

Wilderness Medical Society Clinical Practice Guidelines for Prevention and Management of Avalanche and Nonavalanche Snow Burial Accidents: 2024 Update

Christopher Van Tilburg, MD^{1,2,3}, Peter Paal, MD^{3,4},
Giacomo Strapazzon, MD, PhD^{3,5,6}, Colin K. Grissom, MD⁷,
Pascal Haegeli, PhD⁸, Natalie Hölzl, MD^{3,9},
Scott McIntosh, MD, MPH^{3,10}, Martin Radwin, MD,
William “Will” R. Smith, MD^{2,3,10,11,12},
Stephanie Thomas, MS^{2,3}, Bruce Tremper, MS¹³,
David Weber, FP-C¹⁴, Albert R. Wheeler, MD^{2,3,10,11},
Ken Zafren, MD^{3,15,16}, and Hermann Brugger, MD^{3,5,6}

Abstract

To provide guidance to the general public, clinicians, and avalanche professionals about best practices, the Wilderness Medical Society convened an expert panel to revise the evidence-based guidelines for the prevention, rescue, and resuscitation of avalanche and nonavalanche snow burial victims. The original panel authored the Wilderness Medical Society Practice Guidelines for Prevention and Management of Avalanche and Nonavalanche Snow Burial Accidents in 2017. A second panel was convened to update these guidelines and make recommendations based on quality of supporting evidence.

Keywords

airbags, air pocket, hypothermia, rescue, resuscitation, wilderness medicine

Introduction

Snow and ice avalanches are widespread in mountain regions. Worldwide avalanche-related morbidity and mortality are difficult to estimate because many countries lack

reporting systems. Europe and North America have relatively accurate systems for capturing data on avalanche fatalities. Approximately 130 fatalities occur annually in Europe and 36 in North America.¹⁻⁴ During the 31 winter

¹Occupational Medicine, Mountain Clinic, and Emergency Medicine, Providence Hood River Memorial Hospital, Hood River, OR

²Mountain Rescue Association, San Diego, CA

³International Commission for Alpine Rescue

⁴Department of Anesthesiology and Critical Care Medicine, St. John of God Hospital, Paracelsus Medical University, Salzburg, Austria

⁵Department of Anesthesiology and Critical Care Medicine, University Hospital Innsbruck, Innsbruck, Austria

⁶Institute of Mountain Emergency Medicine, Eurac Research, Bolzano, Italy

⁷Department of Pulmonary and Critical Care, Intermountain Medical Center, Murray, UT

⁸Simon Fraser University, Burnaby, BC, Canada

⁹German Association of Mountain and Expedition Medicine, Munich, Germany

¹⁰Division of Emergency Medicine, University of Utah Health, Salt Lake City, UT

¹¹Department of Emergency Medicine, St. Johns Health, Jackson, WY

¹²University of Washington School of Medicine, Seattle, WA

¹³Utah Avalanche Center, Salt Lake City, UT

¹⁴Intermountain Life Flight, Salt Lake City, UT

¹⁵Himalayan Rescue Association, Kathmandu, Nepal

¹⁶Stanford University Medical Center, Palo Alto, CA

Received November 2022; accepted May 2023

Corresponding Author:

Christopher Van Tilburg, MD, Occupational Medicine, Mountain Clinic, and Emergency Medicine, Providence Hood River Memorial Hospital, Hood River, OR.

Email: vantilburg@gorge.net.

seasons between 1983 and 2015, Europe and North America had 5123 avalanche fatalities.⁵ Although internet databases exist for North America and some European countries, scholarly articles that document the number of fatalities have not been published. From 2002 to 2022, online databases showed a 20-y average of 36 avalanches in North America and 130 in Europe, according to email correspondence with Swiss avalanche expert Jürg Schweizer (January 10, 2022). In the United States, a partnership between the American Avalanche Association and the US Forest Service National Avalanche Center keeps statistics regarding avalanche fatalities at <https://www.avalanche.org/avalanche-accidents>. Avalanche Canada maintains statistics at <https://www.avalanche.ca/incidents>. European statistics for the Alps and Pyrenees are maintained by the European Avalanche Warning Services at <https://www.avalanches.org/fatalities/fatalities-statistics>.

Avalanche fatalities in mountain regions outside North America and Europe are not systematically recorded. Catastrophic avalanches with large death tolls have included the serac fall on Mount Everest in 2014 that killed 16 Sherpas; the earthquake-caused avalanche at Everest Base Camp in 2015 that killed 22; the serac collapse on the Marmolada Glacier, Italy, in 2022 that killed 7; the avalanche in Rigopiano, Italy, in 2017 that killed 29; the avalanche in Galtur, Austria in 1999 that killed 31; an avalanche in Turkey in 2020 that killed 42 motorists followed by a second avalanche that killed 33 rescuers; and an avalanche in 2012 that killed 148 Pakistani Army members in the Siachen Glacier region.⁶ A reasonable estimate of annual global avalanche deaths is 300 to 500, based on media reports, websites, and other sources, according to email correspondence with American avalanche expert Dale Atkins (January 10, 2023). Nonfatal avalanche events are extremely difficult to quantify because many accidents are not reported.

Most documented North American and European avalanche fatalities are recreational users, such as snowmobilers, skiers, snowboarders, mountaineers, and snowshoers. Occupational-related avalanche fatalities among ski patrolers, mountain rescuers, mountain guides, and transportation workers occur less frequently, although job requirements may place these personnel at greater risk.¹

Avalanche avoidance should be the main method to mitigate risk of injury and death. If an avalanche incident occurs, rescue by one's companions, with appropriate resuscitation and advanced life support measures, is critically important to reduce avalanche morbidity and mortality.⁷

Methods

The Wilderness Medical Society (WMS) convened an expert panel to develop evidence-based recommendations for 3 primary aspects of avalanche accidents: prevention, rescue, and resuscitation. We also included nonavalanche

deep snow and tree well burial⁸ as related conditions with pathophysiology and recommendations similar to avalanche burial. The Wilderness Medical Society Practice Guidelines for Prevention and Management of Avalanche and Nonavalanche Snow Burial Accidents were initially published in 2017.⁹ A second panel convened upon request in 2022 to update the guidelines.

We searched the PubMed database for articles from 2016 to 2022 for keywords including avalanche rescue, avalanche burial, avalanche transceiver, avalanche location, avalanche search, avalanche shoveling, avalanche command, avalanche scene, avalanche probe, avalanche RECCO, avalanche dog, avalanche helicopter, deep snow burial, deep snow asphyxiation, deep snow suffocation, tree well asphyxia, tree well suffocation, tree well submersion, tree well immersion, deep snow submersion, deep snow immersion, and nonavalanche-related snow immersion death.

We considered peer-reviewed randomized controlled trials, observational studies, case series, and case reports for inclusion. Because a limited number of studies of avalanche accidents have been published in peer-reviewed journals, we also reviewed conference proceedings, avalanche center data, letters to the editor, review articles, websites, personal communication from experts, and books for background information.

We developed recommendations by consensus. We graded recommendations based on strength of the recommendation and quality of the evidence using the classification scheme of the American College of Chest Physicians (Supplemental Table).¹⁰ When no evidence existed, we made recommendations based on expert consensus based on review articles, textbooks, clinical experience, rescue experience, and first-hand knowledge of equipment, techniques, and avalanches.

Pathophysiology

Avalanche morbidity and mortality depend mainly on the degree of head and chest burial, duration and depth of burial, patency of the airway, presence of and volume of an air pocket, snow density, and traumatic injuries.¹¹ The chance of survival after critical burial (head and chest below the snow) is about 50%.^{2-4,12} For victims not buried critically (head and chest out of the snow), the likelihood of survival is nearly 100% unless trauma is a contributing factor.^{2,12,13} Avalanche deaths are most frequently caused by asphyxia (75% of fatalities) and by trauma (25%).¹³⁻²⁰ These percentages vary by region. Few deaths are caused solely by hypothermia.¹⁵

If an avalanche victim is critically buried, the time to extrication is the main determinant of survival.²¹ Critically buried victims have greater than 90% chance of survival if extricated within about 15 min, but only a 30% chance of survival if extricated after approximately 30 min (Figure 1).^{21,22} Survival of a buried victim after more than 35 min requires a patent airway and the presence of an air

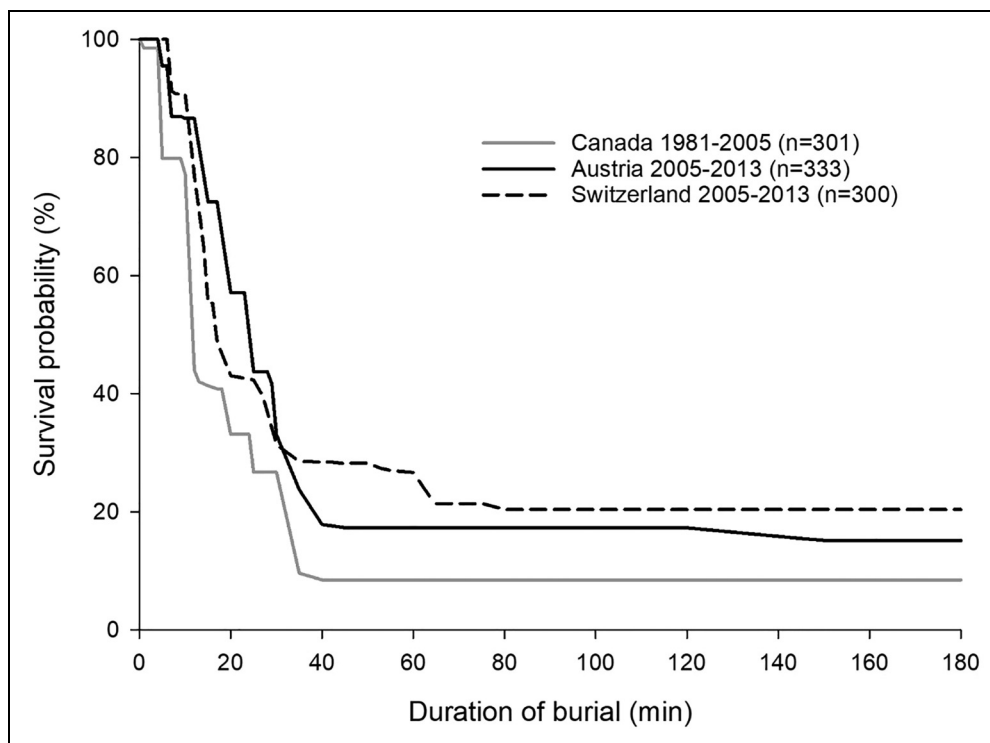


Figure 1. A comparison of avalanche survival curves from Canada, Austria, and Switzerland. Note the rapid drop after 10 min and the plateau at 30 min.^{21,22} Adapted from Haegeli et al.³

pocket.^{2,23,24} A case report described a victim who survived 45 min with a patent airway but no air pocket with a poor neurologic outcome.²⁵ A victim can be found in almost any position. About 45% of buried avalanche victims are found lying prone, 24% supine, 16% sitting or standing, and 15% lying on their sides.²⁶ Mortality increases with increasing depth of burial.^{24,27}

Asphyxia

Asphyxia (deprivation of oxygen) during avalanche burial occurs primarily by 3 mechanisms: 1) Complete or partial obstruction of the upper airway caused by inhaled snow or debris can result in hypoxia and hypercapnia within 10 min and cause death from asphyxia within 35 min of avalanche burial^{11,28-33}; 2) High density snow or lack of an air pocket may not allow sufficient inflow of oxygen and removal of carbon dioxide (CO₂) through the surrounding snow, leading to asphyxia from rebreathing expired air.³⁰ Inspired air contains 21% oxygen and less than 0.03% CO₂. Expired air contains about 16% oxygen and 5% CO₂. Rebreathing expired air during avalanche burial results in a progressive decrease in the fraction of inspired oxygen and a progressive increase in the fraction of inspired CO₂, leading to hypoxia, hypercapnia, and increased ventilatory drive.^{30,32,34} Lack of an air pocket may also increase work of breathing and metabolic

rate.^{13,24,35} Increased snow density and decreased porosity of snow surrounding the air pocket can decrease diffusion of gases^{30,32,36}; and 3) The weight and compaction of snow may limit chest expansion and impair ventilation.¹³

Case reports and human trials have demonstrated that long-term survival is possible without hypoxic brain damage if the buried victim is able to breathe under the snow. The presence of a patent airway and an air pocket (any space in front of mouth and nose) may enable a buried victim to breathe and to survive for far longer than with an obstructed airway or without an air pocket.^{3,13,14,22,24,31,32,37} Increasing the volume of an air pocket can increase the duration of survival after burial.³² If the density of the surrounding snow is low enough to allow sufficient diffusion of oxygen into the air pocket from the snowpack and diffusion of expired CO₂ into the snowpack, a buried victim may survive for several hours.^{30,33,38,39} If snow density is high (>350 kg m⁻³), hypoxia and hypercapnia will occur more quickly.³⁰ High-density snow is more common in maritime climates and during spring conditions. With climate change, wetter and warmer climates are likely to have higher density snow.^{3,40}

Delayed onset of acute respiratory distress syndrome has been reported in avalanche victims after burials as short as 5 min and as long 207 min. This may be noncardiogenic pulmonary edema, triggered by high negative intrathoracic pressures from upper airway obstruction, aspiration, or pulmonary contusion.⁴¹⁻⁴⁵

Trauma

Trauma accounts for 6 to 29% of avalanche deaths in North America and Europe.^{12,14,15,18,19,34,46,47} In catastrophic avalanches and in summer avalanches, trauma often accounts for a higher percentage of fatalities.⁴⁸⁻⁵⁰ The proportion of avalanche deaths associated with trauma in Canada is higher than in Europe and the United States.^{3,20,51,52} Traumatic injuries may become more frequent with climate change.⁴⁰

Avalanche victims can sustain any type of injury during turbulent descent in an avalanche.^{18,47} Severe injuries are frequently the result of collisions with trees or rocks or from falls off cliffs. Minor injuries are likely to be unreported. Injuries of the head, cervical spine, chest, and extremities are the most common life-threatening injuries.^{12,16,18,20,51} In a study of avalanche victims with trauma, the majority had evidence of traumatic brain injury. Altered level of consciousness and chest injury may further decrease survival by accelerating asphyxiation.^{53,54}

Hypothermia

Hypothermia causes few fatalities in avalanche victims because death from asphyxia usually occurs sooner.^{2,32,54-56} The severity of hypothermia is best determined by core temperature measurement in the field.⁵⁷⁻⁵⁹ If core temperature cannot be measured, the stage of hypothermia can be estimated in the field as mild, moderate, or severe, using the WMS Accidental Hypothermia guidelines.⁵⁸ The Revised Swiss System (RSS) can also be used.⁶⁰ Both the WMS and RSS staging may be inaccurate if there is associated trauma or asphyxia contributing to a decreased level of consciousness.^{19,37,43,61-63}

Reported cooling rates of critically buried avalanche victims vary widely from $0.1^{\circ}\text{C h}^{-1}$ to 9°C h^{-1} , but are typically 1°C h^{-1} to 3°C h^{-1} .^{19,37,38,62,63} At least 1 h of avalanche burial is usually required to reach a core temperature $<30^{\circ}\text{C}$, at which fatal arrhythmias become more likely.⁶⁴ In human simulations of avalanche burials, hypercapnia caused a 70% increase in cooling rates.^{37,61} Core temperature cooling rate increases during and after extrication from snow burial because of exposure to the air, removal from the insulation of snow, and vasodilation of the extremities if the victim stands or walks.^{61,65,66}

Prevention

Prevention of avalanche morbidity and mortality depends on avoiding being caught in an avalanche, avoiding being critically buried, preventing trauma if caught, and avoiding asphyxiation if buried. The primary goal of education is to teach how to avoid avalanche accidents. Public safety measures for prevention and mitigation of avalanche accidents, such as the use of explosives, barriers, snow fences, deflectors, and snow sheds across roads, are beyond the scope of these guidelines.

Avalanche Avoidance

In the majority of avalanche accidents, the victim or someone in the victim's party triggered the avalanche.⁶⁷ Avalanche risk can be decreased by avoiding hazardous terrain, snow, and weather conditions and by taking group dynamics and human factors into account. A detailed discussion of decision-making and selecting safe routes in avalanche terrain is beyond the scope of these guidelines.

Education and experience are cornerstones of risk mitigation.^{7,68} Some techniques used to avoid avalanches include avoiding slopes >30 degrees, traveling on ridges, traveling in thickly forested terrain, and avoiding travel in avalanche terrain during high-hazard conditions, such as during and immediately after heavy snowfall, especially with significant wind, and during rapidly increasing temperatures.^{69,70} Avalanche education can help prevent accidents, including avalanche safety courses, textbooks, videos, and local avalanche advisories.⁶⁹⁻⁷¹

Decision aids can facilitate assessment of avalanche hazards, reducing misleading human factors.⁷²⁻⁷⁶ Although it can be difficult to measure their impact, decision aids can be effective in recreational settings.⁷⁷⁻⁷⁹ In addition to education, training, and the use of decision aids, good judgment and regular training with safety equipment are vital to avalanche safety.

In a large Italian study ($n=5576$), adherence to minimum safety procedures, such as carrying personal rescue equipment, was less than 42%. Adherence was significantly greater for skiers than for snowshoers and greater in people who were younger, reported more tours per season, traveled in larger groups, and started earlier in the day.⁵⁷

Recommendations. We recommend travelers in avalanche terrain attend training courses through accredited organizations, supplemented by educational books and videos, avalanche advisories, and decision aids. We recommend travelers in avalanche terrain regularly practice safety and rescue skills. Strong recommendation, low quality evidence.

Burial Avoidance

Physical Maneuvers. When entering a high-risk avalanche path for rescue or avalanche control work, use of a belay line, securely anchored outside the path, can prevent an individual from being swept downslope by an avalanche.^{70,80} Travelers should cross dangerous slopes one at a time, while being watched by a partner, and should move between safer areas such as rock outcroppings, tree clusters, or safer adjacent slopes. Planning an escape route before entering an avalanche-prone area can increase the likelihood of avoiding being caught in an avalanche. Avalanche professionals commonly use slope-cutting techniques in which one person rapidly traverses a potentially unstable slope from one safe zone to another to test stability. This technique may trigger an avalanche, possibly

reducing avalanche hazard because the slope is less likely to slide again.^{70,80}

A person about to be caught in an avalanche should immediately attempt to escape to adjacent terrain outside the avalanche. When descending suspect slopes, a traveler should maintain a speed at which momentum has a chance to carry them off the moving snow to a preplanned safety zone. This may reduce the odds of being caught and buried but requires expert skill.

The next priority, if unable to escape sliding snow, is to avoid burial. One should attempt to remain on the surface and fight to move toward the starting zone of the avalanche where the flow is less turbulent. It may be possible to self-arrest by anchoring into the bed surface with a ski pole or ice ax.⁸¹ One may be able to grab a tree or rock. Some experts recommend swimming motions to stay on the surface. While this practice has been challenged,⁸¹ case studies and theoretical considerations regarding the flow of avalanches support using any type of motion to stay at or near the top of the debris flow.⁴⁶

A victim on skis, snowboard, or snowshoes will likely be buried deeper than a victim without impediments. Extrication will likely be more difficult. Kicking off skis or removing a snowboard may improve the likelihood of survival. Victims should not remove backpacks. A backpack might provide protection from trauma. Equipment in the backpack may be necessary for survival.

Recommendations. We recommend that if caught in an avalanche, immediately attempt to escape the moving snow, or, if engulfed, use any motion possible to avoid critical burial. Strong recommendation, low quality evidence.

Recommendation. We suggest if caught in avalanche and unable to escape, attempt to jettison skis or a snowboard but do not remove a backpack. Ungraded: Expert consensus.

Avalanche Airbags. Avalanche airbags are the only avalanche safety devices that can prevent burial.⁴ Airbags are backpacks or vests that contain 1 or 2 balloons. When caught in an avalanche, the user manually deploys the balloon by pulling a handle and inflating the balloon(s) to a total volume of about 150 L. Airbags use 1 or 2 cylinders of compressed gas or a battery-powered fan to inflate the balloon(s). A deployed airbag increases the effective volume of an avalanche victim, taking advantage of the physical process of granular convection. In a flow of various-sized particles, larger particles are sorted toward the surface.^{48,52,82} Increased effective volume reduces the chance of deep or complete burials.

Use of avalanche airbags is supported by simulations and epidemiologic studies. Trials with intentionally-triggered avalanches and crash test dummies showed that dummies with an inflated airbag had a lower probability of burial.⁸³⁻⁸⁵ Statistical evaluations of accidents have compared the mortality rates of avalanche victims with and without airbags.^{4,86,87} In a retrospective analysis of avalanche accident records from

Europe and North America,²² inflated airbags reduced mortality from 22% to 11%. This study also found that noninflation was a problem with the use of airbags. The noninflation rate from all causes was 20%. Overall mortality for airbag users was 13%.

In another study, dummies with and without airbags were deployed into artificially triggered avalanches. Of the dummies without airbags, the mean burial was 42 cm (range 25–63 cm) and visibility on debris surface was 20% (1/5 dummies). Of the dummies with airbags, the mean burial was 15 cm (18–26) and visibility was 100% (14/14).⁸⁸

Operator error is the most important limitation of airbags, with 60% of noninflations attributable to the user failing to trigger the airbag. Other obstacles to use of airbags include cost, weight, and regulations limiting most compressed gas canisters on commercial airplanes. Airbags are also ineffective if a victim is swept off a cliff or into thick trees, where trauma is a greater risk than asphyxia. Death from asphyxia can occur despite airbag deployment in deep burials, if a second avalanche causes a critical burial, or if the airbag is destroyed by the avalanche.

There are no safety or survival data comparing airbags inflated by different systems. Airbags with fans have the advantage that users can practice or use the devices in the field multiple times. Fan airbags are allowed on commercial airplanes. Canister-actuated airbags require additional canisters for practice or for multiple deployments in the field. Most canisters are not allowed on commercial airplanes. Canister airbags are generally less expensive than fan-actuated airbags.

Travelers have been slow to adopt airbags, possibly because they are expensive, heavy, and bulky.⁸⁹ In the Italian study of 5576 skiers and snowshoers, less than 4% were carrying an airbag.⁵⁷ At least one manufacturer makes a backpack with both an airbag and an artificial air pocket device.

Recommendations. We recommend that travelers entering avalanche terrain should use airbags. Familiarity and regular practice with airbags are essential. Strong recommendation, moderate quality evidence.

Trauma Prevention

Helmets. A retrospective review of autopsies of avalanche victims in Utah suggested that traumatic brain injury contributed to death from asphyxia.⁹⁰ Helmets can prevent minor and major trauma in resort skiers and snowboarders.⁹¹ Helmets are less effective at preventing morbidity and mortality in avalanches, but there is little downside to their use.⁹² There are no studies on the effectiveness of helmets in reducing death from head trauma in avalanche accidents. Velocities of medium and large avalanches may exceed the protective capabilities of helmets designed for recreational skiing and climbing,⁹² but most recreational fatalities are in small- to medium-sized avalanches with lower velocities in which helmets might prevent or ameliorate

traumatic brain injuries.⁶⁷ Helmets may also help to prevent lacerations, minor head injuries, and hypothermia.

Recommendations. We recommend helmets should be worn when traveling in avalanche terrain. Strong recommendation, low quality evidence.

Avalanche Airbags. Some models of avalanche airbags surround the head and neck once deployed. Generally, these are backpacks with single airbags in a “U” shape. They may help to prevent or mitigate injuries from an avalanche or from collisions with objects in the avalanche. Although there are theoretical benefits, there are no data on the use of airbags to reduce the risk of head and neck trauma.

Recommendations. We suggest airbag backpacks may provide head and neck protection from trauma. Ungraded: expert consensus.

Asphyxia Avoidance if Buried

Physical Maneuvers. An unobstructed airway and an air pocket are critical for surviving avalanche burial, but turbulence often forces snow into the mouth and nose of a victim. One technique for protecting the airway during an avalanche is to reach across the face with one arm, holding the crook of the elbow over the mouth.⁸⁰ This may help decrease the amount of inhaled snow, protect against facial trauma, and create an air pocket.

Recommendations. We recommend if caught in an avalanche, a victim should attempt to protect the airway and create an air pocket by reaching across the face with one arm, holding the crook of the elbow over the mouth. Strong recommendation, low quality evidence.

Avalanche Airbags. Some airbags deflate automatically, 3 min after deployment, to create an air pocket. A study that buried 12 subjects, monitoring vital signs for 1 h, tested the hypothesis that an air pocket could prolong survival.⁹¹ Eleven subjects maintained normal vital signs for 60 min, while 1 subject maintained normal vital signs for 49 min before requiring extrication with increasing heart rate, increasing end-tidal carbon dioxide (EtCO₂), and anxiety.

Recommendations. We recommend that an airbag that deflates after burial may help prevent asphyxia by creating an air pocket. Strong recommendation, low quality evidence.

Air Diverters. Air diverters are intended to enable critically buried avalanche victims to channel exhaled CO₂ away from the airway, thus separating carbon-dioxide-rich exhaled air from oxygen-rich inhaled air. The system also diverts moisture-rich air, delaying formation of ice on the surface of the snow in an air pocket that can interfere with

gas exchange. The device consists of a mouthpiece that connects to tubing with a one-way inspiratory valve and a one-way expiratory valve. Inspired air enters from the front of the user, via an intake port. Expired air is diverted to the back of the user via an exhaust port. In addition to delaying asphyxia caused by rebreathing CO₂, the mouthpiece may help keep the airway free of snow.

In a randomized, crossover-controlled trial, in simulated avalanche debris, breathing with an air diverter allowed adequate oxygenation for up to 60 min.³⁵ In the control group, participants breathing directly into a 500 mL air pocket experienced hypoxemia in 5 to 14 min. There have been many any cases of survival with the use of air diverters.^{92,93} There has been no study comparing the mortality of users and nonusers. Currently, air diverters are commercially available in Europe but not in North America. In the Italian study, less than 0.5% of 5576 skiers and snowshoers carried an air diverter.⁵⁷

Recommendations. We recommend that a traveler entering avalanche terrain should consider using an air diverter. Strong recommendation, low quality evidence.

Rescue

Avalanche rescue can be accomplished by companions or professionals. A systematic approach to avalanche rescue maximizes the efficiency and effectiveness of rescuers.⁹⁴

Avalanche Rescue Sequence

A rescue sequence (Figure 2) can be adapted to avalanche rescue regardless of the number of victims or rescue personnel. In a small team, a single individual may be responsible for multiple tasks. In a large team, each role may be assigned to a different rescuer. Some steps may be completed simultaneously. The team should immediately establish leadership. The leader should assess the scene for hazards, formulate a rescue plan, manage available resources, and continuously assess scene safety. If possible, at least 1 person, should be stationed at a vantage point that allows a view of the entire scene.

The surface search for visible clues should occur simultaneously with the transceiver search, especially with small groups. The surface search should begin at the last-seen point from above or at the bottom edge of the debris from below. The last-seen point should be identified with a physical marker such as a ski pole or avalanche probe.

In addition to the surface search, methods of locating a buried victim are transceiver searches (coarse and fine), pin-point searches (probe searches), and shoveling to extricate the victim. A manikin study simulating avalanche rescue found that it takes an average of 7 min to free the airway after locating a simulated avalanche victim buried in a supine position at a depth of 1 m. It takes an additional 3

min to start cardiopulmonary resuscitation (CPR).⁹⁵ One rescuer tended to be slower than 2 rescuers (10.5±SD min vs 9.3±SD min). The position of the manikin did not impact recovery speed (10.8±SD min with head downhill in prone position; 10.6±SD min with head uphill in prone position; and 8.8 min with head uphill supine). Previous training improved rescue times: 6.1 min vs 11.0 min ($P=0.006$).⁹⁷ A major limitation was that the simulated avalanche debris had a lower density than actual avalanche debris.⁹⁶

A retrospective study of 205 fatalities of backcountry skiers and snowboarders, side country (lift-served backcountry) skiers and snowboarders, snowmobilers, and snow bikers concluded that, on average, snowmobilers were buried deepest. Solo travelers had the longest burials. Skiers and snowboarders had the highest proportion of short burials (<15 min). Backcountry skiers and snowboarders were most likely to have avalanche rescue equipment.⁷ In the Italian study of 5576 skiers, snowshoers, and snowboarders, a larger percentage of skiers (81%) than snowshoers (14%) carried personal rescue equipment (transceiver, probe, and shovel).⁵⁷ On days with low avalanche hazard, travelers are less likely to carry avalanche safety gear.⁹⁸

If an avalanche accident requires additional rescue or medical assistance, local emergency services should be notified, but notification should not delay the initial rescue response.⁹⁹ Additional time is required to turn on a phone, acquire a signal, and report an accident.

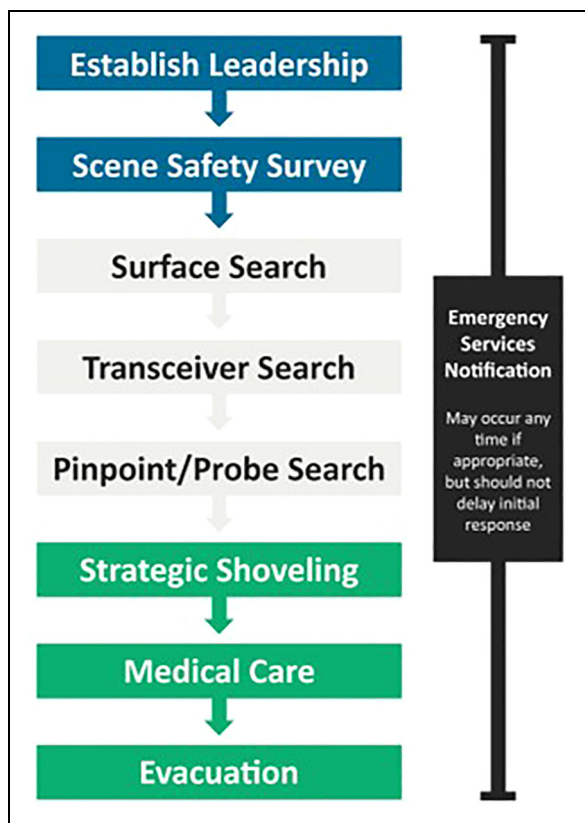


Figure 2. Avalanche rescue algorithm.

In a Swiss study of 3892 avalanche victims, avalanche burial at night was rare (<2%), but mortality was greater than daytime burial.¹⁰⁰ Survival was highest with burial at midday (63%), followed by sunset (40%), and lowest at midnight (29%). Reasons for declining survival may include longer search for completely buried victims (89 min vs 20 min), lower rates of companion rescue (15% vs 51%), and lower rates of locating victims using avalanche transceivers.¹⁰⁰

Recommendations. We suggest that after an avalanche accident, rescuers should establish leadership; secure the scene; perform surface, transceiver, and pinpoint searches; shovel strategically; and notify emergency services when appropriate. Ungraded: Expert consensus.

Transceiver Search. Avalanche transceivers decrease morbidity and mortality when used by both victims and rescuers. Transceivers reduce the time between critical burial and rescue, from 102 min to 20 min in one study. However, mortality of critically buried victims was only decreased from about 68% to about 54%.¹⁰¹

Electronic devices, such as mobile phones, portable radios, global positioning system (GPS), and other digital communication devices, may interfere with avalanche transceiver searches because similar radio frequencies are susceptible to electromagnetic interference.¹⁰² Medical devices, such as cardiac pacemakers, implanted defibrillators, and insulin pumps, can also interfere with transceivers.¹⁰³ It is not yet known whether electronic battery-operated fan airbags interfere with transceivers. To minimize interference, transceivers in transmit mode should be kept at least 20 cm away from other electronics and 50 cm away in search (receive) mode.^{96,104,105}

Current transceivers have 3 internal antennas and use digital processing. Some transceivers provide audible as well as visual signals to help identify search direction and the depth of the victim.¹⁰⁶

Recommendations. We recommend all travelers in avalanche terrain should carry an up-to-date avalanche transceiver, know how to perform effective searches, and practice regularly. Strong recommendation, moderate quality evidence.

Recommendation. We recommend that rescuers should keep transceivers in transmit mode a minimum of 20 cm from other electronics and metal objects, with a minimum of 50 cm in search mode. Strong recommendation, moderate quality evidence.

Other Location Devices. Telecommunication devices other than avalanche transceivers are not useful for avalanche rescue. Global positioning system transceivers are ineffective because the signal is not sufficiently precise.^{107,108} Personal locator beacons have not been studied, but they rely on GPS technology and are not designed for companion rescue.

Cell phones, satellite phones, and hand-held very high frequency/ultra high frequency (VHF/UHF) radios can aid in summoning help but are not useful for searching. Cell phone avalanche applications cannot be used to locate a buried victim in a reasonable amount of time.¹⁰⁹

Recommendations. We suggest that GPS transceivers, cell phones, satellite phones, and VHF/UHF radios are not recommended for locating a buried avalanche victim during companion rescue. Weak recommendation, low quality evidence.

Pinpoint Search. A probe can be critical for finding a buried victim. A 2.5- to 3-m probe is standard.¹¹⁰ A 2-m probe might be adequate because most avalanche victims who are found are buried within 1.5 m of the surface.^{111,112} The main advantage of the shorter length is to save weight and space in a backpack.

After a rescuer has used an avalanche transceiver to find the closest signal of the buried beacon to the snow surface, rescuers should probe, systematically inserting the probe perpendicular to the snow. A concentric circular method is most efficient, beginning at the location of the closest transceiver reading. Probe holes should be 25 cm apart.^{113,114} Rescuers should feel for inconsistencies within the snowpack and monitor changes in the depth at which the probe stops. Whenever there is a possible strike, the probe should be left in place as a target for shoveling.

Recommendations. We recommend that all travelers in avalanche terrain should carry and know how to use a 2.5- to 3-m collapsible probe for pinpoint searching. Probing should be perpendicular to the surface in a concentric circular pattern with probe holes 25 cm apart. Strong recommendation, low quality evidence.

Strategic Shoveling. A shovel is essential to extricate a buried victim. Metal shovel blades are more durable than composite blades.¹¹⁵ Efficient shoveling techniques are critical for minimizing extrication time to increase survival.¹¹² In a simulation with loose snow (density $651 \pm 8 \text{ kg/m}^3$), using a scooped shovel, the amount of snow cleared increased 47% compared to a flat shovel.¹¹⁶ Men moved 44% more snow per unit time than women.¹¹⁶ Shoveling should begin downhill at least 1.5 times the distance of burial depth, based on the probe strike or best estimated location. A working platform the width of a body, level with the buried victim, will help conserve rescuer energy. The shovel can be used like a paddle to scrape or plow snow downhill. Initially, rescuers move to the sides of the pit, leaving the middle for snow from deeper in the pit. No studies have investigated the difference between a shovel handle in line with or perpendicular to the blade.

When multiple rescuers are available to shovel, a conveyor belt method may be used,^{117,118} with rescuers rapidly paddling snow downhill in succession, usually

fanning the snow to the sides to eliminate excess snow buildup. Rescuers should rotate positions frequently, typically every few minutes, to prevent fatigue. They should excavate a wide, flat platform for the extricated victim to aid in resuscitation and packaging for transport. In a simulated avalanche study with manikins, 1 or 2 rescuers required approximately 10 min to locate, excavate the manikin from 1 m below the surface and initiate CPR.⁹⁷ In real avalanche burials, the time required is likely to be much longer because of psychological and technical demands and higher snow densities of avalanche debris.

Recommendations. We recommend that all travelers in avalanche terrain should carry and know how to use a scooped metal shovel designed for avalanche debris. We suggest shoveling techniques should include using the shovel like a paddle to plow snow downhill. We suggest a conveyor system should be used if multiple rescuers are available. Strong recommendation, low quality evidence.

Professional Rescue

Organized rescue groups may include mountain guides, volunteers, or professionals such as ski patrollers. Professional rescue differs from companion rescue because the response time is typically longer, resources are more plentiful, and group size is larger. Because an organized group takes longer to mobilize than the usual 30 min for a victim to asphyxiate, the incidence of live recovery in organized rescue response is low.^{1,119}

Incident Command System. The Incident Command System (ICS) or a similar system should be used to establish a standardized approach to emergency response for avalanche rescue.¹²⁰⁻¹²²

Recommendations. We recommend that all members of organized rescue groups should receive training in ICS or a similar system in avalanche rescue. Strong recommendation, low quality evidence.

Scene Management. Scene management becomes increasingly important as more rescuers and resources become involved in an avalanche response. Effective scene management can reduce false positive signals from well-intentioned bystanders wearing transceivers in transmit mode and can facilitate effective search of an avalanche path while minimizing missed clues or areas. The boundaries of the avalanche path should be marked to keep unauthorized people from introducing erroneous clues and to ensure that rescuers have a clear view of the avalanche site. The entry and exit tracks, the last-seen point, visible clues, and probe locations should be marked with physical markers such as climbing wands, ice axes, skis, ski poles, or backpacks.¹²³

Recommendations. We recommend active scene management techniques such as boundary control and scene marking should be used. Ungraded: Expert consensus.

Probe Line. For buried victims without transceivers, a probe line should be established. In a professional rescue team, a leader should maximize probe line efficiency to increase the likelihood of recovering a live victim.

The initial probe depth should be 1.5 m to maximize efficiency. This would reach 88% of victims recovered alive in the United States and 95% of victims recovered alive in Switzerland.¹¹¹

The probe technique should follow the 3-holes-per-step method, which is 30% faster than standard coarse probing.¹¹¹ The rescuer inserts the probe into the snow 3 times while standing: 20 cm to the rescuer's left, center, and 20 cm to the rescuer's right. The rescuer then takes a step forward and repeats the process.

In slalom probing, organized rescuers probe 3 areas in a left-to-right pattern 50 cm apart while walking in zig-zags in the avalanche debris. The width of the zig-zags and the size of the search area depend on the number of rescuers.¹²⁴ Slalom probing covers the same surface area faster than the 3-holes-per-step method but may be less effective.

Probe line grid spacing influences the probability of detection. A small grid has a greater chance of finding a buried victim but may cause the probe line to move slowly. A large grid may allow rescuers to miss a buried victim. A 50×50 cm grid offers the best probability of detection without prolonging search time.¹²⁵

Recommendations. We recommend the initial probe pass should be limited to a depth of 1.5 m using 3-holes-per-step or slalom probing to cover a 50×50 cm grid. Strong recommendation, low quality evidence.

RECCO. The RECCO search system uses harmonic radar to detect an avalanche victim. The searcher uses a RECCO receiver to identify a RECCO reflector diode embedded in the victim's clothing. The reflector diodes are small and light and do not require a power source. Many manufacturers have incorporated these reflectors into clothing. Critically buried avalanche victims have been located alive with RECCO.²⁷

RECCO is intended only for professional rescue as it requires training and practice. Other disadvantages of RECCO include short detection range because of attenuation of the signal, especially in dense, wet snow, and the potential for false positive signals from searchers or reflective items such as cell phones.^{27,126}

Recommendations. We recommend professional rescue teams have RECCO search capabilities with established search protocols. Strong recommendation, low quality evidence.

Dog Search. Avalanche rescue dogs are trained to detect buried victims by scent. Survival of victims found by dogs may be no better than that of victims found by organized probe lines.¹²⁷ Limitations of dog searching include the time to transport a team to the site and distractions caused by contamination of the debris field by bystanders. Training avalanche rescue dogs requires substantial time and resource commitments.

Recommendations. We suggest professional rescue teams should consider using dogs trained in avalanche rescue to search debris for buried victims, despite the disadvantages, especially for victims without transceivers. Ungraded: Expert consensus.

Helicopters. Helicopters can shorten response times to remote locations, decrease risk by moving rescuers safely over hazardous terrain to reach avalanche accidents, and evacuate victims rapidly from technical or remote terrain.¹²⁸ Helicopters can be used to search from the air with avalanche transceivers and with RECCO.^{126,129} The helicopter RECCO system and long-range helicopter transceiver units have longer ranges. Helicopter Emergency Medical Services (HEMS) may provide resources that complement capabilities of search and rescue helicopters. Some specially trained HEMS programs can perform both avalanche search and medical transport.¹¹⁹

Helicopters can be very useful but also present risks.¹³⁰ Conditions such as inclement weather and pilot proficiency in mountain environments can significantly affect helicopter performance and safety.^{119,131}

Recommendations. We suggest professional rescue teams should only use helicopters with crews specifically trained in avalanche rescue, if possible. Helicopter teams should consider long-range RECCO and avalanche transceivers. We suggest rescuers should make a risk assessment before launching a helicopter and should follow rigorous safety guidelines. Ungraded: Expert consensus.

Multiple Burial and Multiple Causality Incidents. If there is more than one buried victim, a shortage of resources is likely, especially in the first phases of companion and organized rescue.^{132,133} Even highly developed and well-equipped emergency medical services can be overwhelmed.¹³⁴ Teams may need to use rescue triage during the search and rescue phase, based on parameters such as terrain characteristics, vegetation, snowpack, additional avalanche risk, and burial depth. Prioritization of buried victims requiring less effort to extricate or who were less exposed to trauma may improve the overall outcome of the buried cohort. There are evidence-based search and rescue tools, such as AvaLife, that also include medical treatment protocols, striving for the greatest good for the greatest number in avalanche accidents with multiple burials and limited resources.¹³³ Other protocols have also been developed.⁵⁴

AvaLife contains a search and excavate module (Figures 3 and 4) as well as medical modules.¹³⁵ Mountain rescue teams should be prepared to manage accidents with multiple burials according to recommendations of the International Commission for Mountain Emergency Medicine.¹³⁶ Good communication on site is essential for an efficient, safe rescue.¹³⁴

Recommendations. We suggest mountain rescue organizations should be prepared to manage multiple burial accidents. Weak recommendation, low quality evidence.

Resuscitation

Resuscitation at the scene of an avalanche can be difficult.¹⁰⁰ Rescuers may have to start CPR and advanced life support (ALS) in a confined space in an austere environment with limited equipment and personnel. Resuscitation can start once the head and chest have been exposed, even before complete extrication. Information about the duration of burial, patency of the airway, presence of an air pocket, and vital signs at the time of extrication should guide treatment and transport decisions early in the resuscitation.²³

Factors predicting survival after avalanche burial include severity of injury, duration of critical burial, airway patency, core temperature, initial serum potassium, if available in the field, and the Hypothermia Outcome Prediction after Extracorporeal Life Support (HOPE) score.^{53,137}

The European Resuscitation Council (ERC) updated guidelines for on-site triage of avalanche victims in cardiac arrest and for transport decisions in 2021 (Figure 5).²³ Retrospective

observational studies have reported survival rates of avalanche victims in cardiac arrest receiving prolonged CPR and extracorporeal life support (ECLS) as low as 11% in unwitnessed cardiac arrest.^{25,138,139} A Swiss study of 66 victims found that of 126 critical decisions, 117 (93%) conformed to ERC guidelines. Despite high adherence, no victim survived.¹⁴⁰ The likelihood of survival is low for victims cooled slowly to <30°C before cardiac arrest. Victims in ventricular fibrillation and pulseless electrical activity have greater likelihood of survival than victims with asystole. Victims in cardiac arrest with short burial and early initiation of resuscitation by their companions have the best chances of surviving neurologically intact. Published cooling rates of completely buried avalanche victims range from 0.6°C h⁻¹ to 9.4°C h⁻¹.^{19,37,38,43,63,140-142} Rapid cooling under snow is associated with having an air pocket, sweating before being buried, lean body habitus, thin monolayer clothing, uncovered head and hands, impaired consciousness, no shivering, and hypercapnia.⁶³

After 60 min of burial, if the airway is patent, successful resuscitation of victims in cardiac arrest with moderate or severe hypothermia may be possible. There is no reported successful resuscitation of an avalanche victim in cardiac arrest with core temperature >30°C with ECLS rewarming because cardiac arrest is likely caused by asphyxia.

The HOPE score should be used to predict outcome after hypothermic cardiac arrest in avalanche victims being considered for ECLS rewarming (Figure 5).^{137,143} Serum potassium alone should only be used for triage if the HOPE score cannot be used. If there are signs of death, such as freezing of the entire body or trauma incompatible with life, CPR should be terminated or withheld.^{144,145}

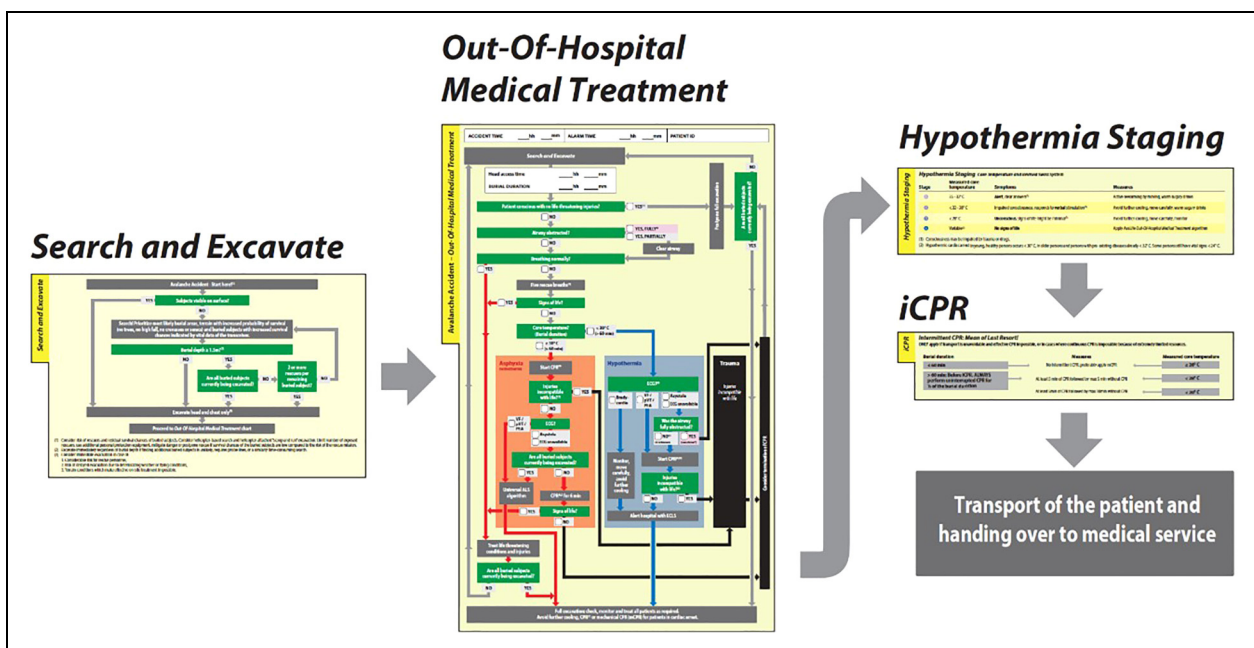


Figure 3. Overview of the AvaLife BLS modules. The modules follow a step-by-step approach to technical and medical avalanche rescue. From Genswein et al.¹³⁵ Used under Creative Commons CC-BY license.

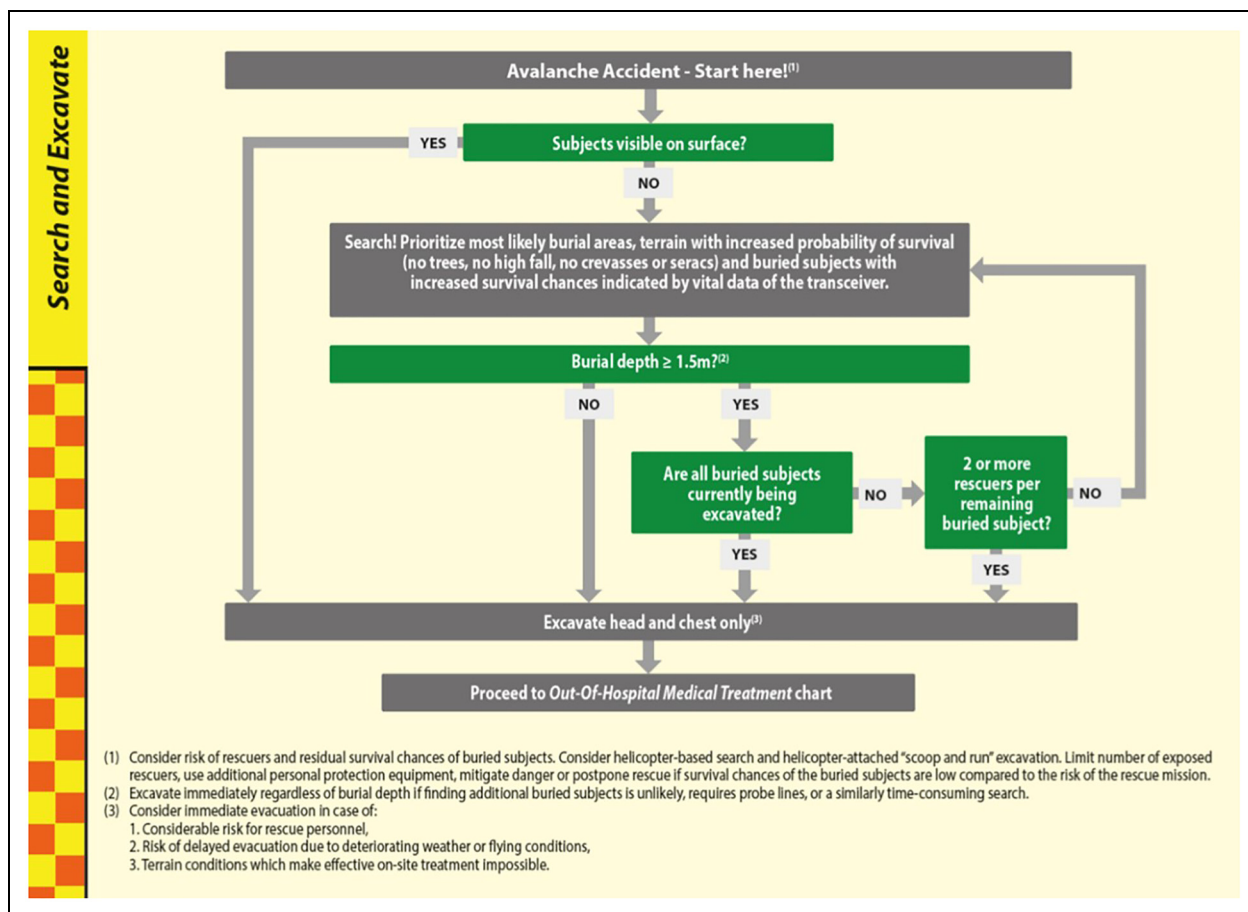


Figure 4. The search and excavate module of Avalife includes the burial depth threshold of ≥ 150 cm and 2 or more rescuers per remaining buried victim. These criteria are required to distinguish victims who should be excavated immediately from cases when excavation should be postponed. From Genswein et al.¹³⁵ Used under Creative Commons CC-BY license.

Critical Burial of an Uninjured Victim

If a victim is alert and responsive after critical burial, cold stress or mild hypothermia is still a possibility, especially with burials longer than 30 min. Rewarming can occur with shivering thermogenesis. Critically buried avalanche victims can develop pulmonary edema several hours after extrication. The etiology seems to be a combination of negative-pressure induced pulmonary edema and hypoxia-induced left heart failure.⁴¹⁻⁴³ In a Swiss study of victims buried >60 min but <24 h, the survival rate was 19%.¹⁴⁶ Burial depth is inversely correlated with survival.²⁴

Recommendations. We suggest that a critically buried victim, even if uninjured, should be transported to the nearest medical facility capable of evaluating and stabilizing the victim. Weak recommendation, low quality evidence.

Management of Trauma

Depending on climate, snow quality, terrain, and speed of rescue, approximately 25% of buried victims will die from trauma. The most common fatal injuries are multiple trauma,

head injury, and spinal injury.^{12,50} Risk factors include steep, forested, and rocky terrain.^{4,12,16,50} A Swiss study reported that summer avalanches are rare (21/482 accidents) but are more likely to result in fatal trauma (33/35 fatalities).⁵⁰

Victims with injuries such as head trauma, spinal injuries, and long bone fractures should be treated using standard advance trauma life support. Suspected cervical spine injuries should be managed using validated guidelines such as NEXUS⁹¹ or the Canadian C-Spine Rule.⁹² The Wilderness Medical Society Clinical Practice Guidelines for Spinal Cord Protection present recommendations for preventing, evaluating, and managing spinal injuries in the wilderness but have not been validated.^{147,148} Hypothermia inhibits coagulation and increases bleeding.¹⁴⁹⁻¹⁵¹ Preventing cooling during long transports may be critical.

Recommendations. We suggest avalanche resuscitation should include trauma care and that suspected spinal injuries should be managed according to the recommendations of validated guidelines such as NEXUS or the Canadian C-Spine Rule. Ungraded: Expert consensus.

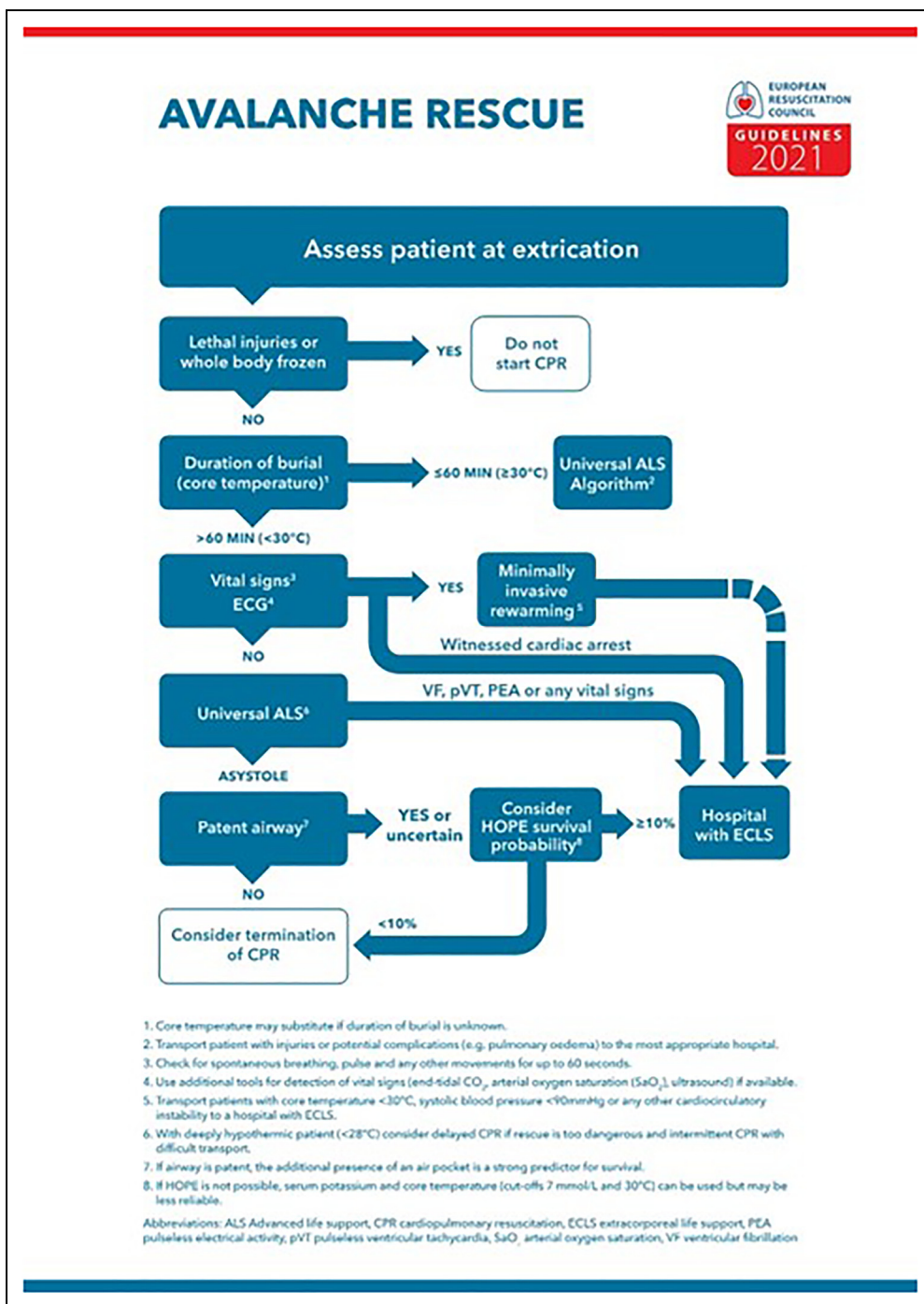


Figure 5. Avalanche accident algorithm for management of critically buried victims. From Lott et al.²³ Used with permission. ECLS, extracorporeal life support.

Management of Hypothermia

Core temperature is most accurately measured using an esophageal probe, but epitympanic temperatures are more practical in victims who are not fully conscious and without airway protection with endotracheal intubation or

extraglottic devices.^{152,153} Tympanic temperatures are unreliable in hypothermic victims.

Vital signs and core temperatures are positively correlated. Level of consciousness has the best correlation.¹⁵⁴ The RSS for staging accidental hypothermia uses level of

	Stage 1	Stage 2	Stage 3	Stage 4
Clinical findings ^a	“Alert” from AVPU	“Verbal” from AVPU	“Painful” or “Unconscious” from AVPU AND Vital signs present	“Unconscious” from AVPU AND No detectable vital signs ^b
Risk of cardiac arrest ^c	Low	Moderate	High	Hypothermic cardiac arrest

Figure 6. The Revised Swiss System for staging of accidental hypothermia. From Musi et al.⁶⁰ Used under Creative Commons CC-BY license. AVPU, Alert, Verbal, Pain, Unresponsive.

consciousness to estimate the degree of hypothermia and the risk of cardiac arrest. (Figure 6).⁶⁰ The RSS is reliable only if the victim does not have a coexisting condition affecting the level of consciousness, such as intoxication or traumatic brain injury. The RSS is useful if temperature measurement is not available. A cold, unconscious avalanche victim likely has moderate or severe hypothermia. The WMS guidelines for accidental hypothermia⁵⁸ and the ERC guidelines²³ present recommendations for treating hypothermia.

Recommendations. We recommend measuring core temperature or using the RSS to estimate the risk of hypothermic cardiac arrest. Strong recommendation, moderate quality evidence.

Recommendation. We recommend that avalanche resuscitation should include treatment of hypothermia according to the WMS guidelines for accidental hypothermia or the ERC guidelines. Strong recommendation, moderate quality evidence.

Initiating Resuscitation

Waiting to start CPR until a victim is supine during the initial extrication is likely to cause a delay. In a manikin study simulating a restricted environment CPR in an over-the-head or straddle position had comparable quality CPR to a standard CPR position.¹⁵⁵ All victims who are extricated should be assessed for airway, breathing, and circulation. Victims with witnessed cardiac arrest should undergo immediate CPR. Witnessed cardiac arrest is often caused by hypothermia.^{65,156} The chances of survival are far better in hypothermic cardiac arrest compared to those of normothermic cardiac arrest from trauma or asphyxia.^{157,158} A meta-analysis of 221 hypothermia victims reported an overall survival rate of 27%. Most survivors (83%) had no neurologic deficit. Even unwitnessed hypothermic cardiac arrest presenting with asystole should not preclude ECLS rewarming. In one study, 48% of victims with asystole survived. Of the survivors, 79% had good neurological outcomes.¹⁵⁸

Unless there is a contraindication to resuscitation, rescuers should start CPR as soon as possible. Rescuers who are suitably trained and equipped should perform ALS interventions.¹⁵⁹

In victims buried ≤ 60 min with core temperatures $\geq 30^{\circ}\text{C}$, cardiac arrest is usually a result of trauma or asphyxia rather

than hypothermia. ECLS rewarming is contraindicated. If standard CPR or ALS does not achieve return of spontaneous circulation (ROSC) within 30 min, the chance of survival is minimal and further attempts at resuscitation should be terminated.^{144,160-162} Definite signs of death, such as trauma incompatible with life or whole body frozen, are indications to withhold or terminate CPR.¹⁴⁵

If duration of burial is >60 min, the core temperature $<30^{\circ}\text{C}$, and the victim had a patent airway at extrication, cardiac arrest may have been caused hypothermia. Rescuers should attempt resuscitation with prolonged CPR, transfer to definitive care, and extracorporeal rewarming.⁸⁴

CPR and ALS may need to continue beyond 60 min, especially when cardiac arrest may have been caused by hypothermia or if there was a witnessed cardiac arrest after extrication. If core temperature is $<30^{\circ}\text{C}$, defibrillation may be unsuccessful, but prolonged CPR may be successful, even if it takes hours until a victim is rewarmed to 30°C .²³ Delayed and intermittent CPR may be necessary in hypothermic victims with suspected severe hypothermia or core temperatures $<28^{\circ}\text{C}$, when immediate and continuous CPR is not possible (Figure 7).

Recommendations. We recommend that if there are no vital signs and no indications for withholding resuscitation, rescuers should start CPR and ALS while performing further assessment. Strong recommendation, moderate quality evidence.

Recommendation. We recommend that in a technically difficult rescue with a severely hypothermic victim (core temperature $<28^{\circ}\text{C}$), delayed and intermittent CPR may be required. Strong recommendation, moderate quality evidence.

Recommendation. We recommend that if duration of burial is >60 min, core temperature is $<30^{\circ}\text{C}$, and the airway is patent, cardiac arrest was possibly caused by hypothermia, so CPR should be continued and the victim transported to a hospital with ECLS capability. We recommend that if duration of burial is ≤ 60 min, core temperature is $\geq 30^{\circ}\text{C}$, and the airway is not patent, resuscitation attempts should be stopped if ROSC is not achieved within 30 min. Strong recommendation, moderate quality evidence.

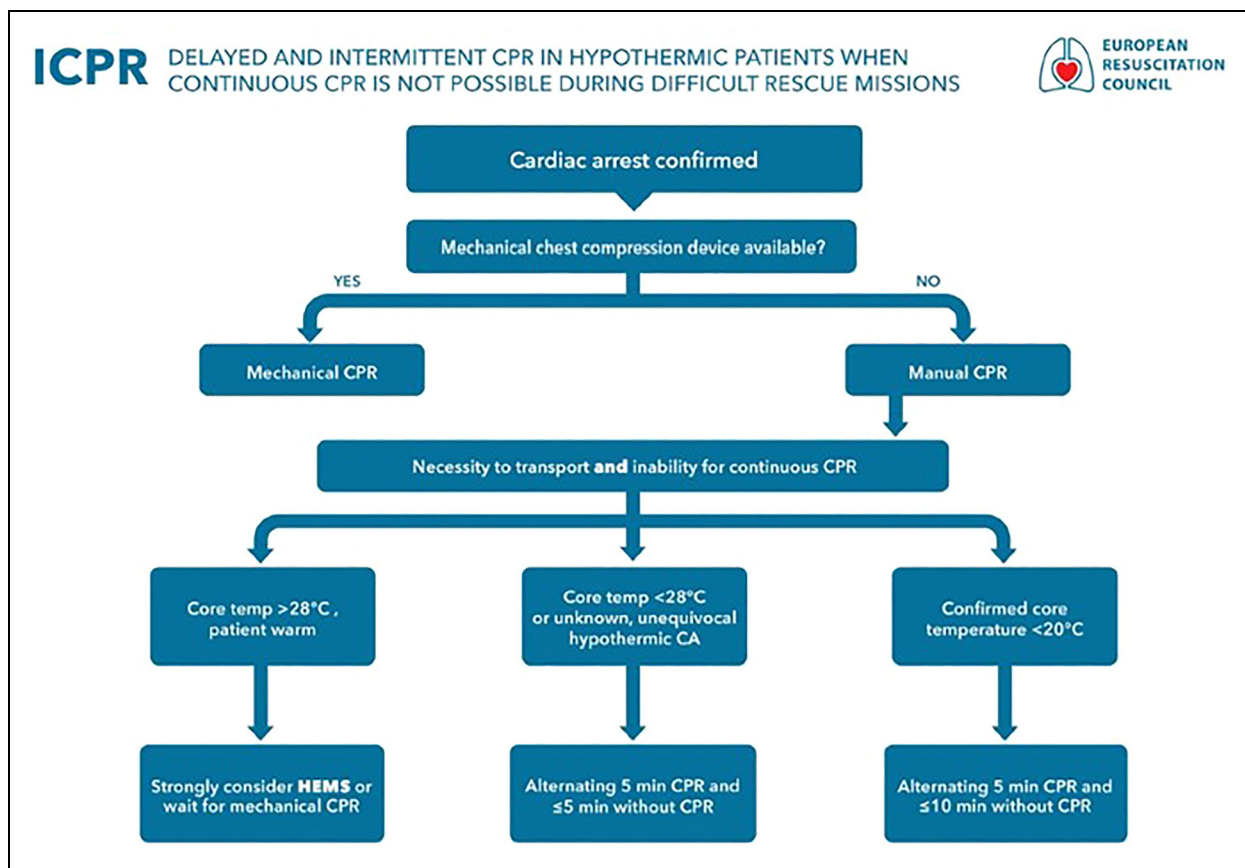


Figure 7. Delayed and intermittent CPR in hypothermic victims when continuous CPR is not possible. From Lott et al.²³ Used with permission. CA, cardiac arrest; CPR, cardiopulmonary resuscitation.

Defibrillation. If a defibrillator is available, rescuers should place pads and analyze the rhythm before moving or extricating the victim. The core temperature at which defibrillation should be initiated and the power and number of shocks for a hypothermic victim in cardiac arrest with a core temperature $<30^{\circ}\text{C}$ have not been established. Defibrillation may be successful below a core temperature of 28°C or even lower. However, ROSC after defibrillation is more stable and less commonly degenerates back into ventricular fibrillation at higher core temperatures ($\geq 30^{\circ}\text{C}$).¹⁶³ Delaying continued defibrillation attempts until core temperature is $\geq 30^{\circ}\text{C}$ may be reasonable, because every shock can cause further myocardial injury.²³ CPR and rewarming may need to be continued for several hours to allow successful defibrillation.¹⁶⁴ The longest resuscitation in a hypothermic victim in cardiac arrest lasted 8 h and 42 min: mechanical CPR lasted 3 hours and 42 min, followed by 5 h of ECLS.^{56,165}

The WMS hypothermia guidelines recommend 1 defibrillation attempt for a victim in cardiac arrest with core temperature $<30^{\circ}\text{C}$.⁵⁸ The American Heart Association recommends defibrillation attempts every 2 min for hypothermic victims in cardiac arrest.¹⁶⁶ The ERC guidelines recommend up to 3 defibrillation attempts with a core temperature $<30^{\circ}\text{C}$, delaying

further attempts until core temperature is $\geq 30^{\circ}\text{C}$ if ventricular fibrillation persists after 3 shocks.²³

Recommendations. We recommend attempting defibrillation in cardiac arrest after avalanche burial according to local protocols. If defibrillation is unsuccessful, we recommend CPR in hypothermic cardiac arrest should continue until the victim is rewarmed to a core temperature $\geq 30^{\circ}\text{C}$. Strong recommendation, moderate quality evidence.

ALS. An unconscious victim of avalanche burial may benefit from endotracheal intubation for airway control and assisted ventilation. Extraglottic airways can be used if part of local protocol. Hypocapnia from hyperventilation decreases cerebral blood flow because of vasoconstriction. This is likely to be detrimental, especially to a victim with traumatic brain injury or hypothermia. Ventilation should be targeted to normocapnia.^{37,61,167} If intravenous fluids are available, intravenous or intraosseous volume resuscitation with isotonic fluids, warmed, if possible to 40°C , can help support circulation. Hypothermic cardiac arrest is associated with a lower EtCO_2 than normothermic cardiac arrest. In contrast to normothermic cardiac arrest, $\text{EtCO}_2 < 10$ mm Hg should not be used to predict a fatal outcome.^{165,168}

Recommendations. We recommend that if duration of burial is ≤ 60 min or core temperature $\geq 30^{\circ}\text{C}$, standard resuscitation and ALS should be performed if possible. This should include volume resuscitation and endotracheal intubation or placement of an extraglottic airway with normocapnic ventilation if indicated. Strong recommendation, moderate quality evidence.

Recommendation. We recommend not using EtCO_2 < 10 mm Hg to predict outcome. Strong recommendation, high quality evidence.

Mechanical Chest Compression. Mechanical chest compression achieves higher quality than manual CPR in technically difficult settings and during prolonged transport. A single study in an urban environment failed to show an improvement in outcome with mechanical chest compressions compared to manual compressions.¹⁶⁹ In a manikin study simulating a technically difficult helicopter rescue, chest compressions with a mechanical device were technically superior to manual chest compressions.¹⁷⁰ The ERC recommends mechanical chest compressions during CPR in long or technically demanding rescues.²³

Recommendations. We recommend that if available, mechanical chest compressions should be used for technically difficult or long transports. Strong recommendation, low quality evidence.

Delayed and Intermittent Resuscitation. If a victim is in cardiac arrest with a known or suspected core temperature $< 28^{\circ}\text{C}$ and continuous CPR is impossible for safety reasons because the number of rescuers is limited or performing CPR during extrication and transport is difficult, CPR can be delayed or intermittent¹⁷¹ according to the WMS hypothermia guidelines and still be successful.^{38,172,173} Without a mechanical chest compression device, a victim with unknown core temperature, but likely in hypothermic cardiac arrest or with core temperature $< 28^{\circ}\text{C}$, should receive at least 5 min of CPR alternating with periods of ≤ 5 min without CPR. In a victim with a core temperature $< 20^{\circ}\text{C}$, pauses in CPR can be extended to ≤ 10 min.¹⁷¹ Hands-off times should be kept as short as possible (Figure 7).²³

Recommendations. We recommend that if continuous CPR is not possible in a victim with a core temperature $< 28^{\circ}\text{C}$ or with an unknown core temperature but likely hypothermic cardiac arrest, CPR can be delayed or intermittent. Strong recommendation, moderate quality evidence.

Withholding or Terminating Resuscitation

Trauma. The likelihood of survival after traumatic cardiac arrest in an avalanche is extremely low.^{144,145} No survivor with traumatic cardiac arrest from an avalanche has ever been reported.

Recommendations. We suggest that if a critically buried victim is in cardiac arrest because of trauma, rescuers should withhold resuscitation. Weak recommendation, low quality evidence.

Duration of Burial, Core Temperature, and Airway. Critically buried victims are very likely to die within 60 min from asphyxia if the airway is not patent or if the air pocket is inadequate to support effective ventilation.^{21,32,35} Standard ALS can lead to ROSC in an asphyxiated victim, but with a high risk of permanent neurologic damage. Avalanche victims who are found pulseless and apneic or in asystole with core temperature $\geq 30^{\circ}\text{C}$ at extrication have most likely died from asphyxia.¹³⁸

An avalanche victim with core temperature $< 30^{\circ}\text{C}$ and a patent airway at extrication with ventricular fibrillation, pulseless electrical activity, pulseless ventricular tachycardia, or a perfusing rhythm after a witnessed cardiac arrest has a good chance of survival.^{38,138,174}

Recommendations. We recommend that in a pulseless and apneic victim, regardless of cardiac rhythm, with duration of burial of ≤ 60 min and core temperature $\geq 30^{\circ}\text{C}$, rescuers should consider terminating resuscitation if ROSC does not occur within 30 min, depending on local protocols. Strong recommendation, moderate quality evidence.

Recommendation. We recommend that in a pulseless and apneic victim, regardless of cardiac rhythm, with an obstructed airway and duration of burial of > 60 min, rescuers should consider terminating resuscitation if ROSC does not occur within 30 min, depending on local protocols. Strong recommendation, moderate quality evidence.

Prediction of Survival with ECLS Using the HOPE Score. The HOPE score is a multivariate algorithm to predict survival of hypothermic victims in cardiac arrest resuscitated with ECLS rewarming. It can be accessed freely at <https://www.hypothermiascore.org>.¹⁴³ Discrimination between survivors and non-survivors is better with the HOPE score than with serum potassium alone.^{59,143} The HOPE score has been externally validated.¹³⁷ If the HOPE score cannot be used, serum potassium alone can be used for triage.⁵⁹ Avalanche victims with possible asphyxia, should be scored with “asphyxia” and “in cardiac arrest at extrication.” The HOPE score was not developed to predict survival with ECLS of avalanche victims in cardiac arrest survival but is currently the best tool for this purpose.^{175,176}

Traditionally serum potassium has been used for outcome prediction. The highest recorded potassium in a successfully resuscitated avalanche victim was 6.4 mmol L^{-1} .¹⁹ One avalanche victim with serum potassium 8.0 mmol L^{-1} had ROSC but did not survive.¹⁷⁷ It may be reasonable to transport an avalanche victim with unwitnessed cardiac arrest and other factors that might lead to termination of resuscitation to the nearest medical facility to

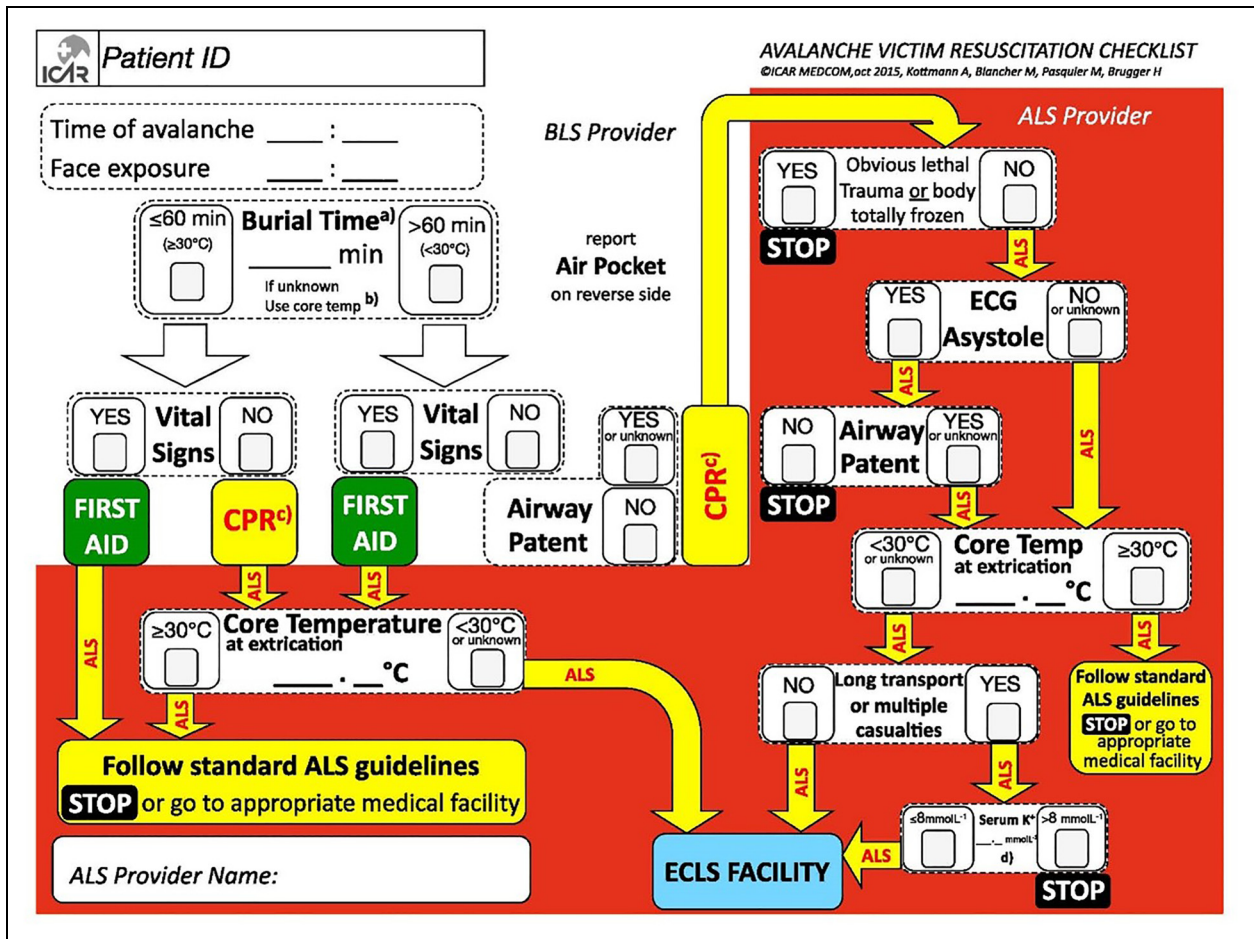


Figure 8. The Avalanche Resuscitation Checklist from the International Commission for Alpine Rescue. Adapted from Kottmann et al.¹⁸⁶ BLS, Basic Life Support. (continued)

determine the HOPE score, including serum potassium, and to assess eligibility for invasive rewarming techniques. If the HOPE score cannot be calculated, ECLS rewarming should not be initiated unless core temperature is <30°C and serum potassium is <7 mmol L⁻¹.⁵⁹

Recommendations. We recommend using the HOPE score for outcome prediction in hypothermic avalanche victims in cardiac arrest being considered for ECLS rewarming. If the circumstances are not clear, choose asphyxia as the reason for cardiac arrest. Strong recommendation, moderate quality evidence.

Recommendation. We recommend in an avalanche victim with a serum potassium of >7 mmol L⁻¹, rescuers should withhold resuscitation, and ECLS rewarming should not be initiated. Strong recommendation, high quality evidence.

Risk to the Rescuers. After an avalanche, ongoing hazards may include additional avalanches, austere weather, and health risks to the rescuers, such as exhaustion, hypothermia, or frostbite. Rescuers should exercise caution when approaching an

avalanche accident to avoid putting themselves in danger. Personal safety should be the first priority of each rescuer. Safety of the rescue team is the second priority. Only after these are assured should rescuers extricate and treat any victims.

Recommendations. We suggest that if the risks to the rescuers are unacceptably high, rescue attempts should be delayed until conditions improve, or the risks can be mitigated sufficiently. Ungraded: Expert consensus.

Transfer to Definitive Care

A severely hypothermic victim in cardiac arrest should be resuscitated with ECLS, if possible.¹⁷⁸⁻¹⁸¹ Transport to a facility with ECLS may be beneficial for a victim with core temperature <30°C and hemodynamic instability, including systolic blood pressure <90 mm Hg or ventricular arrhythmias.²⁸ Victims with trauma should be transferred to a trauma center, if feasible. ECLS rewarming is possible in trauma victims. A hypothermic victim in cardiac arrest who cannot be transported to a facility with ECLS capability within 6 h should be taken to a closer hospital for non-ECLS rewarming.¹⁸²⁻¹⁸⁴


<p>Air Pocket</p> <p><input type="checkbox"/> Yes, ___ x ___ x ___ (cm)</p> <p><input type="checkbox"/> No</p> <p><input type="checkbox"/> Unknown</p>	<p>Rescue Service:</p> <p>Base:</p> <p>Phone:</p>
<p>H The Checklist is to remain with the patient throughout his/her pre-hospital and in-hospital course until final destination.</p>	
<p>Rescue Service At Medical Facility delivery, make a copy, a scan or a digital photograph of this checklist and keep it with the copy of your rescue mission protocol.</p>	
<p>Abbreviations:</p> <p>Patient ID = Patient Identity</p> <p>CPR = Cardiopulmonary Resuscitation</p> <p>ALS = Advanced Life Support</p> <p>ECLS = Extra Corporeal Life Support (CardioPulmonary Bypass / Extra Corporeal Membrane Oxygenation)</p> <p>a) Time between burial and uncovering the face.</p> <p>b) If duration of burial is unknown, core temperature using an oesophageal probe may substitute in patients in cardiac arrest.</p> <p>c) CPR can be withheld if unacceptable level of risk for the rescuer, total body frozen or obvious lethal trauma (decapitation, truncal transection).</p> <p>d) If K^+ at hospital admission exceeds 8 mmolL^{-1} consider terminating resuscitation (after excluding crush injuries and consideration of the use of depolarizing paralytics).</p> <p>Patients who present with cardiac instability (ventricular arrhythmias, systolic blood pressure $<90\text{mmHg}$) or core temperature $<30^\circ\text{C}$ should be transported towards hospital with ECLS rewarming possibility.</p>	
<p> AVALANCHE VICTIM RESUSCITATION CHECKLIST © ICAR, MEDCOM, oct. 2015, Kottmann A, Blancher M, Pasquier M, Brugger H</p>	

Figure 8. Continued.

Recommendations. We recommend that a hypothermic avalanche victim in cardiac arrest or with hemodynamic instability should be transferred as rapidly as possible to a facility with ECLS capability if possible within 6 h. Strong recommendation, high quality evidence.

Recommendation. We recommend that if a hypothermic avalanche victim in cardiac arrest or with hemodynamic instability cannot be transported to an ECLS center within 6 h, the victim should be taken to a closer hospital for non-ECLS rewarming. Strong recommendation, low quality evidence.

Avalanche Victim Resuscitation Checklist

Adherence to avalanche resuscitation guidelines is often suboptimal.¹⁸⁵ The International Commission for Mountain Emergency Medicine (ICAR MedCom) published an avalanche victim resuscitation checklist in 2015¹⁸⁶ and an updated checklist in 2017.¹⁸⁷ The checklist is meant to improve adherence to guidelines and to help collect medical data for refining the guidelines (Figure 8).¹⁸⁷ The checklist is designed to be completed at the site of the accident and remains with the victim until hospital admission.

Recommendations. We recommend that an avalanche resuscitation algorithm be used whenever possible. We recommend that a checklist be used to improve adherence to the ICAR MedCom resuscitation algorithm. Strong recommendation, low quality evidence.

Multiple Burials

Rescuing multiple burial victims can overwhelm locally available resources.^{134,136} A Monte Carlo simulation of avalanche accidents with multiple victims and a limited number of rescuers¹³³ was used to determine the greatest good for the greatest number of victims by limiting the duration of CPR of victims in cardiac arrest when other victims are still buried, and additional personnel are not available. The guidelines were published as AvaLife.¹³⁵ AvaLife limits CPR to 6 min in mass casualty incidents for victims who are normothermic and buried ≥ 150 cm deep.

Recommendations. We suggest rescuers should be prepared to triage in multiple burial situations. Ungraded: Expert consensus.

Post-Traumatic Stress Disorder After Avalanche Burial

Avalanche burial is a traumatic event. Preventive measures and early diagnosis of post-traumatic stress disorder may reduce the psychological burden.^{64,188} Avalanche rescuers are also at risk for long-lasting psychological effects. Formal psychological support may be beneficial.¹⁸⁹

Recommendations. We recommend providing psychological assistance to avalanche victims and rescuers. Strong recommendation, low quality evidence.

Research

The ICAR MedCom has determined quality indicators for the management of avalanche victims^{128,190} that should be used in reporting avalanche accidents. Registries might be useful to improve protocols for the management of avalanche victims.¹⁹¹

Recommendations. We recommend that avalanche accident registries should be used to improve the management of victims. Strong recommendation, moderate quality evidence.

Nonavalanche Snow Burial

Nonavalanche snow burial (NASB), also called “nonavalanche-related snow immersion” or “snow submersion suffocation,” is different from avalanche burial. NASB has been reported in skiers, snowboarders, snowshoers, and snowmobilers who fell headfirst into tree wells or deep powder snow.

Victims who are unable to extricate themselves die from asphyxia when snow compacts around the head.

The only published references are case reports, a review article, and a small simulation study.^{8,192} Self-extrication can be difficult or impossible. Buried victims who remove their skis sink deeper. Position likely affects the chance of successful self-extrication. Victims who were able to extricate themselves were often flexed at the waist. Case reports suggest that asphyxiation can occur rapidly, but there is no good evidence regarding the time it takes for death to occur or the exact mechanism of asphyxia.¹⁹³⁻¹⁹⁷

The best way to prevent NASB is to recognize and avoid tree wells and to avoid burial in soft snow by staying within the limits of one’s skills and not falling. Other possibly effective measures to prevent fatal burial include maintaining voice and visual contact with a partner, alerting a partner when falling by yelling, and grabbing tree branches while falling in an attempt to stay upright.

Buried victims can use gentle rocking motions to try to pack the snow and get a purchase in attempting to self-extricate.¹⁹² However, a simulated burial study found that victims sank deeper when struggling and when skis or snowboards were jettisoned. Parkas collected more snow when the victims were upside down.¹⁹² Whether skis and snowboards should remain attached or be jettisoned is unclear. In 2 cases, victims were spotted because skis or a snowboard was still attached.^{193-195,197}

There are no data on the use of avalanche transceivers, radios, or mobile phones in NASB. One body was recovered using an avalanche beacon and another victim was found alive after using a voice-activated 2-way radio.¹⁹⁷ One manufacturer has speculated that deploying an airbag might create an air pocket.^{196,197} An airbag that deflates after deployment might create an air pocket.⁸⁹ A small study suggested an airbag that deflates after burial might be useful to prevent nonavalanche snow burial asphyxia.⁹³

Recommendations. Avoiding falling into tree wells or deep powder snow is the only known means of preventing NASB. We suggest that a victim of NASB should keep skis or snowboard attached to avoid sinking deeper and to provide visual clues to rescuers. Weak recommendation, low quality evidence.

Recommendation. We suggest that in areas with deep snow or tree wells, travelers should stay in voice and visual contact with a partner. If falling, we suggest that a person should yell to alert a partner, attempt to grab a tree branch, and attempt to land upright. Ungraded: Expert consensus.

Recommendation. We suggest that a transceiver may be useful to locate a person buried in deep snow or a tree well. We also suggest that an airbag that deflates after deployment may create an air pocket that might help prevent or delay asphyxia. Ungraded: Expert consensus.

Discussion

These guidelines are evidence-based recommendations for prevention, rescue, and resuscitation in avalanche and NASB accidents. The foundation of avalanche safety for professional personnel and recreational enthusiasts is avoidance of high-hazard, avalanche-prone areas. Avalanche safety should be learned through education about avalanche mechanics, safe route finding, traveling in appropriate snow and weather conditions, knowledge of local avalanche forecasts, routine practice with equipment, gaining experience from skilled partners and guides, taking courses, and using good judgment. Good judgment is the single most important factor in avalanche safety.

Data regarding avalanche safety techniques and management of avalanche injuries are limited, as with all of wilderness medicine. It is difficult to conduct randomized, controlled trials or simulate avalanche accidents. Future research should evaluate the efficacy of helmets and avalanche airbag configurations in trauma prevention, the causes of airbag nondeployment, and the use of new transceiver technology. Advances in ALS, ECLS, dog search, and aeromedical evacuation may lead to improved methods for managing avalanche victims.

Acknowledgments

The authors thank Dale Atkins and Jürg Schweizer for their assistance with statistics.

Author Contribution(s)

For 2017 and 2024 update, all authors contributed to acquisition of data, analysis of data, drafting the manuscripts, critical revision of the manuscripts, and approval of one or both of the final manuscripts.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Supplemental Material

Supplementary material associated with this article can be found in the online version at <https://doi.org/10.1016/j.wem.2023.05.014>.

References

- Atkins D. 10 years of avalanche rescues in the United States, 2003/04 to 2012/13. *Avalanche Rev.* 2015;33(3):22-24.
- Brugger H, Durrer B, Elsensohn F, Paal P, Strapazon G, Winterberger E, et al. Resuscitation of avalanche victims: evidence-based guidelines of the international commission for mountain emergency medicine (ICAR MEDCOM): intended for physicians and other advanced life support personnel. *Resuscitation.* 2013;84(5):539-546.
- Haegeli P, Falk M, Brugger H, Etter HJ, Boyd J. Comparison of avalanche survival patterns in Canada and Switzerland. *CMAJ.* 2011;183(7):789-795.
- Brugger H, Etter HJ, Zweifel B, Mair P, Hohlrieder M, Ellerton J, et al. The impact of avalanche rescue devices on survival. *Resuscitation.* 2007;75(3):476-483.
- International Commission for Alpine Rescue. 20160115-AVA deadly avalanche accidents statistic 1983-2015. Accessed May 16, 2016. <http://www.alpine-rescue.org/xCMS5/WebObjects/nexus5.woa/wa/icar?menuid=1067&rubricid=263&articleid=12597>
- Oshiro K, Tanioka Y, Schweizer J, Zafren K, Brugger H, Paal P. Prevention of hypothermia in the aftermath of natural disasters in areas at risk of avalanches, earthquakes, tsunamis and floods. *Int J Environ Res Public Health.* 2022;19(3):1098.
- Niemann D, Paul S, Rahman HH. Avalanche preparedness and accident analysis among backcountry skier, sidecountry, and snowmobile fatalities in the United States: 2009 to 2019. *Wilderness Environ Med.* 2022;33(2):197-203.
- Van Tilburg C. Non-avalanche-related snow immersion deaths: tree well and deep snow immersion asphyxiation. *Wilderness Environ Med.* 2010;21(3):257-261.
- Van Tilburg C, Grissom CK, Zafren K, McIntosh S, Radwin MI, Paal P, et al. Wilderness Medical Society Practice Guidelines for prevention and management of avalanche and nonavalanche snow burial accidents. *Wilderness Environ Med.* 2017;28(1):23-42.
- Diekemper RL, Patel S, Mette SA, Ornelas J, Ouellette DR, Casey KR. Making the GRADE: CHEST updates its methodology. *Chest.* 2018;153(3):756-759.
- Brugger H, Zafren K, Festi L, Paal P, Strapazon G. *Mountain Emergency Medicine.* 1st ed. Edra Publishing; 2021.
- Sheets A, Wang D, Logan S, Atkins D. Causes of death among avalanche fatalities in Colorado: a 21-year review. *Wilderness Environ Med.* 2018;29(3):325-329.
- Brugger H, Durrer B, Adler-Kastner L, Falk M, Tschirky F. Field management of avalanche victims. *Resuscitation.* 2001;51(1):7-15.
- Boyd J, Haegeli P, Abu-Laban RB, Shuster M, Butt JC. Patterns of death among avalanche fatalities: a 21-year review. *CMAJ.* 2009;180(5):507-512.
- Brugger H, Etter HJ, Boyd J, Falk M. Causes of death from avalanche. *Wilderness Environ Med.* 2009;20(1):93-96.
- Hohlrieder M, Brugger H, Schubert HM, Pavlic M, Ellerton J, Mair P. Pattern and severity of injury in avalanche victims. *High Alt Med Biol.* 2007;8(1):56-61.
- Stalsberg H, Albretsen C, Gilbert M, Kearney M, Moestue E, Nordrum I, et al. Mechanism of death in avalanche victims. *Virchows Arch A Pathol Anat Histopathol.* 1989;414(5):415-422.
- Grossman MD, Saffle JR, Thomas F, Tremper B. Avalanche trauma. *J Trauma.* 1989;29(12):1705-1709.
- Locher T, Walpoth BH. Differential diagnosis of circulatory failure in hypothermic avalanche victims: retrospective analysis of 32 avalanche accidents [in German]. *Praxis (Bern 1994).* 1996;85(41):1275-1282.

20. McIntosh SE, Grissom CK, Olivares CR, Kim HS, Tremper B. Cause of death in avalanche fatalities. *Wilderness Environ Med.* 2007;18(4):293-297.
21. Falk M, Brugger H, Adler-Kastner L. Avalanche survival chances. *Nature.* 1994;368(6466):21.
22. Haegeli P, Falk M, Procter E, Zweifel B, Jarry F, Logan S, et al. The effectiveness of avalanche airbags. *Resuscitation.* 2014;85(9):1197-1203.
23. Lott C, Truhlar A, Alfonzo A, Barelli A, Gonzalez-Salvado V, Hinkelbein J, et al. European Resuscitation Council Guidelines 2021: cardiac arrest in special circumstances. *Resuscitation.* 2021;161:152-219.
24. Procter E, Strapazzon G, Dal Cappello T, Zweifel B, Wurtele A, Renner A, et al. Burial duration, depth and air pocket explain avalanche survival patterns in Austria and Switzerland. *Resuscitation.* 2016;105:173-176.
25. Boue Y, Payen JF, Brun J, Thomas S, Levrat A, Blancher M, et al. Survival after avalanche-induced cardiac arrest. *Resuscitation.* 2014;85(9):1192-1196.
26. Kornhall DK, Logan S, Dolven T. Body positioning of buried avalanche victims. *Wilderness Environ Med.* 2016;27(2):321-325.
27. Grasegger K, Strapazzon G, Procter E, Brugger H, Soteras I. Avalanche survival after rescue with the RECCO rescue system: a case report. *Wilderness Environ Med.* 2016;27(2):282-286.
28. Brown DJ, Brugger H, Boyd J, Paal P. Accidental hypothermia. *N Engl J Med.* 2012;367(20):1930-1938.
29. Brugger H, Durrer B, International Commission for Mountain Emergency Medicine. On-site treatment of avalanche victims ICAR-MEDCOM-recommendation. *High Alt Med Biol.* 2002;3(4):421-425.
30. Strapazzon G, Paal P, Schweizer J, Falk M, Reuter B, Schenk K, et al. Effects of snow properties on humans breathing into an artificial air pocket - an experimental field study. *Sci Rep.* 2017;7(1):17675.
31. Paal P, Strapazzon G, Braun P, Ellmauer PP, Schroeder DC, Sumann G, et al. Factors affecting survival from avalanche burial--a randomised prospective porcine pilot study. *Resuscitation.* 2013;84(2):239-243.
32. Brugger H, Sumann G, Meister R, Adler-Kastner L, Mair P, Gunga HC, et al. Hypoxia and hypercapnia during respiration into an artificial air pocket in snow: implications for avalanche survival. *Resuscitation.* 2003;58(1):81-88.
33. Strapazzon G, Gatterer H, Falla M, Dal Cappello T, Malacrida S, Turner R, et al. Hypoxia and hypercapnia effects on cerebral oxygen saturation in avalanche burial: a pilot human experimental study. *Resuscitation.* 2021;158:175-182.
34. Grissom CK, Radwin MI, Harmston CH, Hirshberg EL, Crowley TJ. Respiration during snow burial using an artificial air pocket. *JAMA.* 2000;283(17):2266-2271.
35. Roubik K, Sieger L, Sykora K. Work of breathing into snow in the presence versus absence of an artificial air pocket affects hypoxia and hypercapnia of a victim covered with avalanche snow: a randomized double blind crossover study. *PLoS One.* 2015;10(12):e0144332.
36. Grissom CK, Radwin MI, Harmston CH. Improving survival during snow burial in avalanches. *JAMA.* 2000;284(10):1242-1243.
37. Grissom CK, Radwin MI, Scholand MB, Harmston CH, Muetterties MC, Bywater TJ. Hypercapnia increases core temperature cooling rate during snow burial. *J Appl Physiol.* (1985). 2004;96(4):1365-1370.
38. 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):474-480.
39. Strapazzon G, Beikircher W, Procter E, Brugger H. Electrical heart activity recorded during prolonged avalanche burial. *Circulation.* 2012;125(4):646-647.
40. Strapazzon G, Schweizer J, Chiambretti I, Brodmann Maeder M, Brugger H, Zafren K. Effects of climate change on avalanche accidents and survival. *Front Physiol.* 2021;12:639433.
41. Sumann G, Putzer G, Brugger H, Paal P. Pulmonary edema after complete avalanche burial. *High Alt Med Biol.* 2012;13(4):295-296.
42. Glisenti P, Rakusa J, Albrecht R, Luedi MM. Negative pressure pulmonary oedema with haemorrhage after 5-minute avalanche burial. *Lancet.* 2016;388(10057):2321-2322.
43. Strapazzon G, Nardin M, Zanon P, Kaufmann M, Kritzingner 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):193-196.
44. Aydin Y, Ogul H, Araz O, Eroglu A. A rare cause of pulmonary oedema: buried under an avalanche. *Br J Hosp Med (Lond).* 2020;81(12):1.
45. Schmid F. The pathogenesis of pulmonary edema after being buried by an avalanche [in German]. *Schweiz Med Wochenschr.* 1981;111(39):1441-1445.
46. Birkeland KWM, Meiners T, Bartelt P. Avalanche survival strategies for different parts of a flowing avalanche. *Proceedings Whistler 2008 International Snow Science Workshop.* 2008:73-79.
47. Hohlrieder M, Eschertzhuber S, Schubert H, Zinnecker R, Mair P. Severity and pattern of injury in survivors of alpine fall accidents. *High Alt Med Biol.* 2004;5(3):349-354.
48. Gray JMNT, Ancey C. Segregation, recirculation and deposition of coarse particles near two-dimensional avalanche fronts. *J Fluid Mech.* 2009;629:387-423.
49. Zafren K, Brants A, Tabner K, Nyberg A, Pun M, Basnyat B, et al. Wilderness mass casualty incident (MCI): rescue chain after avalanche at Everest Base Camp (EBC) in 2015. *Wilderness Environ Med.* 2018;29(3):401-410.
50. Pasquier M, Hugli O, Kottmann A, Techel F. Avalanche accidents causing fatalities: are they any different in the summer? *High Alt Med Biol.* 2017;18(1):67-72.
51. Johnson SM, Johnson AC, Barton RG. Avalanche trauma and closed head injury: adding insult to injury. *Wilderness Environ Med.* 2001;12(4):244-247.

52. Kern MB, Buser O, Peinke J, Siefert M, Vulliet L. Stochastic analysis of single particle segregational dynamics. *Physics Letters A*. 2005;336(4-5):428-433.
53. Boyd J, Brugger H, Shuster M. Prognostic factors in avalanche resuscitation: a systematic review. *Resuscitation*. 2010;81(6):645-652.
54. Bogle LB, Boyd JJ, McLaughlin KA. Triaging multiple victims in an avalanche setting: the Avalanche Survival Optimizing Rescue Triage algorithmic approach. *Wilderness Environ Med*. 2010;21(1):28-34.
55. Strapazzon G, Putzer G, Dal Cappello T, Falla M, Braun P, Falk M, et al. Effects of hypothermia, hypoxia, and hypercapnia on brain oxygenation and hemodynamic parameters during simulated avalanche burial: a porcine study. *J Appl Physiol* (1985). 2021;130(1):237-244.
56. 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):52-57.
57. Procter E, Strapazzon G, Dal Cappello T, Castlunger L, Staffler HP, Brugger H. Adherence of backcountry winter recreationists to avalanche prevention and safety practices in northern Italy. *Scand J Med Sci Sports*. 2014;24(5):823-829.
58. Dow J, Giesbrecht GG, Danzl DF, Brugger H, Sagalyn EB, Walpoth B, et al. Wilderness Medical Society clinical practice guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia: 2019 update. *Wilderness Environ Med*. 2019;30(4S):S47-S69.
59. Brugger H, Bouzat P, Pasquier M, Mair P, Fieler J, Darocha T, et al. Cut-off values of serum potassium and core temperature at hospital admission for extracorporeal rewarming of avalanche victims in cardiac arrest: a retrospective multicentre study. *Resuscitation*. 2019;139:222-229.
60. Musi ME, Sheets A, Zafren K, Brugger H, Paal P, Holz N, et al. Clinical staging of accidental hypothermia: the Revised Swiss System: recommendation of the International Commission for Mountain Emergency Medicine (ICAR MedCom). *Resuscitation*. 2021;162:182-187.
61. Grissom CK, McAlpine JC, Harmston CH, Radwin MI, Giesbrecht GG, Scholand MB, et al. Hypercapnia effect on core cooling and shivering threshold during snow burial. *Aviat Space Environ Med*. 2008;79(8):735-742.
62. Putzer G, Schmid S, Braun P, Brugger H, Paal P. Cooling of six centigrades in an hour during avalanche burial. *Resuscitation*. 2010;81(8):1043-1044.
63. Mittermair C, Foidl E, Wallner B, Brugger H, Paal P. Extreme cooling rates in avalanche victims: case report and narrative review. *High Alt Med Biol*. 2021;22(2):235-240.
64. Leonard C, Charriau-Perret A, Debaty G, Belle L, Ricard C, Sanchez C, et al. Survivors of avalanche accidents: posttraumatic stress disorder symptoms and quality of life: a multicentre study. *Scand J Trauma Resusc Emerg Med*. 2021;29(1):96.
65. Daniel N, Weinberg N, Carus F, Church B, Zafren K. Witnessed cardiac arrest in a hypothermic avalanche victim completely buried for 2 hours. *Wilderness Environ Med*. 2021;32(1):92-97.
66. 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):229-235.
67. Jamieson JB, Haegeli P, Gauthier DM. Avalanche Accidents in Canada 1996-2007. vol 5. Cadian Avalanche Association; 2010.
68. Hallandvik L, Svarstad Andresen M, Aadland E. Decision-making in avalanche terrain-how does assessment of terrain, reading of avalanche forecast and environmental observations differ by skiers' skill level? *J Outdoor Recreat Tour*. 2017;20(December):45-51.
69. McClung DM, Schaerer PA. The Avalanche Handbook. 3rd ed. The Mountaineers Book Company; 2006.
70. Tremper B. Staying Alive in Avalanche Terrain. 2nd ed. The Mountaineers Book Company; 2008.
71. Tremper B. Avalanche Essentials: A Step-by-Step System for Safety and Survival. The Mountaineers Book Company; 2013.
72. Bolognesi R. NivoTest: a pocket tool for avalanche risk assessing. *Proceedings of the 2000 International Snow Science Workshop*. 2000:554-557.
73. Haegeli P. Avaluator V2.0 - Avalanche Accident Prevention Card. *Canadian Avalanche Centre*; 2010.
74. McCammon I. Heuristic traps in recreational avalanche accidents: evidence and implications. *Avalanche News*. 2004;68.
75. Munter W. 3 x 3 Lawinen: Risikomanagement im Wintersport. 3rd ed. Agentur Pohl & Schellhammer; 2003.
76. Landroe M, Hetland A, Engeset RV, Pfuhl G. Avalanche decision-making frameworks: factors and methods used by experts. *Cold Reg Sci Technol*. 2020;170:102897.
77. Haegeli P, Haider W. Evaluating the Avaluator - first reflections on the Canadian decision aid. *Proceedings Whistler 2008 International Snow Science Workshop*. 2008:455-464.
78. McCammon IH, Hageli P. An evaluation of rule-based decision tools for travel in avalanche terrain. *Cold Reg Sci Technol*. 2007;47(1-2):193-206.
79. Johnson J, Mannberg A, Hendriks J, Hetland A, Stephensen M. Rethinking the heuristic traps paradigm in avalanche education: past, present and future. *Cogent Soc*. 2020;6(1):1807111.
80. Grissom CK, Radwin MR, Atkins D, McIntosh SE. Avalanches. In: Auerbach PS, ed. Wilderness Medicine. 6th ed. Elsevier; 2012.
81. Atkins D. No swimming: Dale Atkins says much of what you know about surviving an avalanche is wrong. Daily Camera. August 14, 2009.
82. Kern M. Inverse grading in granular flow [dissertation]. Ecole Polytechnique Federale de Lausanne; 2000.
83. Kern MT, Tschirky F, Schweizer J. Field tests of some new avalanche rescue devices. *Proceedings of the International Snow Science Workshop 2002*. Pentincton, BC; September 29-October 4, 2002.
84. Meier LH, Feldversuche S. mit Lawinen-Notfallgeraeten Winter 2010/11. WSL Institute for Snow and Avalanche Research SLF; 2011.

85. Tschirky FS, Schweizer J. Avalanche balloons - preliminary test results. *Proceedings of the 1996 International Snow Science Workshop Banff, Canada*. October 6-11, 1996:309-312.
86. Brugger HK, Kern M., Mair P., Etter HJ, Falk M. Efficiency at the avalanche cone: emergency equipment for tourers and variant drivers: a critical analysis. [in German]. *Bergundsteigen*. 2003;4:60-65.
87. Tschirky FB, Brabec B, Kern M. Avalanche rescue systems in Switzerland: experience and limitations. *Proceedings of the 2000 International Snow Science Workshop*, October 1-6, Big Sky, Montana. 2000:369-376.
88. Meier L, Harvey S. How effective are avalanche airbags? Field tests of avalanche safety equipment. *Proceedings, 2012 International Snow Science Workshop*, Anchorage, Alaska. 2012:756-763.
89. Van Tilburg C. Should airbag backpacks be standard avalanche safety equipment? *Wilderness Environ Med*. 2021; 32(4):495-498.
90. Hagel BE, Pless IB, Goulet C, Platt RW, Robitaille Y. Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. *BMJ*. 2005;330(7486):281.
91. Haider AH, Saleem T, Bilaniuk JW, Barraco RD, Eastern Association for the Surgery of Trauma Injury Control/Violence Prevention Committee. An evidence-based review: efficacy of safety helmets in the reduction of head injuries in recreational skiers and snowboarders. *J Trauma Acute Care Surg*. 2012;73(5):1340-1347.
92. Vargyas G. Backcountry skiers, avalanche trauma mortality, and helmet use. *Wilderness Environ Med*. 2016;27(1):181-182.
93. McIntosh SE, Little CE, Seibert TD, Polukoff NE, Grissom CK. Avalanche airbag post-burial active deflation - the ability to create an air pocket to delay asphyxiation and prolong survival. *Resuscitation*. 2020;146:155-160.
94. Crowley TJ, Atkins D, Grissom CK, Radwin MI, Morrissey MP. *An AvaLung-associated avalanche survival*. 2002 International Snow Science Workshop, Penticton, British Columbia. 2002:189-193.
95. Radwin MI, Grissom CK. Technological advances in avalanche survival. *Wilderness Environ Med*. 2002;13(2):143-152.
96. Genswein M, Atkins D, Obad J, Grady E, Pich A M, Guyn T, et al. Recommendation on how avoid interference issue in companion and organized avalanche rescue. *Proceedings of the International Snow Science Workshop*. Grenoble-Chamonix, France. October 7-11, 2013:1402-1410.
97. Wallner B, Moroder L, Brandt A, Mair P, Erhart S, Bachler M, et al. Extrication times during avalanche companion rescue: a randomized single-blinded manikin study. *High Alt Med Biol*. 2019;20(3):245-250.
98. Nichols TB, Hawley AC, Smith WR, Wheeler AR 3rd, McIntosh SE. *Avalanche safety practices among backcountry skiers and snowboarders in Jackson Hole in 2016*. *Wilderness Environ Med*. 2018;29(4):493-498.
99. Genswein M. Survival chance optimized procedures in rescue and how to minimize injuries during excavation. *Proceedings of the International Snow Science Workshop*. Grenoble-Chamonix, France. October 7-11, 2013:1408-1417.
100. Rauch S, Koppenberg J, Josi D, Meuli L, Strapazzon G, Pasquier M, et al. Avalanche survival depends on the time of day of the accident: a retrospective observational study. *Resuscitation*. 2022;174:47-52.
101. Hohlrieder M, Mair P, Wuertl W, Brugger H. The impact of avalanche transceivers on mortality from avalanche accidents. *High Alt Med Biol*. 2005;6(1):72-77.
102. Miller SC. Electromagnetic interference from electronic devices used in the management of type 1 diabetes can impair the performance of an avalanche transceiver in search mode. *Wilderness Environ Med*. 2015;26(2):232-235.
103. Dorenkamp M, Blaschke F, Voigt K, Fleck E, Goetze S, Roser M. Electromagnetic interference of avalanche transceivers with cardiac pacemakers and implantable cardioverter defibrillators. *Pacing Clin Electrophysiol*. 2013; 36(8):931-938.
104. Barkhausen J. The effect of external interference on avalanche transceiver functionality. *Proceedings, 2012 International Snow Science Workshop*. Anchorage, AK. 2012:348-352.
105. Meister E, Dammert I. The effect of consumer electronics on avalanche transceivers. *International Snow Science Workshop 2014 Proceedings*. Banff, Canada. 2014:1134-1139.
106. Ortovox. Diract Voice. Accessed September 22, 2022. <https://www.ortovox.com/hu-en/shop/categories/p251699-avalanche-transceivers-diract-voice>
107. Schleppe JB, Lachapelle G. Tracking performance of a HSGPS receiver under avalanche deposited snow. *GPS Solut*. 2008;12:13-21.
108. Stepanek J, Claypool DW. GPS signal reception under snow cover: a pilot study establishing the potential usefulness of GPS in avalanche search and rescue operations. *Wilderness Environ Med*. 1997;8(2):101-104.
109. Floyer J, Storm I, Klassen K. Benefit-detriment analysis new rescue technologies. *International Snow Science Workshop 2014 Proceedings*, Banff, Canada. 2014:351-355.
110. Lane C. Tech Tips: How To Choose an Avalanche Probe. Equipment Shop American Alpine Institute. November 25, 2020. Accessed September 28, 2022, <https://shop.alpineinstitute.com/blogs/equipment-shop-blog/how-to-choose-an-avalanche-probe>
111. Auger T, Jamieson B. Avalanche probing revisited. *Proceedings of the 1996 International Snow Science Workshop*, Banff, Canada. 1996:295-298.
112. Edgerly B, Atkins D. Strategic shoveling: the next frontier in companion rescue. *Proceedings of the 2006 International Snow Science Workshop*, Telluride, Colorado. 2006:522-529.
113. Konigsberg J. The importance of methodical probing for rescuers. *Avalanche Rev*. 2015;33(4):8.
114. Genswein M, Eide R. The efficiency of companion rescuers with minimal training. *Proceedings Whistler 2008 International Snow Science Workshop*. Whistler, Canada. September 21-27, 2008: 581-590.

115. Genswein M, Eide R. Shovels that span the divide between heaven and hell. *Canadian Avalanche Center News*. 2008;54:60.
116. Schindelwig K, Hoffmann A, Mossner M, Nachbauer W. Does avalanche shovel shape affect excavation time: a pilot study. *Sports (Basel)*. 2017;5(2):31.
117. Genswein M, Eide R. V-shaped conveyor belt approach to snow transport. *Avalanche Rev*. 2008;26:20-21.
118. Genswein M, Eide R. The V-shaped snow conveyor-belt. *Avalanche Rev*. 2008;26:20-21.
119. Mair P, Frimmel C, Vergeiner G, Hohlrieder M, Moroder L, Hoessl P, et al. Emergency medical helicopter operations for avalanche accidents. *Resuscitation*. 2013;84(4):492-495.
120. Bogie D, Hobman A. Applying search theory and coordinated incident management to avalanche rescue. *Proceedings, 2012 International Snow Science Workshop, Anchorage, Alaska*. 2012:740-745.
121. Davis D, Atkins D. Rationale and models for Transition of Management of Avalanche Rescues Form the Three Stage Model to the Incident Command System. *Proceedings Whistler 2008 International Snow Science Workshop September 21-27, 2008*:881-886.
122. Ferrara M. Creating or morphing avalanche rescue plans in accordance with the Incident Command System. *Proceedings of the 2004 International Snow Science Workshop, Jackson Hole, Wyoming*. 2004:370.
123. International Commission for Alpine Rescue. Regarding the marking of locations on an avalanche. 2004. Minutes of the IKAR Assembly of Delegates October 16, 2004, in Zakopane (PL). October 16, 2004.
124. Genswein M, Letang D, Jarry F, Reiweger I, Atkins D. Slalom probing - a survival chance optimized probe line search strategy. *International Snow Science Workshop 2014 Proceedings, Banff, Canada*. 2014:374-379.
125. Ballard H, Atkins D, Ballard L. Probing for avalanche victims. *Proceedings of the 2004 International Snow Science Workshop, Jackson Hole, Wyoming*. 2004:343-348.
126. Genswein M. Terrestrial and helicopter based RECCO search. *International Snow Science Workshop 2014 Proceedings, Banff, Canada*. 2014:1102-1106.
127. Hohlrieder M, Thaler S, Wuertl W, Voelckel W, Ulmer H, Brugger H, et al. Rescue missions for totally buried avalanche victims: conclusions from 12 years of experience. *High Alt Med Biol*. 2008;9(3):229-233.
128. Kottmann A, Carron PN, Theiler L, Albrecht R, Tissi M, Pasquier M. Identification of the technical and medical requirements for HEMS avalanche rescue missions through a 15-year retrospective analysis in a HEMS in Switzerland: a necessary step for quality improvement. *Scand J Trauma Resusc Emerg Med*. 2018;26(1):54.
129. SH94 Milford Road Avalanche Control Programme NZ. Helicopter mounted avalanche beacon rescue technique. 2002 International Snow Science Workshop, Penticton, British Columbia. 2002:461.
130. Glomseth R, Gulbrandsen FI, Fredriksen K. Ambulance helicopter contribution to search and rescue in North Norway. *Scand J Trauma Resusc Emerg Med*. 2016;24(1):109.
131. Lunde A, Tellefsen C. Patient and rescuer safety: recommendations for dispatch and prioritization of rescue resources based on a retrospective study of Norwegian avalanche incidents 1996-2017. *Scand J Trauma Resusc Emerg Med*. 2019;27(1):5.
132. Genswein M, Thorvaldsdottir S, Zweifel B. Remote reverse triage in avalanche rescue. *Proceedings Whistler 2008 International Snow Science Workshop*. 2008:63-72.
133. Reiweger I, Genswein M, Paal P, Schweizer J. A concept for optimizing avalanche rescue strategies using a Monte Carlo simulation approach. *PLoS One*. 2017;12(5):e0175877.
134. Blancher M, Bauvent Y, Bare S, Wuyts B, Fillet Y, Brun J, et al. Multiple casualty incident in the mountain: experience from the Valfrejus avalanche. *Resuscitation*. 2017;111:e7-e8.
135. Genswein M, Macias D, McIntosh S, Reiweger I, Hetland A, Paal P. AvaLife-a new multi-disciplinary approach supported by accident and field test data to optimize survival chances in rescue and first aid of avalanche patients. *Int J Environ Res Public Health*. 2022;19(9):5257.
136. Blancher M, Albasini F, Elsensohn F, Zafren K, Holzl N, McLaughlin K, et al. Management of multi-casualty incidents in mountain rescue: evidence-based guidelines of the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). *High Alt Med Biol*. 2018;19(2):131-140.
137. Pasquier M, Rousson V, Darocha T, Bouzat P, Kosinski S, Sawamoto K, et al. Hypothermia outcome prediction after extracorporeal life support for hypothermic cardiac arrest patients: an external validation of the HOPE score. *Resuscitation*. 2019;139:321-328.
138. Mair P, Brugger H, Mair B, Moroder L, Ruttman E. Is extracorporeal rewarming indicated in avalanche victims with unwitnessed hypothermic cardiorespiratory arrest? *High Alt Med Biol*. 2014;15(4):500-503.
139. 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):1204-1211.
140. Metrailler-Mermoud J, Hugli O, Carron PN, Kottmann A, Frochoux V, Zen-Ruffinen G, et al. Avalanche victims in cardiac arrest are unlikely to survive despite adherence to medical guidelines. *Resuscitation*. 2019;141:35-43.
141. Pasquier M, Moix PA, Delay D, Hugli O. Cooling rate of 9.4 degrees C in an hour in an avalanche victim. *Resuscitation*. 2015;93:e17-e18.
142. Strohle M, Putzer G, Procter E, Paal P. Apparent cooling rate of 7 degrees C per hour in an avalanche victim. *High Alt Med Biol*. 2015;16(4):356-357.
143. Pasquier M, Hugli O, Paal P, Darocha T, Blancher M, Husby P, et al. Hypothermia outcome prediction after extracorporeal life support for hypothermic cardiac arrest patients: the HOPE score. *Resuscitation*. 2018;126:58-64.
144. Paal P, Milani M, Brown D, Boyd J, Ellerton J. Termination of cardiopulmonary resuscitation in mountain rescue. *High Alt Med Biol*. 2012;13(3):200-208.

145. Schon CA, Gordon L, Holzl N, Milani M, Paal P, Zafren K. Determination of death in mountain rescue: recommendations of the International Commission for Mountain Emergency Medicine (ICAR MedCom). *Wilderness Environ Med.* 2020;31(4):506-520.
146. Eidenbenz D, Techel F, Kottmann A, Rousson V, Carron PN, Albrecht R, et al. Survival probability in avalanche victims with long burial (≥ 60 min): A retrospective study. *Resuscitation.* 2021;166:93-100.
147. Quinn RH, Williams J, Bennett BL, Stiller G, Islas AA, McCord S, et al. Wilderness Medical Society practice guidelines for spine immobilization in the austere environment: 2014 update. *Wilderness Environ Med.* 2014; 25(4 Suppl):S105-S117.
148. Hawkins SC, Williams J, Bennett BL, Islas A, Kayser DW, Quinn R. Wilderness Medical Society clinical practice guidelines for spinal cord protection. *Wilderness Environ Med.* 2019;30(4S):S87-S99.
149. Wang HE, Callaway CW, Peitzman AB, Tisherman SA. Admission hypothermia and outcome after major trauma. *Crit Care Med.* 2005;33(6):1296-1301.
150. Wallner B, Schenk B, Paal P, Falk M, Strapazon G, Martini WZ, et al. Hypothermia induced impairment of platelets: assessment with multiplate vs. ROTEM-an in vitro study. *Front Physiol.* 2022;13:852182.
151. Wallner B, Schenk B, Hermann M, Paal P, Falk M, Strapazon G, et al. Hypothermia-associated coagulopathy: a comparison of viscoelastic monitoring, platelet function, and real time live confocal microscopy at low blood temperatures, an in vitro experimental study. *Front Physiol.* 2020;11:843.
152. Pasquier M, Paal P, Kosinski S, Brown D, Podsiadlo P, Darocha T. Esophageal temperature measurement. *N Engl J Med.* 2020;383(16):e93.
153. Paal P, Pasquier M, Darocha T, Lechner R, Kosinski S, Wallner B, et al. Accidental hypothermia: 2021 update. *Int J Environ Res Public Health.* 2022;19(1):501.
154. Pasquier M, Cools E, Zafren K, Carron PN, Frochoux V, Rousson V. Vital signs in accidental hypothermia. *High Alt Med Biol.* 2021;22(2):142-147.
155. Wallner B, Moroder L, Salchner H, Mair P, Wallner S, Putzer G, et al. CPR with restricted patient access using alternative rescuer positions: a randomised cross-over manikin study simulating the CPR scenario after avalanche burial. *Scand J Trauma Resusc Emerg Med.* 2021;29(1):129.
156. Podsiadlo P, Smolen A, Kosinski S, Hymczak H, Waligorski S, Witt-Majchrzak A, et al. Impact of rescue collapse on mortality rate in severe accidental hypothermia: a matched-pair analysis. *Resuscitation.* 2021;164:108-113.
157. Frei C, Darocha T, Debaty G, Dami F, Blancher M, Carron PN, et al. Clinical characteristics and outcomes of witnessed hypothermic cardiac arrest: a systematic review on rescue collapse. *Resuscitation.* 2019;137:41-48.
158. Podsiadlo P, Darocha T, Svendsen OES, Kosinski S, Silfvast T, Blancher M, et al. Outcomes of patients suffering unwitnessed hypothermic cardiac arrest rewarmed with extracorporeal life support: a systematic review. *Artif Organs.* 2021;45(3):222-229.
159. Wallner B, Brugger H, Ellerton J, Paal P. In mountain and rural areas all CPR providers should perform chest compressions and rescue breaths for patients in cardiac arrest. *Resuscitation.* 2018;127:e5.
160. Ong MEH, Jaffey J, Stiell I, Nesbitt L, Study Group OPALS. Comparison of termination-of-resuscitation guidelines for basic life support: defibrillator providers in out-of-hospital cardiac arrest. *Ann Emerg Med.* 2006;47(4):337-343.
161. Morrison LJ, Visentin LM, Kiss A, Theriault R, Eby D, Vermeulen M, et al. Validation of a rule for termination of resuscitation in out-of-hospital cardiac arrest. *N Engl J Med.* 2006;355(5):478-487.
162. Morrison LJ, Verbeek PR, Zhan C, Kiss A, Allan KS. Validation of a universal prehospital termination of resuscitation clinical prediction rule for advanced and basic life support providers. *Resuscitation.* 2009;80(3):324-328.
163. 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):71-77.
164. Lexow K. Severe accidental hypothermia: survival after 6 hours 30 minutes of cardiopulmonary resuscitation. *Arctic Med Res.* 1991;50(Suppl 6):112-114.
165. Swol J, Darocha T, Paal P, Brugger H, Podsiadlo P, Kosinski S, et al. Extracorporeal life support in accidental hypothermia with cardiac arrest-a narrative review. *ASAIO J.* 2022;68(2):153-162.
166. 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-S518.
167. Protheroe RT, Gwinnutt CL. Early hospital care of severe traumatic brain injury. *Anaesthesia.* 2011;66(11):1035-1047.
168. Darocha T, Debaty G, Ageron FX, Podsiadlo P, Hutin A, Hymczak H, et al. Hypothermia is associated with a low ET_{CO2} and low pH-stat Pa_{CO2} in refractory cardiac arrest. *Resuscitation.* 2022;174:83-90.
169. Rubertsson S, Lindgren E, Smekal D, Ostlund O, Silfverstolpe J, Lichtveld RA, et al. Mechanical chest compressions and simultaneous defibrillation vs conventional cardiopulmonary resuscitation in out-of-hospital cardiac arrest: the LINC randomized trial. *JAMA.* 2014;311(1):53-61.
170. Putzer G, Braun P, Zimmermann A, Pedross F, Strapazon G, Brugger H, et al. LUCAS compared to manual cardiopulmonary resuscitation is more effective during helicopter rescue-a prospective, randomized, cross-over manikin study. *Am J Emerg Med.* 2013;31(2):384-389.
171. Gordon L, Paal P, Ellerton JA, Brugger H, Peek GJ, Zafren K. Delayed and intermittent CPR for severe accidental hypothermia. *Resuscitation.* 2015;90:46-49.
172. Althaus U, Aeberhard P, Schubach P, Nachbur BH, Muhlemann W. Management of profound accidental hypothermia with cardiorespiratory arrest. *Ann Surg.* 1982;195(4):492-495.

173. 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-e170.
174. Boue Y, Payen JF, Torres JP, Blancher M, Bouzat P. Full neurologic recovery after prolonged avalanche burial and cardiac arrest. *High Alt Med Biol*. 2014;15(4):522-523.
175. Wallner B, Putzer G, Mair P. Prognostication of cardiac arrest in avalanche victims. *Resuscitation*. 2022;171:121-122.
176. Paal P, Lott C, Brugger H, Falk M, Rousson V, Pasquier M. Reply to Wallner B et al. *Prognostication of outcome for hypothermic avalanche victims in cardiac arrest*. *Resuscitation*. 2022;171:123-125.
177. Mair P, Komberger E, Furtwaengler W, Balogh D, Antretter H. Prognostic markers in patients with severe accidental hypothermia and cardiocirculatory arrest. *Resuscitation*. 1994;27(1):47-54.
178. 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):1500-1505.
179. 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 Praestoe Fjord boating accident. *Resuscitation*. 2012;83(9):1078-1084.
180. Ruttman 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.
181. Soar J, Becker LB, Berg KM, Einav S, Ma Q, Olasveengen TM, et al. Cardiopulmonary resuscitation in special circumstances. *Lancet*. 2021;398(10307):1257-1268.
182. Cools E, Latscher H, Strohle M, Paal P. Successful non-extracorporeal rewarming from hypothermic cardiac arrest: 2 cases. *Wilderness Environ Med*. 2021;32(4):503-507.
183. Kuhnke M, Albrecht R, Schefold JC, Paal P. Successful resuscitation from prolonged hypothermic cardiac arrest without extracorporeal life support: a case report. *J Med Case Rep*. 2019;13(1):354.
184. Gruber E, Beikircher W, Pizzinini R, Marsoner H, Pornbacher M, Brugger H, et al. Non-extracorporeal rewarming at a rate of 6.8 degrees C per hour in a deeply hypothermic arrested patient. *Resuscitation*. 2014;85(8):e119-e120.
185. Strapazon G, Plankensteiner J, Mair P, Ruttman E, Brugger H. Triage and survival of avalanche victims with out-of-hospital cardiac arrest in Austria between 1987 and 2009. *Resuscitation*. 2012;83(suppl 1):e81.
186. Kottmann A, Blancher M, Spichiger T, Elsensohn F, Letang D, Boyd J, et al. The Avalanche Victim Resuscitation Checklist, a new concept for the management of avalanche victims. *Resuscitation*. 2015;91:e7-e8.
187. Kottmann A, Blancher M, Pasquier M, Brugger H. Avalanche Victim Resuscitation Checklist adaptation to the 2015 ERC resuscitation guidelines. *Resuscitation*. 2017;113:e3-e4.
188. Brugger H, Flora G, Falk M. Self-rescue techniques and post-traumatic stress disorders in avalanche accident [in German]. *Notarzt*. 2002;18(1):1-4.
189. Dolan N, Tedeschi C. A qualitative study of psychological outcomes in avalanche first responders. *High Alt Med Biol*. 2018;19(4):344-355.
190. Kottmann A, Pasquier M, Strapazon G, Zafren K, Ellerton J, Paal P. Quality indicators for avalanche victim management and rescue. *Int J Environ Res Public Health*. 2021;18(18):9570.
191. Brugger H, Strapazon G, Wallner B, Paal P. Low incidence of avalanche victims in cardiac arrest calls for multi-centre studies and registries for the validation of resuscitation guidelines. *Resuscitation*. 2019;144:195-196.
192. Cadman R. Eight nonavalanche snow-immersion deaths a 6-year series from British Columbia ski areas. *Phys Sportsmed*. 1999;27(13):31-43.
193. Kizer KW, MacQuarrie MB, Kuhn BJ, Scannell PD. Deep snow immersion deaths. *Phys Sportsmed*. 1994;22(12):48-61.
194. Kosinski S, Jasinski J, Krzeptowski-Sabala S, Jr Gasiénica-Roj J, Gorka A. Deep snow immersion suffocation - the deadly threat. *Anaesthesiol Int Ther*. 2013;45(1):33-34.
195. Shephard RJ. Asphyxial death of a young skier. *J Sports Med Phys Fitness*. 1996;36(3):223-227.
196. Van Tilburg CS. Preventing avalanche and deep snow submersion deaths using an artificial air pocket device and a digital dual-antenna avalanche transceiver. *Wilderness Environ Med*. 2003;14(1):69-70.
197. Van Tilburg CS. Utilizing avalanche safety equipment to prevent snow immersion asphyxiation revisited. *Wilderness Environ Med*. 2012;23(1):96-97.