 1998;61(6):662–7.
22. Ford TE. Microbiological safety of drinking water: United States and global perspectives. *Environ Health Perspect*. 1999;107(suppl 1):191–206.
23. Hurst C, Clark R, Regli S. Estimating the risk of acquiring infectious disease from ingestion of water. In: Hurst C, ed. *Modeling Disease Transmission and its Prevention by Disinfection*. Melbourne: Cambridge University Press; 1996:99–139.

24. Sobsey M, Handzel T, Venczel L. Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease. *Water Sci Technol*. 2003;47(3):221–8.
25. Murphy JL, Kahler AM, Nansubuga I, Nanyunja EM, Kaplan B, Jothikumar N, et al. Environmental survey of drinking water sources in Kampala, Uganda, during a typhoid fever outbreak. *Appl Environ Microbiol*. 2017;83(23):1–11.
26. World Health Organization. *Guidelines for drinking water quality*. Geneva: WHO; 2011.
27. US Environmental Protection Agency. *Report to Task Force: Guide Standard and Protocol for Testing Microbiological Water Purifiers*. Cincinnati: USEPA; 1987 (Revision).
28. Geldreich E, Reasoner D. Home treatment devices and water quality. In: McFeters G, ed. *Drinking Water Microbiology*. New York: Springer-Verlag; 1990:147–68.
29. Rosen A, Booth R. Taste and odor control. In: American Water Works Association, ed. *Water Quality and Treatment: A Handbook of Public Water Supplies*. New York: McGraw Hill; 1971.
30. US Environmental Protection Agency Drinking Water Health Effects Task Force. *Health Effects of Drinking Water Treatment Technologies*. Michigan: Lewis Publisher; 1989.
31. National Academy of Sciences Safe Drinking Water Committee. The disinfection of drinking water. In: *Drinking Water and Health*. 2;1980:5–139.
32. Le Chevallier M, McFeters G. Microbiology of activated carbon. In: McFeters G, ed. *Drinking Water Microbiology*. New York: Springer-Verlag; 1990:104–20.
33. Medema GJ, Schets FM, Teunis PF, Havelaar AH. Sedimentation of free and attached *Cryptosporidium* oocysts and *Giardia* cysts in water. *Appl Environ Microbiol*. 1998;64(11):4460–6.
34. AWWA Coagulation Committee. Committee report: coagulation as an integrated water treatment process. *J Am Water Works Assoc*. 1989:74.
35. Cohen J, Hannah S. *Water Quality and Treatment: A Handbook of Public Water Supplies*. New York: McGraw-Hill; 1971.
36. Crump JA, Okoth GO, Slutsker L, Ogaja DO, Keswick BH, Luby SP. Effect of point-of-use disinfection, flocculation and combined flocculation-disinfection on drinking water quality in western Kenya. *J Appl Microbiol*. 2004;97(1):225–31.
37. Preston K, Lantagne D, Kotlarz N, Jellison K. Turbidity and chlorine demand reduction using alum and moringa flocculation before household chlorination in developing countries. *J Water Health*. 2010;8(1):60–70.
38. Kotlarz N, Lantagne D, Preston K, Jellison K. Turbidity and chlorine demand reduction using locally available physical water clarification mechanisms before household chlorination in developing countries. *J Water Health*. 2009;7(3):497–506.
39. LeChevallier MW, Evans T, Seidler RJ. Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water. *Appl Environ Microbiol*. 1981;42(1):159–67.
40. Crump JA, Otieno PO, Slutsker L, Keswick BH, Rosen DH, Hoekstra ROM, et al. Household based treatment of drinking water with flocculant-disinfectant for preventing diarrhoea in areas with turbid source water in rural western Kenya: cluster randomised controlled trial. *BMJ*. 2005;331(7515):478–84.
41. Reller ME, Mendoza CE, Lopez MB, Alvarez M, Hoekstera RM, Olson CA, et al. A randomized controlled trial of household-based flocculant-disinfectant drinking water treatment for diarrhea prevention in rural Guatemala. *Am J Trop Med Hyg*. 2003;69(4):411–9.
42. Powers E. Efficacy of Flocculating and Other Emergency Water Purification Tablets. In: *Report Natick/TR-93/033*. Natick, MA: United States Army Natick Research, Development and Engineering Center; 1993.
43. Powers E, Boutros C, Harper B. Biocidal efficacy of a flocculating emergency water purification tablet. *Appl Environ Microbiol*. 1994;60:2316–23.
44. Islam MS, Ansaruzzaman M, Mahmud ZH, Marin MA, Malik AK, Neogi SB, et al. A novel and simple mixture as point-of-use water treatment agent to produce safe drinking water. *Trans R Soc Trop Med Hyg*. 2014;108(5):290–6.
45. US Army. Sanitary control and surveillance of field water supplies. In: *Dept. of Army Technical Bulletin (TB Med 577)*. Washington, DC: Departments of the Army, Navy, and Air Force; 2005. Available at: https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/tbmed577.pdf. Accessed February 25, 2019.
46. Chaudhuri M, Sattar S. Domestic water treatment for developing countries. In: McFeters G, ed. *Drinking Water Microbiology*. New York: Springer-Verlag; 1990.
47. Sobsey M. *Managing water in the home: accelerated health gains from improved water supply*. Geneva: WHO/SDE/WSH/02.07; 2002. Available at: https://www.who.int/water_sanitation_health/dwq/WSH02.07.pdf. Accessed February 25, 2019.
48. Frazier W, Westhoff D. *Preservation by Use of High Temperatures*. New York: McGraw-Hill; 1978.
49. Islam MF, Johnston RB. Household pasteurization of drinking-water: the chulli water-treatment system. *J Health Popul Nutr*. 2006;24(3):356–62.
50. Fayer R. Effect of high temperature on infectivity of *Cryptosporidium parvum* oocysts in water. *Appl Environ Microbiol*. 1994;60(8):273–5.
51. Bandres J, Mathewson J, DuPont H. Heat susceptibility of bacterial enteropathogens. *Arch Intern Med*. 1988;148(10):2261–3.
52. Alder V, Simpson R. Sterilization and disinfection by heat methods. In: Russel A, Hugo W, Ayliffe G, eds. *Principles and Practice of Disinfection, Preservation, and Sterilization*. 2nd ed. Oxford: Blackwell Scientific; 1992:483.
53. Aukerman R, Monzingo D. Water treatment to inactive *Giardia*. *J Forestry*. 1989;87(11):18–21.
54. Ongerth J, Johnson R, MacDonald S, Frost F, Stibbs H. Backcountry water treatment to prevent giardiasis. *Am J Public Health*. 1989;79:1633–7.

55. Bingham A, Jarroll E, EA M. Physical factors of excystation in vitro and excystation vs eosin exclusion as determinants of viability. *Exp Parasitol*. 1979;47(2):284–91.
56. Anderson B. Moist heat inactivation of *Cryptosporidium*. *Am J Public Health*. 1985;75:1433–4.
57. Shephart M. Helminthological aspects of sewage treatment. In: Feachem R, McGarry M, Mara D, eds. *Water, Wastes, and Health in Hot Climates*. New York: John Wiley and Sons; 1977:299–310.
58. Perkins J. Thermal destruction of microorganisms: Heat inactivation of viruses. In: Thomas C, ed. *Principles and Methods of Sterilization in Health Sciences*. Springfield; 1969:63–94.
59. Tuladhar E, Bouwknegt M, Zwietering MH, Koopmans M, Duizer E. Thermal stability of structurally different viruses with proven or potential relevance to food safety. *J Appl Microbiol*. 2012;112(5):1050–7.
60. Baert L, Debevere J, Uyttendaele M. The efficacy of preservation methods to inactivate foodborne viruses. *Int J Food Microbiol*. 2009;131(2–3):83–94.
61. Bidawid S, Farber JM, Sattar SA, Hayward S. Heat inactivation of hepatitis A virus in dairy foods. *J Food Prot*. 2000;63(4):522–8.
62. Krugman S, Giles J, Hammond J. Hepatitis virus: effect of heat on the infectivity and antigenicity of the MS-1 and MS-2 strains. *J Infect Dis*. 1970;122:432–6.
63. World Health Organization. Boil water. Available at: http://www.who.int/water_sanitation_health/dwq/Boiling_water_01_15.pdf?ua=1; 2015. Accessed February 25, 2019.
64. Neumann H. Alternatives to water chlorination (Correspondence). *Rev Infect Dis*. 1981;3(6):1255–7.
65. Neumann H. Bacteriological safety of hot tapwater in developing countries. *Public Health Rep*. 1969;84(9):812–4.
66. Groh C, MacPherson D, Groves D. Effect of heat on the sterilization of artifically contaminated water. *J Travel Med*. 1996;3(1):11–3.
67. McGuigan KG. Solar disinfection: use of sunlight to decontaminate drinking water in developing countries. *J Med Microbiol*. 1999;48(9):785–7.
68. Ciochetti DA, Metcalf RH. Pasteurization of naturally contaminated water with solar energy. *Appl Environ Microbiol*. 1984;47(2):223–8.
69. LeChevallier M, Kwok-Keung A. *Water Treatment and Pathogen Control*. London: UK. 2004.
70. Abd-Elmaksoud S, Naranjo JE, Gerba CP. Assessment of a portable handheld UV light device for the disinfection of viruses and bacteria in water. *Food Environ Virol*. 2013;5(2):87–90.
71. Reygadas F, Gruber JS, Ray I, Nelson KL. Field efficacy evaluation and post-treatment contamination risk assessment of an ultraviolet disinfection and safe storage system. *Water Res*. 2015;85:74–84.
72. Hijnen WA, Beerendonk EF, Medema GJ. Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: a review. *Water Res*. 2006;40(1):3–22.
73. Linden KG, Shin GA, Faubert G, Cairns W, Sobsey MD. UV disinfection of *Giardia lamblia* cysts in water. *Environ Sci Technol*. 2002;36(11):2519–22.
74. Zimmer JL, Slawson RM, Huck PM. Inactivation and potential repair of *Cryptosporidium* parvum following low- and medium-pressure ultraviolet irradiation. *Water Res*. 2003;37(14):3517–23.
75. McGuigan KG, Conroy RM, Mosler HJ, Preez du M, Ubomba-Jaswa E, Fernandez-Ibañez P. Solar water disinfection (SODIS): a review from bench-top to roof-top. *J Hazard Mater*. 2012;235–236:29–46.
76. Berney M, Weilenmann HU, Simonetti A, Egli T. Efficacy of solar disinfection of *Escherichia coli, Shigella flexneri, Salmonella typhimurium* and *Vibrio cholerae*. *J Appl Microbiol*. 2006;101(4):828–36.
77. Cervantes DXF. *Feasibility of semi-continuous solar disinfection system for developing countries at the household level*. Massachusetts Institute of Technology; 2003. Available at: http://hdl.handle.net/1721.1/29551. Accessed February 25, 2019.
78. Joyce T, McGuigan K, Elmore-Meegan M, Conroy R. Inactivation of fecal bacteria in drinking water by solar heating. *Appl Environ Microbiol*. 1996;62(2):399–402.
79. Conroy RM, Meegan ME, Joyce T, McGuigan K, Barnes J. Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Arch Dis Child*. 2001;85(4):293–5.
80. King BJ, Hoefel D, Daminato DP, Fanok S, Monis PT. Solar UV reduces *Cryptosporidium parvum* oocyst infectivity in environmental waters. *J Appl Microbiol*. 2008;104(5):1311–23.
81. Tedeschi C, Barsi C, Peterson S, Carey K. A pilot study of solar water disinfection in the wilderness setting. *J Wild Environ Med*. 2014;25(3):340–5.
82. Mausezahl D, Christen A, Pacheco GD, Tellez FA, Inarte M, Zapata ME, et al. Solar drinking water disinfection (SODIS) to reduce childhood diarrhoea in rural Bolivia: a cluster-randomized, controlled trial. *PLoS Med*. 2009;6(8), e1000125.
83. Du Preez M, McGuigan KG, Conroy RM. Solar disinfection of drinking water in the prevention of dysentery in South African children aged under 5 years: the role of participant motivation. *Environ Sci Technol*. 2010;44(22):8744–9.
84. du Preez M, Conroy RM, Ligondo S, Hennessy J, Elmore-Meegan M, Soita A, et al. Randomized intervention study of solar disinfection of drinking water in the prevention of dysentery in Kenyan children aged under 5 years. *Environ Sci Technol*. 2011;45(21):9315–23.
85. Conroy RM, Elmore-Meegan M, Joyce T, McGuigan KG, Barnes J. Solar disinfection of drinking water and diarrhoea in Maasai children: a controlled field trial. *Lancet (Lond Engl)*. 1996;348(9043):1695–7.
86. Meierhofer R, Wegelin M. *SODIS Manual*. Gallen: department of water and sanitation in developing countries, Swiss federal institute of envirnomental science and technology; 2002. Available at: https://www.sodis.ch/methode/anwendung/ausbildungsmaterial/dokumente_material/sodismanual_2016.pdf. Accessed February 25, 2019.

87. McGuigan K, Joyce T, Conroy R, Gillespie J, Elmore-Meegan M. Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process. *J Appl Microbiol*. 1998;84(6):1138–48.
88. Rijal GK, Fujioka RS. Synergistic effect of solar radiation and solar heating to disinfect drinking water sources. *Water Sci Technol*. 2001;43(12):155–62.
89. Jenkins M. What's in the water?. In: *Backpacker*. 1996:56.
90. Larson KL, Hansen C, Ritz M, Carreno D. Acceptance and impact of point-of-use water filtration systems in rural Guatemala. *J Nurs Scholarsh*. 2017;49(1):96–102.
91. Zhang Y, Wang Q, Lou W, Wang Y, Zhu X. Microbiological safety of household membrane water filter. *J Environ Biol*. 2013;34(2 Spec No):481–7.
92. Environmental Health Directorate Health Protection Branch. *Assessing the Effectiveness of Small Filtration Systems for Point-of-Use Disinfection of Drinking Water Supplies*. Ottawa: Department of National Health and Welfare; 1980, 80-EHD-54.
93. Schlosser O, Robert C, Bourderioux C, Rey M, de Roubin MR. Bacterial removal from inexpensive portable water treatment systems for travelers. *J Travel Med*. 2001;8(1):12–8.
94. Clasen T, Brown J, Suntura O, Collin S. Safe household water treatment and storage using ceramic drip filters: a randomised controlled trial in Bolivia. *Water Sci Technol*. 2004;50(1):111–5.
95. Rao V, Symons JM, Ling A, Wang P, Metcalf TG, Hoff JC, et al. Removal of hepatitis A virus and rotavirus by drinking water treatment. *J Am Water Works Assoc*. 1988;80(2):59–67.
96. Horman A, Rimhanen-Finne R, Maunula L, von Bonsdorff CH, Rapala J, Lahti K, et al. Evaluation of the purification capacity of nine portable, small-scale water purification devices. *Water Sci Technol*. 2004;50(1):179–83.
97. Mull B, Hill VR. Recovery of diverse microbes in high turbidity surface water samples using dead-end ultrafiltration. *J Microbiol Methods*. 2012;91(3):429–33.
98. Lindquist ED, George CM, Perin J, Neiswender de Calari K, Norman WR, Davis TP, et al. A cluster randomized controlled trial to reduce childhood diarrhea using hollow fiber water filter and/or hygiene-sanitation educational interventions. *Am J Trop Med Hyg*. 2014;91(1):190–7.
99. Lantagne D, Person B, Smith N, Mayer A, Preston K, Blanton E, et al. Emergency water treatment with bleach in the United States: the need to revise EPA recommendations. *Environ Sci Technol*. 2014;48(9):5093–100.
100. Kozlicic A, Hadzic A, Bevanda H. Improvised purification methods for obtaining individual drinking water supply under war and extreme shortage conditions. *Prehosp Disaster Med*. 1994;9(2 Suppl):S25–8.
101. Morris JF, Murphy J, Fagerli K, Schneeberger C, Jarohn P, Moke F, et al. A randomized controlled trial to assess the impact of ceramic water filters on prevention of diarrhea and Cryptosporidiosis in infants and young children-Western Kenya, 2013. *Am J Trop Med Hyg*. 2018;98(5):1260–8.
102. Moropeng RC, Budeli P, Mpenyana-Monyatsi L, Momba MNB. Dramatic reduction in diarrhoeal diseases through implementation of cost-effective household drinking water treatment systems in Makwane Village, Limpopo Province, South Africa. *Int J Environ Res Public Health*. 2018;15(3):410.
103. Kirby MA, Nagel CL, Rosa G, Umupfasoni MM, Iyakeremye L, Thomas EA, et al. Use, microbiological effectiveness and health impact of a household water filter intervention in rural Rwanda-A matched cohort study. *Int J Hyg Environ Health*. 2017;220(6):1020–9.
104. du Preez M, Conroy RM, Wright JA, Moyo S, Potgieter N, Gundry SW. Use of ceramic water filtration in the prevention of diarrheal disease: a randomized controlled trial in rural South Africa and Zimbabwe. *Am J Trop Med Hyg*. 2008;79(5):696–701.
105. Clasen TF, Brown J, Collin S, Suntura O, Cairncross S. Reducing diarrhea through the use of household-based ceramic water filters: a randomized, controlled trial in rural Bolivia. *Am J Trop Med Hyg*. 2004;70(6):651–7.
106. Clasen T, Garcia Parra G, Boisson S, Collin S. Household-based ceramic water filters for the prevention of diarrhea: a randomized, controlled trial of a pilot program in Colombia. *Am J Trop Med Hyg*. 2005;73(4):790–5.
107. Brown J, Sobsey MD, Loomis D. Local drinking water filters reduce diarrheal disease in Cambodia: a randomized, controlled trial of the ceramic water purifier. *Am J Trop Med Hyg*. 2008;79(3):394–400.
108. Tiwari SS, Schmidt WP, Darby J, Kariuki ZG, Jenkins MW. Intermittent slow sand filtration for preventing diarrhoea among children in Kenyan households using unimproved water sources: randomized controlled trial. *Tropical Med Int Health*. 2009;14(11):1374–82.
109. Stauber CE, Ortiz GM, Loomis DP, Sobsey MD. A randomized controlled trial of the concrete biosand filter and its impact on diarrheal disease in Bonao, Dominican Republic. *Am J Trop Med Hyg*. 2009;80(2):286–93.
110. Stauber CE, Kominek B, Liang KR, Osman MK, Sobsey MD. Evaluation of the impact of the plastic BioSand filter on health and drinking water quality in rural Tamale, Ghana. *Int J Environ Res Public Health*. 2012;9(11):3806–33.
111. Fabiszewski de Aceituno AM, Stauber CE, Walters AR, Meza Sanchez RE, Sobsey MD. A randomized controlled trial of the plastic-housing BioSand filter and its impact on diarrheal disease in Copan, Honduras. *Am J Trop Med Hyg*. 2012;86(6):913–91.
112. Duke WF, Nordin RN, Baker D, Mazumder A. The use and performance of BioSand filters in the Artibonite Valley of Haiti: a field study of 107 households. *Rural Remote Health*. 2006;6(3):570.
113. Regli S. *Regulations on filtration and disinfection. Conference on current research in drinking water treatment*. 1987. Cincinnati, OH.
114. Fagerli K, Trivedi KK, Sodha SV, Blanton E, Ati A, Nguyen T, et al. Comparison of boiling and chlorination on the quality of stored drinking water and childhood

diarrhoea in Indonesian households. *Epidemiol Infect*. 2017;145(15):3294−302.
115. World Health Organization. *Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water*. London, UK: World Health Organization; 2004.
116. White G. *Handbook of Chlorination*. 3rd ed. New York: Van Nostrand Reinhold; 1992.
117. Jarroll E, Hoff J, Meyer E. Resistance of cysts to disinfection agents. In: Erlandsen S, Meyer E, eds. *Giardia and Giardiasis: Biology, Pathogenesis and Epidemiology*. New York: Plenum Press; 1984:311−28.
118. Centers for Disease Control and Prevention. *Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects*. Atlanta, GA: Centers for Disease Control and Prevention; 2001.
119. Lantagne DS. Viability of commercially available bleach for water treatment in developing countries. *Am J Public Health*. 2009;99(11):1975−8.
120. Arnold BF, Colford Jr JM. Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *Am J Trop Med Hyg*. 2007;76(2):354−64.
121. Pickard B, Clarke S, Bettin W. *Chlorine disinfection in the use of individual water purification devices*. US Army Center for Health Promotion and Preventive Medicine (USACHPPM); 2006. Available at: https://apps.dtic.mil/dtic/tr/fulltext/u2/a454058.pdf. Accessed February 26, 2019.
122. Mengistie B, Berhane Y, Worku A. Household water chlorination reduces incidence of diarrhea among under-five children in rural Ethiopia: a cluster randomized controlled trial. *PLoS One*. 2013;8(10), e77887.
123. Shrestha RK, Marseille E, Kahn JG, Lule JR, Pitter C, Blandford JM, et al. Cost-effectiveness of home-based chlorination and safe water storage in reducing diarrhea among HIV-affected households in rural Uganda. *Am J Trop Med Hyg*. 2006;74(5):884−90.
124. Blaser M. Inactivation of *Campylobacter jejuni* by chlorine and monochlorine. *Appl Environ Microbiol*. 1986;51(2):307−11.
125. Engelbrecht R, Weber MJ, Salter BL, Schmidt CA. Comparative inactivation of viruses by chlorine. *Appl Environ Microbiol*. 1980;40:249−55.
126. Shin GA, Sobsey MD. Inactivation of norovirus by chlorine disinfection of water. *Water Res*. 2008;42(17):4562−8.
127. Grabow W, Gauss-Muller V, Prozesky OW, Deinhardt F. Inactivation of hepatitis A virus and indicator organisms in water by free chlorine residuals. *Appl Environ Microbiol*. 1983;46(3):619−24.
128. Sobsey M, Fuji T, Hall R. Inactivation of cell-associated and dispersed hepatitis A virus in water. *J Am Water Works Assoc*. 1991;83(11):64−7.
129. Craun G, Swedlow D, Tauxe R, Clark R, Fox K, Geldreich E, et al. Prevention of waterborne cholera in the United States. *J Am Water Works Assoc*. 1991;83(11):40−5.
130. Thraenhart O. Measures for disinfection and control of viral hepatitis. In: Block S, ed. *Disinfection, Sterilization, and Preservation*. 4th ed. Philadelphia: Lea & Febiger; 1991:445−72.
131. Fraker L, Gentile D, Krivoy D, Condon M, Backer H. *Giardia* cyst inactivation by iodine. *J Wilderness Med*. 1992;3(4):351−8.
132. Hibler C, Hancock C, Perger L, Wegrzyn J, Swabby K. *Inactivation of Giardia Cysts With Chlorine at 0.5C to 5.0C*. AWWA Research Foundation: Denver; 1987.
133. Hoff J. *Inactivation of Microbial Agents by Chemical Disinfectants*. Cincinnati: US Environmental Protection Agency; 1986. EPA/600/2-86/067.
134. Rubin A, Evers D, Eyman C, Jarroll E. Inactivation of Gerbil-cultured *Giardia lamblia* cysts by free chlorine. *Appl Environ Microbiol*. 1989;55(10):2592−4.
135. Wallis P, Hammond BR. Removal and inactivation of *Giardia* cysts in a mobile water treatment plant under field condition: preliminary results. In: Wallis P, Hammond B, eds. *Advances in Giardia Research*. Calgary: University of Calgary Press; 1988:137−44.
136. Carpenter C, Fayer R, Trout J, Beach MJ. Chlorine disinfection of recreational water for *Cryptosporidium parvum*. *Emerg Infect Dis*. 1999;5(4):579−84.
137. Korich DG, Mead JR, Madore MS, Sinclair NA, Sterling CR. Effects of ozone, chlorine dioxide, chlorine, and monochloramine on *Cryptosporidium parvum* oocyst viability. *Appl Environ Microbiol*. 1990;56(5):1423−8.
138. Briton G. *Introduction to Environmental Virology*. New York: Wiley; 1980.
139. Chang S. Modern concepts of disinfection: water treatment in the seventies. In: *Proceedings of National Specialty Conference on Disinfection*. 1970.
140. Rice E, Hoff J, Schaefer F. Inactivation of *Giardia* cysts by chlorine. *Appl Environ Microbiol*. 1982;43:250−1.
141. Shields J, Hill V, Arrowood M, Beach M. Inactivation of *Cryptosporidium parvum* under chlorinated recreational water conditions. *J Water Health*. 2018;6(4):513−20.
142. Sobsey M, Oldham C, McCall D. Comparative inactivation of hepatitis A and other enteroviruses in water by iodine. *Water Sci Technol*. 1991;24(2):331−7.
143. Berg G, Chang S, Harris E. Devitalization of microorganisms by iodine. *Virology*. 1964;22:469−81.
144. Gerba C, Johnson D, Hasan M. Efficacy of iodine water purification tablets against *Cryptosporidium* oocysts and *Giardia* cysts. *Wilderness Environ Med*. 1997;8(2):96−100.
145. Mohamed H, Brown J, Njee RM, Clasen T, Malebo HM, Mbuligwe S. Point-of-use chlorination of turbid water: results from a field study in Tanzania. *J Water Health*. 2015;13(2):544−52.
146. Lantagne DS, Cardinali F, Blount BC. Disinfection by-product formation and mitigation strategies in point-of-use chlorination with sodium dichloroisocyanurate in Tanzania. *Am J Trop Med Hyg*. 2010;83(1):135−43.
147. Kinman R, Black A, Thomas W. Disinfection with iodine. In: *Water Treatment in the Seventies: Procedings of national specialty conference on disinfection*. 1970.
148. Thomas W, Black A, Freund G, Kinman R. Iodine disinfection of water. *Arch Environ Health*. 1969;19(1):124−32.

149. Backer H, Hollowell J. Use of iodine for water disinfection: iodine toxicity and maximum recommended dose. *Environ Health Perspect*. 2000;108(8):679–84.
150. Gottardi W. Iodine and iodine compounds. In: Block S, ed. *Disinfection, Sterilization, and Preservation*. 4th ed. Philadelphia: Lea & Febiger; 1991:152–67.
151. Rutala WA, Weber DJ. New disinfection and sterilization methods. *Emerg Infect Dis*. 2001;7(2):348–53.
152. Venczel L, Arrowood M, Hurd M, Sobsey M. Inactivation of *Cryptosporidium parvum* oocysts and *Clostridium perfringens* spores by a mixed-oxidant disinfectant and by free chlorine. *Appl Environ Microbiol*. 1997;63(4):1598–601.
153. Clark RM, Sivagnesan M, Rice EW, Chen J. Development of a Ct equation for the inactivation of *Cryptosporidium* oocysts with chlorine dioxide. *Water Res*. 2003;37(11):2773–83.
154. Murphy JL, Haas CN, Arrowood MJ, Hlavsa MC, Beach MJ, Hill VR. Efficacy of chlorine dioxide tablets on inactivation of cryptosporidium oocysts. *Environ Sci Technol*. 2014;48(10):5849–56.
155. Pereira JT, Costa AO, de Oliveira Silva MB, Schuchard W, Osaki SC, de Castro EA, et al. Comparing the efficacy of chlorine, chlorine dioxide, and ozone in the inactivation of *Cryptosporidium parvum* in water from Parana State, Southern Brazil. *Appl Biochem Biotechnol*. 2008;151(2–3):464–73.
156. Marchin G. Fina L Contact and demand-release disinfectants. *Crit Rev Environ Control*. 1989;19:227–90.
157. Fisher MB, Keenan CR, Nelson KL, Voelker BM. Speeding up solar disinfection (SODIS): effects of hydrogen peroxide, temperature, pH, and copper plus ascorbate on the photoinactivation of *E. coli*. *J Water Health*. 2008;6(1):35–51.
158. D'Aquino M, Teves SA. Lemon juice as a natural biocide for disinfecting drinking water. *Bull Pan Am Health Organ*. 1994;28(4):324–30.
159. United States Environmental Protection Agency. Alternative Disinfectants and Oxidants Guidance Manual. In: *EPA 815-R-99-014*. US EPA; 1999. Available at: https://nepis.epa.gov. Accessed February 26, 2019.
160. Chong MN, Jin B, Chow CW, Saint C. Recent developments in photocatalytic water treatment technology: a review. *Water Res*. 2010;44(10):2997–3027.
161. Li Q, Mahendra S, Lyon DY, Brunet L, Liga MV, Li D, et al. Antimicrobial nanomaterials for water disinfection and microbial control: potential applications and implications. *Water Res*. 2008;42(18):4591–602.
162. Sunnotel O, Verdoold R, Dunlop PS, Snelling WJ, Lowery CJ, Dooley JS, et al. Photocatalytic inactivation of *Cryptosporidium parvum* on nanostructured titanium dioxide films. *J Water Health*. 2010;8(1):83–91.
163. Blanco-Galvez J, Fernandez-Ibanez P, Malato-Rodriguez S. Solar photocatalytic detoxification and disinfection of water: recent overview. *J Solar Energy Eng*. 2006;129(1):4–15.
164. Alrousan DM, Dunlop PS, McMurray TA, Byrne JA. Photocatalytic inactivation of *E. coli* in surface water using immobilised nanoparticle TiO2 films. *Water Res*. 2009;43(1):47–54.
165. Sobsey MD, Stauber CE, Casanova LM, Brown JM, Elliott MA. Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environ Sci Technol*. 2008;42(12):4261–7.
166. Bielefeldt AR, Kowalski K, Summers RS. Bacterial treatment effectiveness of point-of-use ceramic water filters. *Water Res*. 2009;43(14):3559–65.
167. Mwabi JK, Mamba BB, Momba MN. Removal of *Escherichia coli* and faecal coliforms from surface water and groundwater by household water treatment devices/systems: a sustainable solution for improving water quality in rural communities of the Southern African development community region. *Int J Environ Res Public Health*. 2012;9(1):139–70.
168. Clasen T, Menon S. Microbiological performance of common water treatment devices for household use in India. *Int J Environ Health Res*. 2007;17(2):83–93.
169. Brunkard JM, Ailes E, Roberts VA, Hill V, Hilborn ED, Craun GF, et al. Surveillance for waterborne disease outbreaks associated with drinking water—United States, 2007–2008. *MMWR Surveill Summ*. 2011;60(12):38–68.
170. Sobel J, Mahon B, Mendoza C, Passaro D, Cano F, Baier K, et al. Reduction of fecal contamination of street-vended beverages in Guatemala by a simple system for water purification and storage, handwashing, and beverage storage. *Am J Trop Med Hyg*. 1998;59(3):380–7.
171. Cullimore D, Jacobsen H. The efficiency of point of use devices for the exclusion of *Giardia muris* cysts from a model water supply system. In: Wallis P, Hammond B, eds. *Advances in Giardia Research*. Calgary: University of Calgary Press; 1988:107–12.
172. Hutton P, Ongerth J. *Performance evaluation for portable water treatment filters*. Seattle, WA: Department of Environmental Health, University of Washington; 1995.
173. Hutton P, Ongerth J. *Performance evaluation of ten commercially available portable water filters*. Sydney, Austalia: Department of Water Engineering, University of New South Wales; 1997.
174. Jarroll E, Bingham A, Meyer E. *Giardia* cyst destruction: effectiveness of six small water disinfection methods. *Am J Trop Med Hyg*. 1980;29(1):8–11.
175. Logsdon G, Symons J, Hoye R, Arozarena M. Alternative filtration methods for removal of *Giardia* cysts and cyst models. *J Am Water Works Assoc*. 1981;73(2):111–8.
176. Naranjo J, Gerba C. *Evaluation of portable water treatment devices by a condensed version of the guide of standard protocol for microbiological purifiers (USEPA, 1987)*. Tucson, AZ: University of Arizona; 1995.
177. Powers E, Boyd C, Harper B, Rubin A. Removal of biological and chemical challenge from water by commercial fresh and salt water purification devices. In: *Technical Report Natick/TR-91-042*. Natick, MA: United States Army Natick Research, Development and Engineering Center; 1991.
178. Tobin R. Performance of point-of-use water treatment devices. In: *Proceedings of the first conference on cold regions environmental engineering*. 1983. Fairbanks, AK.

179. Tobin R. Testing and evaluating point-of-use treatment devices in Canada. *J Am Water Works Assoc*. 1987;79(10):42−5.
180. Backer H. Field water disinfection. In: Auerbach P, ed. *Wilderness Medicine*. 7th ed. Philadelphia: Elsevier; 2017.
181. McDonnell GE. *Antisepsis, Disinfection, and Sterilization*. Washington, DC: ASM Press; 2007.
182. Bielefeldt AR. Appropriate and sustainable water disinfection methods for developing communities. In: Buchanan K, ed. *Water Disinfection*. New York City, NY: Nova Science Publishers; 2011:45−75.
183. Clasen T, Roberts I, Rabie T, Schmidt W, Cairncross S. *Interventions to improve water quality for preventing diarrhoea*. Cochrane Library: John Wiley & Sons; 2006.
184. Opryszko MC, Majeed SW, Hansen PM, Myers JA, Baba D, Thompson RE, et al. Water and hygiene interventions to reduce diarrhoea in rural Afghanistan: a randomized controlled study. *J Water Health*. 2010;8(4):687−702.
185. Jung S, Doh YA, Bizuneh DB, Beyene H, Seong J, Kwon H, et al. The effects of improved sanitation on diarrheal prevalence, incidence, and duration in children under five in the SNNPR State, Ethiopia: study protocol for a randomized controlled trial. *Trials*. 2016;17(1):204.
186. Garrett V, Ogutu P, Mabonga P, Ombeki S, Mwaki A, Aluoch G, et al. Diarrhoea prevention in a high-risk rural Kenyan population through point-of-use chlorination, safe water storage, sanitation, and rainwater harvesting. *Epidemiol Infect*. 2008;136(11):1463−71.
187. Dreibelbis R, Freeman MC, Greene LE, Saboori S, Rheingans R. The impact of school water, sanitation, and hygiene interventions on the health of younger siblings of pupils: a cluster-randomized trial in Kenya. *Am J Public Health*. 2014;104(1):e91−7.
188. Cha S, Lee J, Seo D, Park BM, Mansiangi P, Mernard K, et al. Effects of improved sanitation on diarrheal reduction for children under five in Idiofa, DR Congo: a cluster randomized trial. *Infect Dis Poverty*. 2017;6(1):137−49.
189. Quick RE, Kimura A, Thevos A, Tembo M, Shamputa I, Hutwagner L, et al. Diarrhea prevention through household-level water disinfection and safe storage in Zambia. *Am J Trop Med Hyg*. 2002;66(5):584−9.
190. Luby SP, Agboatwalla M, Painter J, Altaf A, Billhimer WL, Hoekstra RM, et al. Effect of intensive handwashing promotion on childhood diarrhea in high-risk communities in Pakistan: a randomized controlled trial. *JAMA*. 2004;291(21):2547−54.
191. Hashi A, Kumie A, Gasana J. Hand washing with soap and WASH educational intervention reduces under-five childhood diarrhoea incidence in Jigjiga District, Eastern Ethiopia: a community-based cluster randomized controlled trial. *Prev Med Rep*. 2017;6:361−8.
192. Ortega YR, Roxas CR, Gilman RH, Miller NJ, Cabrera L, Taquiri C, et al. Isolation of *Cryptosporidium parvum* and *Cyclospora cayetanensis* from vegetables collected in markets of an endemic region in Peru. *Am J Trop Med Hyg*. 1997;57(6):683−6.