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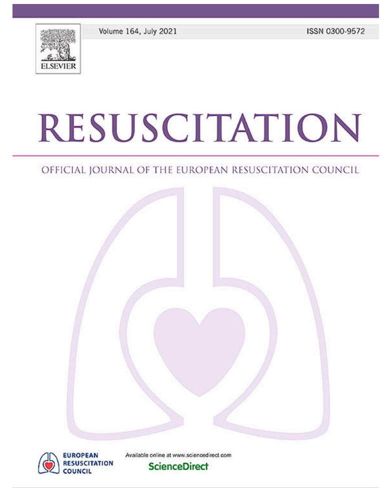

Review

On-site Treatment of Avalanche Victims: Scoping Review and 2023 Recommendations of the International Commission for Mountain Emergency Medicine (ICAR MedCom)

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On-site Treatment of Avalanche Victims: Scoping Review and 2023 Recommendations of the International Commission for Mountain Emergency Medicine (ICAR MedCom)

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ABSTRACT

Introduction: The International Commission for Mountain Emergency Medicine (ICAR MedCom) developed updated recommendations for the management of avalanche victims.

Methods: ICAR MedCom created Population Intervention Comparator Outcome (PICO) questions and conducted a scoping review of the literature. We evaluated and graded the evidence using the American College of Chest Physicians system.

Results: We included 120 studies including original data in the qualitative synthesis. There were 45 retrospective studies (38%), 44 case reports or case series (37%), and 18 prospective studies on volunteers (15%). The main cause of death from avalanche burial was asphyxia (range of all studies 65-100%). Trauma was the second most common cause of death (5-29%). Hypothermia accounted for few deaths (0-4%).

Conclusions and recommendations: For a victim with a burial time ≤60 minutes without signs of life, presume asphyxia and provide rescue breaths as soon as possible, regardless of airway patency. For a victim with a burial time >60 minutes, no signs of life but a patent airway or airway with unknown patency, presume that a primary hypothermic CA has occurred and initiate cardiopulmonary resuscitation (CPR) unless temperature can be measured to rule out hypothermic cardiac arrest. For a victim buried >60 minutes without signs of life and with an obstructed airway, if core temperature cannot be measured, rescuers can presume asphyxia-induced CA, and should not initiate CPR. If core temperature can be measured, for a victim without signs of life, with a patent airway, and with a core temperature <30°C attempt resuscitation, regardless of burial duration.

Keywords: Accidental Hypothermia; Avalanche; Emergency Medical Services; Extracorporeal Life Support; Hypothermia; Resuscitation; Triage

INTRODUCTION

In 1996 the International Commission for Mountain Emergency Medicine (ICAR MedCom) established field management guidelines including an algorithm for the prehospital management of persons buried in avalanches.[1] The guidelines were updated in 2002[2] and 2013.[3] Since 2010, avalanche burial has been classified as a special type of cardiac arrest (CA) in the recommendations of the European Resuscitation Council (ERC).[4,5] In 2015[6] the ERC published a resuscitation algorithm for victims buried in avalanches. The ERC updated the algorithm in the 2021 ERC guidelines.[7] In 2017 the Wilderness Medical Society (WMS) published recommendations for the prevention and management of avalanche and non-avalanche snow burial accidents.[8] The overall level of evidence used in constructing the recommendations was low.[3] Our goal was to develop evidence-based updated recommendations for the prehospital management of avalanche victims.

METHODS

We conducted a scoping review of avalanche-specific knowledge by systematically assessing and synthesising the available evidence. We collected the reported outcomes of avalanche victims using all reported definitions regarding avalanche-specific terminology, including airway patency, air pocket, and degree of burial. In parallel, we constructed a list of Population, Intervention, Comparator and Outcomes (PICO) questions to focus on the most important questions pertaining to the management of avalanche victims. From the results of the scoping review, we produced a narrative summary of the rationale and evidence. We developed management recommendations by consensus. The final manuscript was endorsed by ICAR MedCom at the ICAR assembly in Montreux, Switzerland on 15 October 2022.

Scoping review

The protocol for the scoping review was registered on 14 October 2021 and is available at the URL: https://osf.io/x7u2n/. We considered studies including victims of any age involved in avalanche accidents and experimental studies on manikins, animals, and healthy volunteers. We only included review articles if they focused on avalanche burial and rescue. We excluded letters and other correspondence unless they included new data or scientific content. We excluded studies of related topics not specific to avalanche victims that did not include any data from avalanche victims and studies of avalanche prevention and location of victims.

We performed the literature search for studies of avalanche-specific knowledge, designed with the help of a research librarian (CJ), on 18 October 2021 and updated it on 25 August 2022. Databases we accessed were PubMed, Embase.com, Cochrane Central Register of Controlled Trials Wiley and Web of Science Core collection. Clinical trials registries accessed were: Clinicaltrials.gov and the WHO International Clinical Trials Registry Platform. The completed strategies were peer reviewed by another information specialist using the PRESS Checklist (**Supplemental file 1**).[9] There were no restrictions on language or date of the studies.

We reviewed the records identified by the search to eliminate duplicates and then uploaded them into EndNote™ 20 (Clarivate™). Two reviewers (GS and MP) independently screened the titles and abstracts of the retrieved studies to check for eligibility, using the Rayyan app for systematic reviews.[10] We retrieved all eligible references in full text. They were independently analysed by each reviewer to confirm that they met the inclusion criteria. We resolved disagreements by consensus between the reviewers.

We extracted the following data: year of publication, nationality of the first author, language, and type of study. We identified mass casualty incidents, defined arbitrarily as events with at least 10 victims. We classified retrospective studies with fewer than five victims as case reports or case series. We reported the scoping review following the Preferred Reporting Items for Systematic Reviews and the Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) statement (**Supplemental file 2**).[11]

Terminology

We used the following terminology to describe the medical aspects of the management of avalanche victims:

Air pocket: An air pocket is any space in front of the mouth and nose in a victim with a patent airway.[12,13] The term 'no air pocket' is only documented if the extricated victim's mouth and nose are found to be completely filled with snow or debris.[1,14]

Airway patency: The terms *obstructed airway* and *blocked airway* require that both the mouth and nose be completely filled with compacted snow or debris. The obstruction can be caused by snow or vomitus. If there is no information about airway patency, the airway should be presumed to be patent and the victim treated accordingly. 'Unknown patency' should be documented in the patient record.

Critical burial: The term critical burial refers to a burial in which the head and chest are buried under snow.[14-16]

ECLS rewarming: Extracorporeal life support (ECLS) rewarming includes rewarming with cardiopulmonary bypass (CPB) and extracorporeal membrane oxygenation (ECMO).

Signs of life: Signs of life include any of the following: A, V or P from AVPU (alert, responsive to verbal stimuli, responsive to pain, unresponsive) or Glasgow Coma Scale >3, any visible movement, respirations, or a palpable carotid or femoral pulse.[17] Ultrasound may expand the options to detect signs of life, using echocardiography or doppler ultrasound of large arteries.

PICO questions

We used a list of questions to focus on the most important decision points involved in the management of avalanche victims. We used the PICO format when appropriate. The writing group developed the original list of questions. We then opened the list for comments in the closed forum of ICAR MedCom for 15 days. The writing group voted on the 25 questions. We excluded two questions, leaving 23 questions on the final list (**Supplemental file 3**).

Recommendations and algorithm

For avalanche-specific recommendations, we used the results of the literature search and the answers to the PICO questions. For recommendations that were not avalanche-specific, we used the most recent recommendations for general medical management.[7,18-22] We discussed the recommendations within the ICAR MedCom to reach a consensus. We graded the evidence using the American College of Chest Physicians grading system (**Table 1**).[23] Finally, we constructed an algorithm for avalanche rescue. We updated the avalanche victim resuscitation checklist[24] based on the updated algorithm.

RESULTS

We identified 157 studies for possible inclusion. Thirty-five of the studies were reviews or guidelines and two were research protocols. The remaining 120 studies presented original data and were included in the qualitative synthesis (**Fig. 1**).

The study types were 45 retrospective studies (38%), 44 case reports or case series (37%), 18 prospective studies, including seven randomised-controlled studies with volunteers[26-32] (15%), eight descriptions of mass casualty incidents (7%), three observational studies (surveys) of avalanche victims (2%) and two prospective studies on animals (2%).

Three countries accounted for more than a half of the 120 reports: Austria (19%), Italy (18%) and Switzerland (17%) (**Supplemental file 4**). There was an increase in the annual number of reports over the years.

SUMMARY OF THE EVIDENCE

Survival

Human retrospective data

The degree of burial is closely related to survival. Of 1886 avalanche victims in one large study, 96 % of the victims not buried or partially buried were alive at extrication, compared with 48% of those critically buried ($p<0.001$).[14] In five studies, the percentage of victims surviving critical burial ranged from 39% to 48%.[13,14,33-35] In a single study, survival was lower in victims extricated by organised rescue (19%) compared with companion rescue (74%).[36] Overall survival was 18% in a study of 109 victims.[37] In a study, from a helicopter emergency medical system (HEMS), of 66 avalanche victims in CA, no victim survived. Seven (11%) became organ donors. Thirty-one (47%) were declared dead at the scene, seven (11%) had a prehospital return of spontaneous circulation (ROSC), and 25 (38%) had persistent CA in hospital, of whom seven underwent extracorporeal life support (ECLS) rewarming.[38] In another study of 170 avalanche victims in CA rescued by HEMS, only one victim survived after a long burial. The victim was hypothermic and underwent ECLS rewarming. The victim survived neurologically intact with cerebral performance category (CPC) 1.[39,40] In another study of 55 avalanche victims who experienced out-of-hospital CA (OHCA), five (9%) survived to hospital discharge, only two had good neurological outcomes.[41]

Other studies involved avalanche victims with OHCA who were admitted to hospital. In one study of 37 victims, 18 (49%) had prehospital ROSC, 19 (51%) underwent ECLS rewarming, and 12 (32%) survived to hospital discharge. Three (9%) had good neurological outcomes.[42] In another study of 48 victims, eight (17%) survived.[43] In a multi-center study of 61 avalanche victims admitted to ECLS centres in CA, six (10%) survived.[44] In a study of 28 avalanche victims rewarmed with ECLS, two (7%) survived.[45]

Causes of death

Human retrospective data

Most avalanche death are caused by asphyxia. In nine studies, the causes of death ranged from 65-100%[34,44,46-52] for asphyxia, 5-29%[34,44,46,48-52] for trauma and 0-4%[34,44,49,50,52] for hypothermia.

Duration of burial

Human retrospective data: retrospective studies

Epidemiological data show a rapid decrease in the survival probability of critically-buried avalanche victims.[13,14,34,53-55] In six studies, the survival of critically-buried victims was 93%[53,55] at 15 minutes, 91%[14] at 18 minutes, 28-34%[13,14,55] at 35 minutes, 18%[13] at 40 minutes, and 25% at 45 minutes.[53] Among 140 avalanche victims with a burial time ≥60 minutes but less than 24 hours, 27 (19%) survived.[54] None of the survivors had CA.[54] Short burial duration was associated with higher survival rates[13,37] even in avalanche victims with OHCA,[41] and was associated with higher rates of ROSC before admission.[39,42] The mean duration of burial in those with prehospital ROSC (n=18) was 27±16 minutes, and the mean time to ROSC from initiation of CPR was 35±20 minutes.[42] Avalanche accidents occurring at night are rare, but are associated with longer durations of burial and lower probabilities of survival compared with avalanches occurring during the daytime.[56]

Human retrospective data: extreme cases[40,41,43,54,55,57-66]

The most extreme reported avalanche cases are reported in **Table 2**. The longest burial in a CA victim with long (>60 minutes) burial who survived with good neurological outcome was 7 hours.[43,63]

Airway patency

In the available data, all survivors to hospital discharge who had cardiac arrest during avalanche burial had patent airways, including hypothermic victims rewarmed with ECLS (**Table 3, Supplemental file 5**). Only one case report mentioned whether the airway was patent in a victim with short burial. The patient in this case report was successfully resuscitated on site with Basic Life Support (BLS). The airway was patent. The burial duration was 20 minutes and the victim had a respiratory arrest before being successfully resuscitated on site with mouth-to-mouth ventilation (**Supplemental file 5**).[60] Because the airway was patent, respiratory arrest may have been caused by compression of the chest by snow.[60] Usually, asphyxia from airway obstruction is the likely explanation for the clinical course of victims who had ROSC after ventilation. This is supported by the case report of a victim critically buried for 3-5 minutes. There were body parts visible on the surface of the avalanche, but the airway was blocked with compacted snow. There was no CA but the victim developed respiratory distress with pulmonary oedema.[67] The time to asphyxial CA is variable. In one case with an obstructed airway, asystole occurred after 30 minutes.[68] Even if the airway is patent and there is an air pocket, short burial does not guarantee survival.[13,43,54]

Air pocket

Human retrospective data

The presence of an air pocket is associated with increased survival.[13,43] The absence of air pockets in victims with patent airways who survived CA with burial times ≤45 minutes is associated with unfavourable neurological outcomes (**Supplemental file 5**). An air pocket may also be present in victims with fatal injuries.[54] Severe asphyxia may occur despite the presence of an air pocket.[69,70] Connection of the air pocket with the outside may be associated with a better outcome.[71] An air pocket of 15x15x15 cm was present for a victim with long burial who had an undetected rescue collapse and died.[72] Victims with air pockets are more likely to survive, especially when buried >15 minutes.[13] In victims with burial times ≤15 minutes, survival was 95% with an air pocket and 69% without an air pocket ($p<0.001$). In victims with burial times >15 minutes, survival was 67% with an air pocket and 4% without ($p<0.001$). Three survivors with no air pocket were buried for 20, 25 and 120 minutes. Survival may be possible despite long burial and absence of an air pocket.[13]

Prospective experimental studies:

Studies on human volunteers buried in snow, breathing into artificial 4 L air pockets found a rapid decline in arterial oxygen saturation (SpO_2) and an increase in end-tidal carbon dioxide ($EtCO_2$).[70] Another study found a greater decrease in SpO_2 at 4 minutes ($p=0.013$) with a small (1L) air pocket compared with a large air pocket (2L). The increase in $EtCO_2$ at 4 minutes did not correlate with air pocket size.[27] Compared with the absence of an air pocket, the presence of a small (1L) air pocket significantly reduced the effort of breathing ($p<0.05$), the decrease in SpO_2 ($p<0.05$), and the increase in $EtCO_2$ ($p<0.05$).[29] Using an Avalung™, a device that creates and artificial air pocket, resulted in a smaller decrease in SpO_2 and a smaller increase in $EtCO_2$ and partial pressure of inspired CO_2 ($PiCO_2$) when compared with breathing into a 500 cm^3 air pocket.[73] The use of a different artificial air pocket device (Ferrino Airsafe™) was associated with a slower fall in SpO_2, allowing for increased burial time when compared with breathing into a 1L air pocket.[26] The administration of air through a tube in front of the face of volunteers buried in a simulated avalanche with an air pocket was associated with higher SpO_2 and lower $EtCO_2$ ($p<0.05$) compared with the absence of air administration.[31] An animal study with piglets buried in snow, simulating avalanche burial, breathing either into an air pocket (1 or 2 L) or ambient air found that the time to asystole was shorter in the air pocket group compared to the ambient air group ($p=0.025$). This suggests that severe asphyxia can occur despite the presence of an air pocket.[69] Hypercapnia was likely the main cause of cardiovascular instability, which was likely the main cause of decreased cerebral oxygenation despite severe hypothermia.[74] Severe hypercapnia might also limit the hypothermia-related beneficit of increased oxygen uptake in the lungs.[75]

Snow density

Studies of human volunteers breathing into artificial air pockets showed that higher snow densities are associated with more rapid declines in SpO_2 and increases in $EtCO_2$.[27,70] In high snow densities, cerebral venous oxygen saturation (ScO_2) measured by near-infrared spectroscopy (NIRS) showed significant decreases.[76]

Burial depth

Burial depth should be measured at the head of the victim. Greater burial depth is associated with higher mortality,[13,33,53] independent of the duration of burial.[13] There was one survivor without CA after a 2.5 m deep burial[61] and another survivor, despite CA, at 7 m in a victim buried by snow in a crevasse.[77]

Core temperature measurement

The most accurate core temperature measurement in CA victims is oesophageal temperature, with the distal tip of the probe in the lower third of the oesophagus.[22,78-80] Esophageal temperature measurement is the preferred method in intubated victims and in victims with supraglottic airway devices with a gastric channel.[22,79,80] Epitympanic measurement, if available, may also be used in non-intubated victims who are not in CA.[22,79,80]

In two case reports of survivors of witnessed CA following critical burials of 6 and 7 hours, the cooling rates were estimated at 2.3 and 1.8°C/h.[63] The published cooling rates for critically buried victims not in CA is variable, ranging from low values between 0.3 and 0.6°C/h[81] to much higher values, of 5.1°C/h,[74,82] 6°C/h,[83] or 8.5°C/h[84] An extreme cooling rate of 9.4°C/h was measured in a lightly dressed victim in a very cold environment who was extricated in CA.[85] A rate of 7°C/h was measured in a partially buried victim.[86]

A systematic review of hypothermic victims with witnessed CA suggested that hypothermia alone is unlikely to be the sole cause of CA if core temperature is >30°C.[87]In addition to hypothermia, hypercapnia and hypoxia have roles in the pathophysiology of CA in avalanche victims.[69, 74,76]

Cardiac arrest type

CA rhythm

The most frequent initial cardiac rhythm in a hypothermic survivor of CA following an avalanche accident is ventricular fibrillation (VF). Asystole is the most frequent initial cardiac rhythm in non-hypothermic victims (**Table 3**).[45] Asystole can be the presenting rhythm in hypothermic CA, but in avalanche victims, hypothermic asystolic CA is rare (**Table 3**) and is associated with poor outcomes.[43,87]

Witnessed and unwitnessed CA

Witnessed CA in an avalanche victim is associated with increased survival.[43,45] If traumatic CA is excluded, witnessed CA is common in hypothermic CA following a long burial (**Table 3**). Vital signs may be faint and difficult to detect in deep hypothermia. Rescuers should check for signs of life, including vital signs, for up to one minute before diagnosing CA if deep hypothermia (<30°C) is suspected.[16,21] A victim buried >60 minutes with unwitnessed cardiac arrest and asystole has a low probability of survival. We found only one report of a survivor with unwitnessed CA following long burial and hypothermic CA. The presenting rhythm was asystole (**Table 3**).[77] CA may occur but be clinically undetected when the victim is extricated.[72,87] This may have occurred in one victim with a patent airway and an air pocket who was extricated after a burial of 253 minutes.[72] No CPR was provided but the victim was later shown by the post-mortem analysis of the data on his multifunction sport watch to have had a CA at the time of extrication.[72]

Time between locating a victim and the start of BLS

Most critically buried victims are not in a horizontal supine position when found. In one study of 159 critically buried avalanche victims, the head was lower than the body in 65% of the victims.[88] Forty-five percent of the victims were in the prone position, 24% supine, 16% sitting or standing, and 15% lying on their sides.[88] In a simulation study, the median time from the location of a critically buried victim to airway access was 7.2

minutes and the median time to supine position for CPR was 10.1 minutes.[30] Chest compressions can be provided effectively by lay rescuers, before complete extrication, even in atypical positions. This may reduce the time to CPR in avalanche rescue.[32,89] The quality of ventilation provided by lay rescuers using mouth to mouth ventilation or using a pocket mask is generally poor.[32] In victims with very short burial times (≤20 minutes) extricated in CA, ROSC after BLS and survival with good outcome is possible (**Supplemental file 5**).[41,60,65,90,91] We found nine such cases of ROSC on site after BLS (**Supplemental file 5**).[41,60,65,90,91] The clinical course of these victims was compatible with CA from asphyxia and successful resuscitation after restoration of ventilation and oxygenation. A case reported 40 years ago described a victim who was extricated in asystole after being critically buried for 5 h. He survived without sequelae despite a no-flow time of 70 minutes after extrication.[77]

Trauma

Trauma is a significant cause of death in fatal avalanche accidents. In Canada, trauma accounted for 19% of fatalities in one study[34] and 24%[44] of fatalities in another study. In other studies, the percentage of fatalities caused by trauma was 6% in Austria,[49] 5%[48] and 29% in the USA,[50] and 15% in Japan.[52] Trauma may be severe.[36,50,52,86,92] Injuries may include head injuries[50,93] chest injuries,[44,49,94] including pneumothorax,[66,86,92,93,95] unstable spinal injuries, and pelvic fractures.[49,50,92-94,96,97] Frostbite can also occur.[57,96] Severe trauma may be suspected on site but not found at autopsy[98] or severe trauma may not be detected on site but found later in hospital. Invasive procedures, such as thoracostomies, may precipitate bleeding and complicate rewarming with ECLS in hypothermic CA victims.[99,100]

Negative pressure pulmonary oedema

Pulmonary oedema, thought to be caused by negative pressure, has been described in critically buried avalanche victims, usually occurring in victims with short burial durations. Pulmonary oedema can occur in burials as short as 3-5 minutes.[10,67,101-103] Although pulmonary oedema requires hospitalisation, generally with non-invasive ventilation or intubation, it usually resolves with treatment within 24 hours.[67,103]

AVALANCHE-SPECIFIC RECOMMENDATIONS (Table 4)

The initial management of critically buried avalanche victims and decision-making for advanced management of critically buried avalanche victims in CA are summarised in two separate algorithms **(Fig. 2** and **Fig. 3)**. The We have revised the Avalanche Victim Resuscitation Checklist (AVRC), based on the updated algorithms, for clinical decision support and documentation in the field (**Supplemental file 6**).[24]

In-hospital rewarming

The decision whether to perform ECLS rewarming in-hospital for hypothermic avalanche victims in CA has traditionally been based on the serum potassium, or, more recently, using a combination of potassium (7 mmol/L) and temperature (30°C) cutoffs.[15,104] This approach has recently changed. The 2021 ERC guidelines no longer advise the use of a single potassium value as a primary triage tool, but rather as part of a multivariable tool such as the Hypothermia Outcome Prediction score after ECLS (HOPE) score. Alternatively, the combination of a potassium <7 mmol/L and a temperature <30°C indicates a need for ECLS.[16,104,105] Having the head fully covered by snow is defined in the HOPE derivation and validation studies as an asphyxia-related mechanism, linked to lower survival probability.[105,106] Because there were few avalanche victims in the HOPE validation study (fewer than 10 survivors after ECLS rewarming with avalanche burial), the HOPE score should be used cautiously, especially if there is doubt about the reliability of airway patency. In case of uncertainty, other parameters should be considered, such as cooling after extrication, clothing, asociated trauma, and laboratory parameters, including pH, lactate, and coagulopathy. If there is a possibility that an avalanche victim may not have been asphyxiated despite critical burial or for a victim buried >60minutes and who had a witnessed CA, calculating the HOPE score using the non-asphyxia scenario will decrease the risk of underestimating the probability of survival and choosing not to provide ECLS rewarming despite a potentially favourable survival probability.

NON-AVALANCHE-SPECIFIC RECOMMENDATIONS

There are guidelines for the management of medical conditions that may occur in avalanche victims, that are not specific to, avalanche victims. This is the case for accidental hypothermia,[16,21,22,79] normothermic CA, trauma,[16,19] and termination of CPR.[20]

Limitations

A major limitation of the present work is that most data supporting the recommendations are retrospective. The number of reported survivors is low. Prospective collection of high-quality data, including use of dedicated registries, would be useful. We did not address multiple triage situations.[107,108] Although organ donation by brain-dead avalanche victims was not included in the analysis when formulating the recommendations, it may be an important consideration.[38,109]

CONCLUSIONS

The initial management of victims in CA with a short (≤60 minutes) duration of burial should focus on ventilation. Initial management of victims with a long (>60 minutes) duration of burial should focus on a prolonged (1 minute) check for signs of life, including vital signs, and detection of hypothermia. Victims with a burial duration > 60 minutes, an obstructed airway, and asystole should not be resuscitated. Victims with a core temperature <30˚C, as well as victims with an unknown core temperature but with a long (>60 minutes) duration of burial and witnessed CA or a CA rhythm of VF or PEA, should be transported with ongoing CPR to a hospital with ECLS capability.

CONFLICT OF INTEREST

None to declare. None of the authors has any financial or personal relationships that could have influenced the work.

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LEGENDS TO FIGURES

Figure 1.

Flow diagram of the search. We included two studies with original retrospective data, management recommendations, and the ICAR algorithm[14,25] in the qualitative synthesis group.

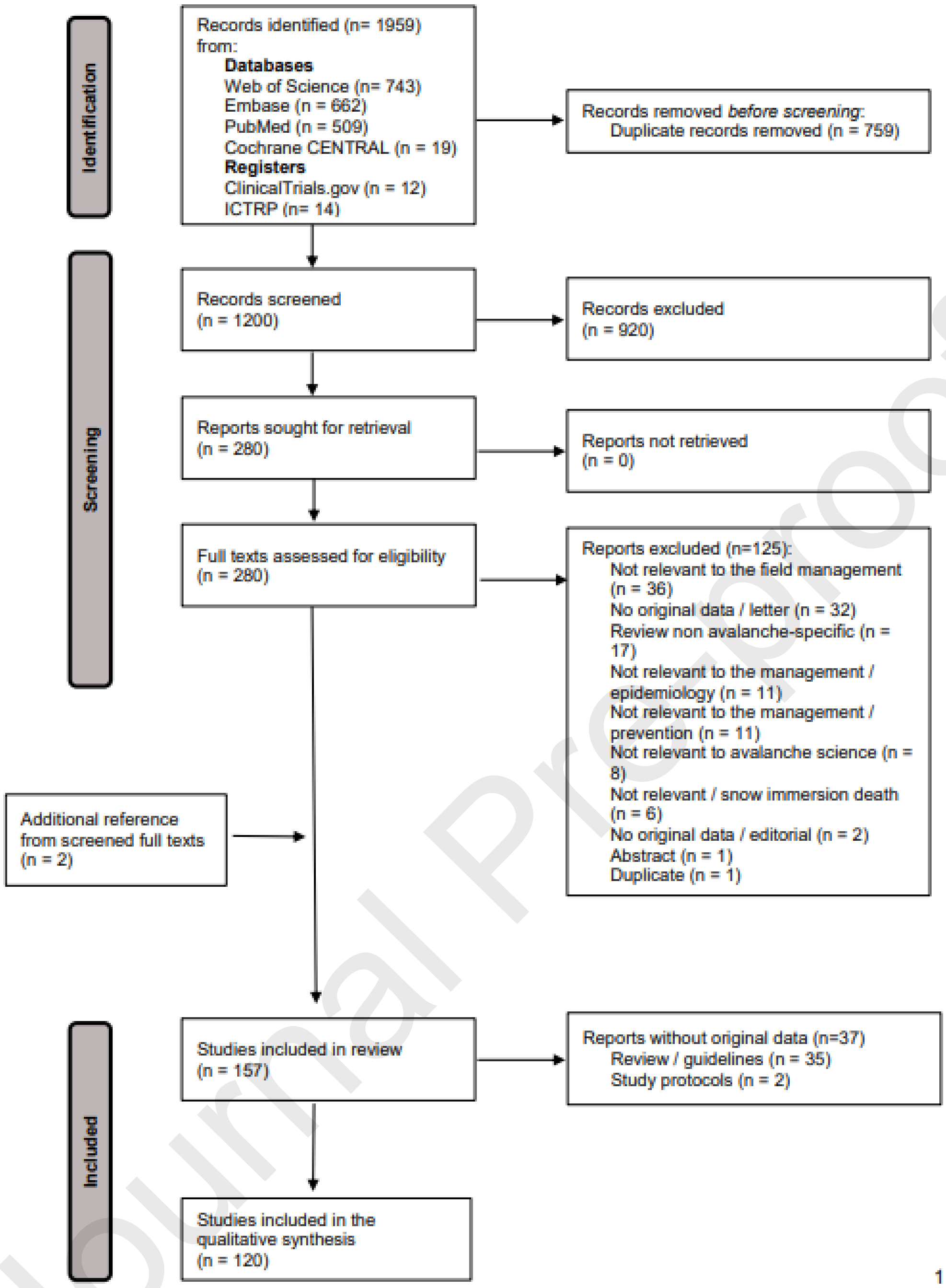


Figure 2.

Initial management of critically buried avalanche victims

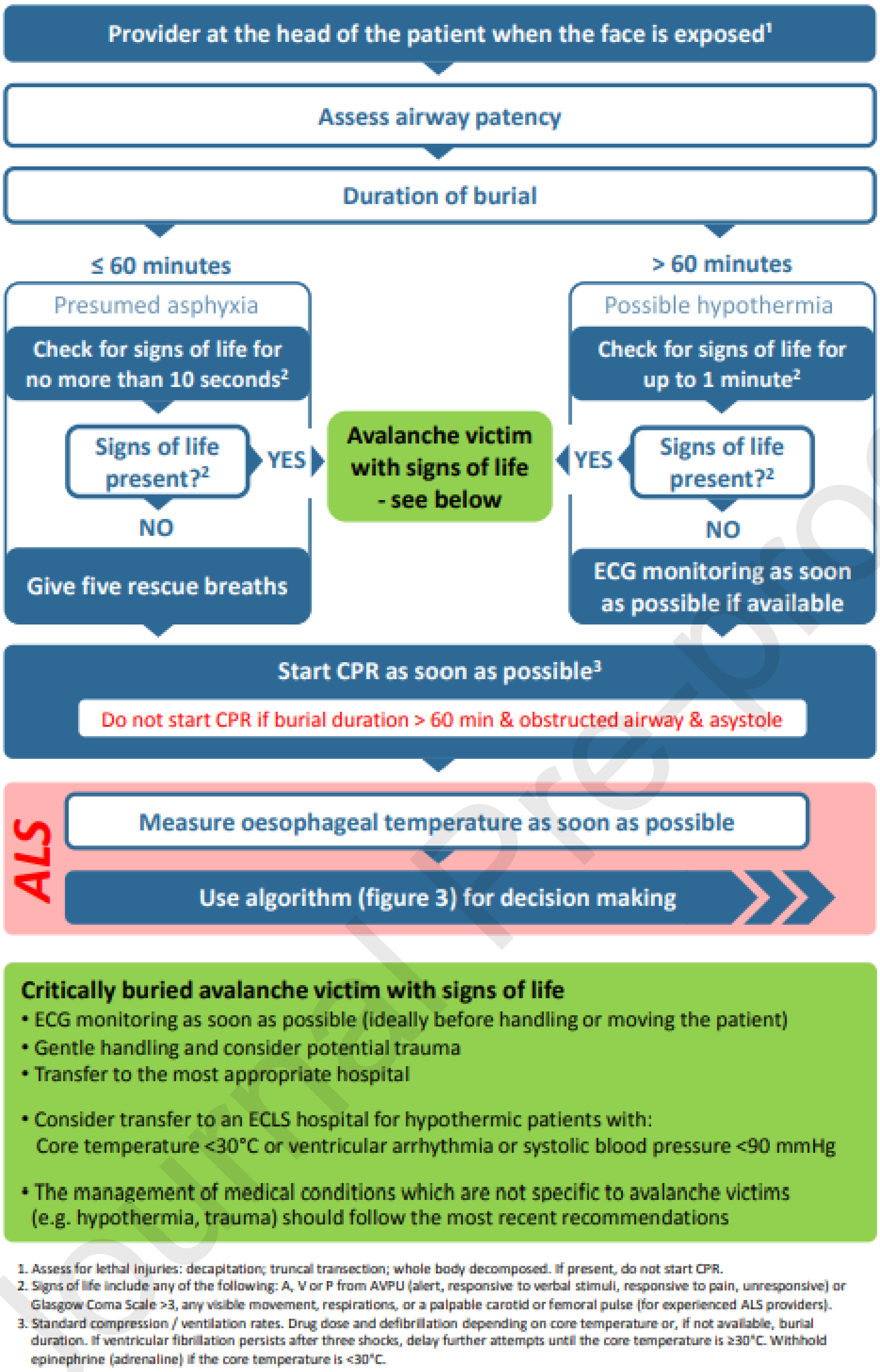
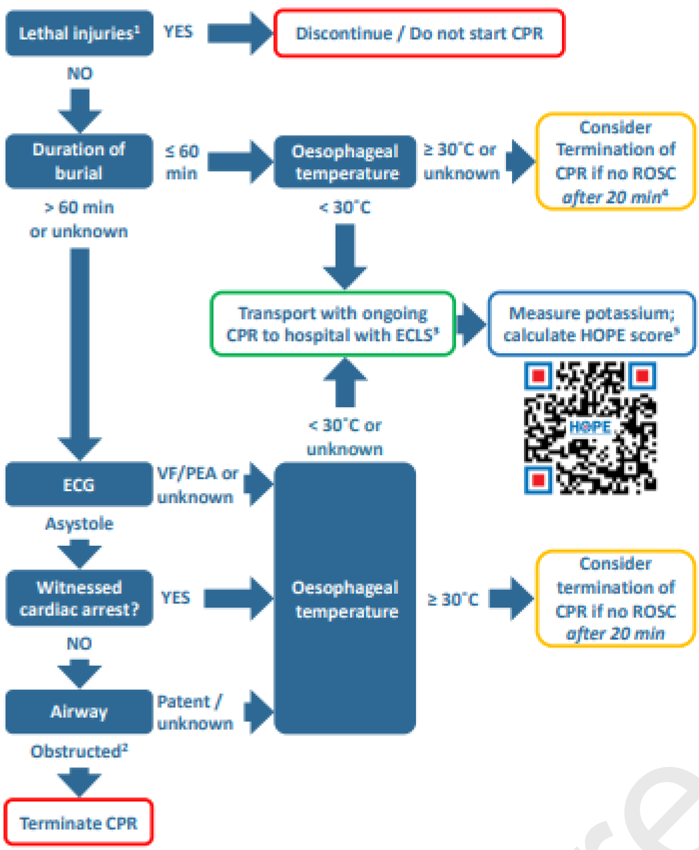


Figure 3.

Decision-making algorithm for advanced management of critically buried avalanche victims in cardiac arrest



1. Decapitation, truncal transection, whole body decomposed
2. An obstructed or blocked airway requires that both the nose and mouth be completely filled with compact snow or debris.
3. With a deeply hypothermic patient (<28°C), if rescue is too dangerous consider delayed CPR and if transport is difficult consider intermittent CPR.
4. If core temperature measurement is not available, hypothermic CA may be considered, at the rescuer's discretion, despite a burial duration of ≤60 minutes in a victim with a patent airway and no vital signs when there is a possibility of very rapid cooling (e.g burial during ascent, low body mass index or small persons, minimally dressed, sweating before burial).
5. In-hospital prognostication of successful rewarming in an avalanche victim should include estimation of the survival probability using the HOPE score. If any doubt exists whether the avalanche victim may have asphyxiated despite critical burial, the HOPE score should be calculated using the NON-ASPHYXIA option. This will reduce the risk of under-treatment. If the HOPE score cannot be determined, the combination of a potassium <7 mmol/L and a temperature <30°C may be used instead to help indicate ECLS rewarming.

Table 1. Grading strength of recommendations and quality of evidence in clinical guidelines (American College of Chest Physicians).[23]

Grade of Recommendation/ Description	Benefit vs Risk and Burdens	Methodological Quality of Supporting Evidence	Implications
1A/strong recommendation, high-quality evidence	Benefits clearly outweigh risk and burdens, or vice versa	RCTs without important limitations or overwhelming evidence from observational studies	Strong recommendation, can apply to most patients in most circumstances without reservation

1B/strong recommendation, moderate quality evidence	Benefits clearly outweigh risk and burdens, or vice versa	RCTs with important limitations (inconsistent results, methodological flaws, indirect, or imprecise) or exceptionally strong evidence from observational studies	Strong recommendation, can apply to most patients in most circumstances without reservation
1C/strong recommendation, low-quality or very low-quality evidence	Benefits clearly outweigh risk and burdens, or vice versa	Observational studies or case series	Strong recommendation but may change when higher quality evidence becomes available
2A/weak recommendation, high-quality evidence	Benefits closely balanced with risks and burden	RCTs without important limitations or overwhelming evidence from observational studies	Weak recommendation, best action may differ depending on circumstances or patients' or societal values
2B/weak recommendation, moderate-quality evidence	Benefits closely balanced with risks and burden	RCTs with important limitations (inconsistent results, methodological flaws, indirect, or imprecise) or exceptionally strong evidence from observational studies	Weak recommendation, best action may differ depending on circumstances or patients' or societal values
2C/weak recommendation, low-	Uncertainty in the estimates of benefits,	Observational studies or case series	Very weak recommendations;

quality or very low-quality evidence	risks, and burden; benefits, risk, and burden may be closely balanced		other alternatives may be equally reasonable

Table 2. The most extreme reported avalanche cases. CA: cardiac arrest; CPB: cardiopulmonary bypass; CPC: cerebral performance category; CPR: cardiopulmonary resuscitation; ECLS: extracorporeal life support; ECMO: extracorporeal membrane oxygenation; PEA: pulseless electrical activity; ROSC: return of spontaneous circulation; VF: ventricular fibrillation.

Non-CA victims	
Longest burial times for survivors (buried in open areas)[a]	43 hours 45 minutes (Italy, female, age unknown, 1972).[57] 25 hours 30 minutes (Canada, 59 yo male, 1960).[58] 17 hours (Switzerland, 21 yo male, 2010).[54]
Longest burial time for survivors (inside a building buried in an avalanche)	37 days (Italy, two women and a 11 yo child buried in a 2x3 metre cavity inside a building. No CA).[59]
CA victims	
Shortest burial duration leading to CA from asphyxia and death	10 minutes (France, 29 yo male, no airway obstruction but no air pocket, extricated in CA and died from asphyxia).[43] 10 minutes (Switzerland, age and sex not specified).[53]
Longest burial duration leading to CA from asphyxia and survival	45 minutes (France, 39 yo male, CPC unfavourable).[43] 20 minutes, (France, 33 yo male, 44 yo male, and 23 yo male, all ROSC on site, all CPC unfavourable).[43] 20 minutes (UK), 32 yo, sex unknown, burial time 20 min, chest compressions, ROSC, CPC 1).[60] 20 minutes (Austria, 26 yo male and 31 yo male, both prehospital ROSC and CPC 4).[41]

Shortest burial duration leading to CA from hypothermia and survival	100 minutes (Italy, 29 yo male, air pocket, witnessed CA (VF), 21.7°C, potassium 4.3 mmol/L, ECMO, CPC1).[40]
Longest burial duration leading to CA from asphyxia, ROSC and death	60 minutes (France, 29 yo male, 15 minutes CPR, prehospital ROSC).[43] 60 minutes (Austria, 53 yo, sex unknown, prehospital ROSC).[61] 60 minutes (Italy, 41 yo male, ROSC after ECLS, organ donor).[62]
Longest burial duration leading to hypothermic CA and survival	7 hours (France, 41 yo male, witnessed CA (PEA), ECLS, CPC 1).[43,63] See **Table 4, Supplemental file 3.**
Longest CPR duration in a survivor	5 hours 45 minutes (Poland, 25 yo female, burial time 2 hours, witnessed CA (VF), ECLS, CPC1).[64]
Longest CPR duration leading to prehospital ROSC.	148 minutes (France, 51 yo female, burial time 30 minutes, asystole, potassium 4.7 mmol/L at admission, died).[43] 100 minutes (France, 41 yo female, burial time 40 minutes, PEA, ROSC, potassium 10.4 mmol/L, died).[43]
Highest potassium in a survivor of avalanche CA rewarmed with ECLS	6.4 mmol/L (Switzerland, age and sex unknown, witnessed CA, burial duration 120 minutes, T° 24.2°C, CPR duration 108 minutes, CPB, CPC 1).[65]

[a] Case report of a victim extricated after a 6-day burial. The victim later died from trauma (India, 33 yo male).[66]

Table 3. Characteristics of victims of critical avalanche burial and CA at extrication who survived to hospital discharge. Victims in the non-hypothermic ("normothermic") group include victims with a burial duration ≤60 minutes (n=12), or if burial duration was unknown but the victim was successfully resuscitated on site (n=3), and victims listed as normothermic by the authors (n=6). Victims in the hypothermic group include victims with no ROSC on site who underwent hospital extracorporeal life support rewarming and a hypothermic (<30°C) victim in CA without ROSC on site who survived, even if the rewarming method is unknown.[65] Prehospital ROSC was associated with shorter burial times and higher temperatures than without ROSC before admission.[39,42]

BLS: basic life support; CA: cardiac arrest; CPC: cerebral performance category; CPR: cardiopulmonary resuscitation; ECLS: extracorporeal life support; IQR: interquartile range; min: minutes; PEA: pulseless electrical activity; ROSC: return of spontaneous circulation.

	Missing data	Overall (n=35)	Hypothermic CA	Non-hypothermic CA	p value

			(n=14)	(n=21)	
Age (years), median (IQR)	16	32 (25-41)	33 (24-41)	32 (26-40)	0.68[c]
Age (years), range	16	17-49	17-42	23-49	-
Burial duration (min), median (IQR)	15	20 (20-128)	143 (120-330)	20 (15-20)	<0.001[c]
Burial duration (min), range	15	10-420	100-420	10-45	-
Temperature (°C), median (IQR)	20	24 (22-27)	22 (21.7-24)	26.5 (26-29.3)	0.007[c]
Temperature (°C), range	20	16.9-34	16.9-26.9	26[a]-34	
Airways patent, n (%)	24	11 (100%)	11 (100%)	.	-
Air pocket present, n (%)	25	5/10 (50%)	5/5 (100%)	0/5 (0%)	0.008[b]
Witnessed cardiac arrest, n (%)	19	9/16 (56%)	9/10 (90%)	0/6 (0%)	0.001[b]
CA rhythm, n (%)	22	13			0.021[b]
Ventricular fibrillation		5	5	0	
PEA		1	1	0	
Asystole		7	2	5	
ROSC after BLS, n (%)	11	9/24 (38%)	0/10 (0%)	9/14 (64%)	0.002[b]
Prehospital ROSC, n (%)	3	18/32 (56%)	0/14 (0%)	18/18 (100%)	0.000[b]
Rewarming method, n (%)	23	12			-
ECLS		11	11	NA	
Thoracotomy and continuous irrigation		1	1	NA	
CPC 1-2, n (%)	4	17/31 (55%)	10/12 (83%)	7/19 (37%)	0.024[b]

[a] All with short (≤45min) burial duration

[b] Fisher exact test

[c] Wilcoxon rank-sum (Mann-Whitney) test

Table 4. Recommendations of the International Commission for Mountain Emergency Medicine (ICAR MedCom) for the on-site treatment of avalanche victims. The evidence and strength of the recommendations are graded using the American College of Chest Physicians grading system.

General actions
Companions should locate and extricate buried victims as quickly as possible (1B).
Professional rescue should be mobilised early (1B).
Duration of burial and airway patency
For victims with burial time of ≤60 minutes without signs of life, presume asphyxia and provide rescue breaths as soon as possible regardless of airway patency (1A).
If the burial time is >60 minutes, airway patency should be determined when the face is exposed (1A).
The possibility of hypothermic CA should be considered for victims with a burial time of >60 minutes without signs of life but a patent or airway of unknown patency. Unless core temperature can be measured to exclude hypothermic CA, the victim should be resuscitated and transported to a hospital with ECLS rewarming capability. (1C)
Air pocket
A victim with patent or airway of unknown patency and an air pocket should be resuscitated unless resuscitation would otherwise not be attempted (1C).
Snow density
Information about snow density should not be used to change management of the victim (1C).
Burial depth
Information about burial depth should not be used to change management of the victim (1C).
Core temperature measurement
A timely core temperature measurement is recommended in victims buried for >60 minutes with a patent airway and no signs of life (1C).
Oesophageal temperature with the tip of the probe inserted into the lower third of the oesophagus is the preferred method of core temperature measurement in victims in CA or with a secured airway (1C).
Core temperature should be used instead of burial duration to determine if a victim with a patent or airway of unknown airway patency without signs of life has had a hypothermic CA. (1C).
Victims without signs of life, with a patent airway, and a core temperature <30°C should be resuscitated and transported to a hospital with ECLS rewarming capabilities (1B).

Core temperature is not useful to predict the outcomes of victims with asystolic CA buried >60 minutes, without signs of life and with an obstructed airway (1C).
Hypothermic CA may be considered, at the rescuer's discretion, despite a burial duration of ≤60 minutes in a victim with a patent airway and no signs of life when there is the possibility of very rapid cooling because of inadequate clothing, a lean victim, an environment favourable to rapid cooling, or burial after physical exertion (2C).
Cardiac arrest type
For victims buried >60 minutes without signs of life, electrocardiographic (ECG) monitoring, ideally using defibrillator pads ready to defibrillate, should be started as soon as the thorax is accessible and ideally before moving the victim (1C).
The possibility of hypothermic CA should be considered for victims buried >60 minutes without signs of life with VF or pulseless electrical activity (PEA) regardless of airway patency. Unless core temperature can be measured to exclude hypothermic CA, the victim should be resuscitated and transported to a hospital with ECLS rewarming capabilities (1B).
Resuscitation should not be attempted on victims with an obstructed airway in asystole, who have been buried for >60 minutes (1A).
For victims buried >60 minutes, carefully check for signs of life, including vital signs, for up to one minute (1B).
Hypothermia should be considered as a likely cause of CA in victims buried >60 minutes when there is a witnessed CA. Unless a core temperature can be measured to exclude hypothermic CA, the victim should be resuscitated and transported to a hospital with ECLS rewarming capability (1A).
Trauma should be considered as a likely cause of witnessed CA for victims buried ≤60 minutes or with a core temperature >30°C (1B).
Rescuers should consider the poor prognosis of victims buried >60 minutes with unwitnessed cardiac arrest and asystole. Rescuers may decide to withhold CPR under these circumstances especially in a difficult rescue or when resources are limited at the scene. (2B).
For victims with burial time of ≤60 minutes without signs of life, presume asphyxia and provide rescue breaths as soon as possible regardless of airway patency (2B).

Chest compressions can be provided effectively even in atypical position before complete extrication (2A).
Trauma
Severe trauma should be suspected in avalanches in steep terrain with rocks and trees. When severe trauma is suspected, on-site trauma treatment should be started as soon as possible according to international trauma guidelines (1C).
Rescuers should provide spinal motion restriction when indicated during extrication, packaging, and transportation of avalanche victims (1C).
Trauma should be considered as a potential cause of CA in avalanche victims. (1B)
For victims without signs of life and with a patent airway buried >60 minutes or with a temperature <30°C, chest decompression should be considered only in cases of clinically suspected chest trauma (1C).
Negative pressure pulmonary edema
A victim with a critical burial and signs or symptoms of respiratory distress at extrication, should be considered to have pulmonary oedema and should be admitted to an appropriate hospital (1B).
A victim with critical burial should be transported to the nearest emergency department for advanced assessment and observation (1C).
In-hospital rewarming
In-hospital prediction of successful rewarming in an avalanche victim should include the estimation of the survival probability using the HOPE score (1C).
Hypothermia should be considered as a likely cause of CA for a victim buried >60 minutes with a witnessed CA. In this case, the HOPE score should be calculated using the non-asphyxia scenario (1A).
If there is a possibility that an avalanche victim may not have been asphyxiated despite full burial, calculating the HOPE score using the non-asphyxia scenario will decrease the risk of underestimating the probability of survival after rewarming (1C).
If the HOPE score cannot be determined, the combination of a potassium <7 mmol/L and a temperature <30°C may be used instead to indicate the need for ECLS rewarming (1C).
Non-avalanche-specific recommendations
Management of associated medical conditions such as hypothermia, normothermic CA, trauma, and termination of CPR) should follow the most current guidelines (1A).

CONFLICT OF INTEREST

None to declare. None of the authors has any financial or personal relationships that could have influenced the work.

Authors' contributions

MP, HB, GS, PP, KZ, and JE conceived and designed the study. All authors elaborated the list of PICO questions. CJ and MP searched the literature for studies of avalanche-specific knowledge. MP and GS independently screened the titles, abstracts and analyzed the full texts to confirm that they met the inclusion criteria. MP, HB, RM, LG, KZ, PP drafted the manuscript. MP performed the statistical analysis. All authors contributed to the elaboration of the recommendations and algorithms. AK and MP elaborated the Avalanche Victim Resuscitation Checklist (AVRC). All authors critically revised the manuscript, read and approved the final manuscript.