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Clinical paper

Avalanche victims in cardiac arrest are unlikely to survive despite adherence to medical guidelines

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Abstract

Aims: Our goals were to describe and analyse the medical management and clinical course of avalanche victims in cardiac arrest (CA), focusing on adherence to international recommendations on avalanche victims in CA regarding critical decisions.

Methods: We retrospectively included all avalanche victims with CA from 1st January 2004 to 1st June 2016 in a single physician-staffed alpine helicopter emergency medical service. Data regarding cardiopulmonary resuscitation (CPR), transportation to hospital whilst undergoing CPR, and extracorporeal life support rewarming (ECLSR) for patients still in CA at hospital admission were abstracted from the prehospital and medical health records.

Results: Sixty-six victims were included in this study; 31 (47%) were declared dead on scene. Of the remaining 35 victims, 7 (20%) had prehospital return of spontaneous circulation (ROSC), 28 (80%) were transported whilst undergoing CPR, 3 had hospital ROSC and 7 (28%) of the 25 patients with persistent CA at hospital underwent ECLSR. The medical management comprised 126 documented critical decisions, corresponding to guidelines in 117 (93%) decisions. None of the 66 studied patients survived to hospital discharge, and 7 (11%) were organ donors.

Conclusions: The management of avalanche victims in CA respect current guidelines regarding the critical decisions, but no patient survived in this sample. The presence of a few cases with incorrect management and potential undertreatment suggests some room for improvement.

Keywords: Avalanche, Cardiac arrest, ECPR, Guidelines, HEMS, Hypothermia, Accidental, Resuscitation, Triage

Introduction

The technical and medical management of avalanche victims is challenging for mountain rescuers, as it requires a large panel of competencies and skills.[1] Victims tend to be young and healthy, but if completely buried their mortality is >50%.[2–4] Resuscitative measures and on-site triage of patients in cardiac arrest (CA) is guided by the presumed causes of CA: asphyxia, trauma, hypothermia, or by a combination of these.[3] If rescuers can recognise hypothermic CA victims, they may survive with good neurological outcomes.[5,6] The first resuscitation guidelines for avalanche victims with asystolic CA were published in 1996,[2] and then subsequently adapted by the International Commission of Mountain Emergency Medicine (ICAR MEDCOM)[7,8] and incorporated into the 2015 European Resuscitation Council (ERC) guidelines.[9] However, retrospective data suggest that the management of avalanche victims in CA infrequently follows these guidelines when it comes to critical decisions, such as the initiation of

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CPR, transport to hospital, or extracorporeal life support rewarming (ECLSR).[10,11] Insufficient transfer of information from the accident site to the hospital has been alleged as a potential reason for suboptimal management.[11]

In Switzerland, approximately 25 people die each year in avalanche accidents,[12] representing a substantial proportion of the 150 annual deaths in North America and Europe combined.[7] Air-Glaciers is a physician-staffed alpine helicopter emergency medical service (HEMS) in the French-speaking part of Switzerland. With 10–15 rescue missions annually involving fully buried avalanche victims, this specific HEMS is experienced in avalanche rescue procedures. The staff of the first dispatched helicopter engaged in an avalanche rescue includes an emergency physician specifically trained in mountain rescue. Rescue teams are trained annually during a two-day pre-winter season field training, which also allows for implementation and review of the latest medical guidelines. The nearest hospital uses cardiopulmonary bypass for ECLSR. Our goal was to describe the medical management of avalanche victims in CA, focusing on adherence to international recommendations for CPR, the decision to transport the patient to hospital whilst undergoing CPR, and ECLSR for patients still in CA at hospital admission.

Methods

Study population

We retrospectively screened all rescue missions from a single physician-staffed alpine HEMS (Air-Glaciers, Sion and Collombey, Valais, Switzerland) from 1st January 2004 to 1st June 2016. We included all avalanche victims with out-of-hospital CA (OHCA), who were either declared dead on scene or transported to a hospital. We excluded patients found 24 h after the initial alarm, victims not buried by an avalanche, and patients transported outside of the French-speaking part of Switzerland. All relevant prehospital data were extracted from each patient's prehospital chart, which was completed by the physician at the end of each rescue mission. We specifically assessed the presence of the following information in the chart: duration and degree of burial (complete, partial, or not

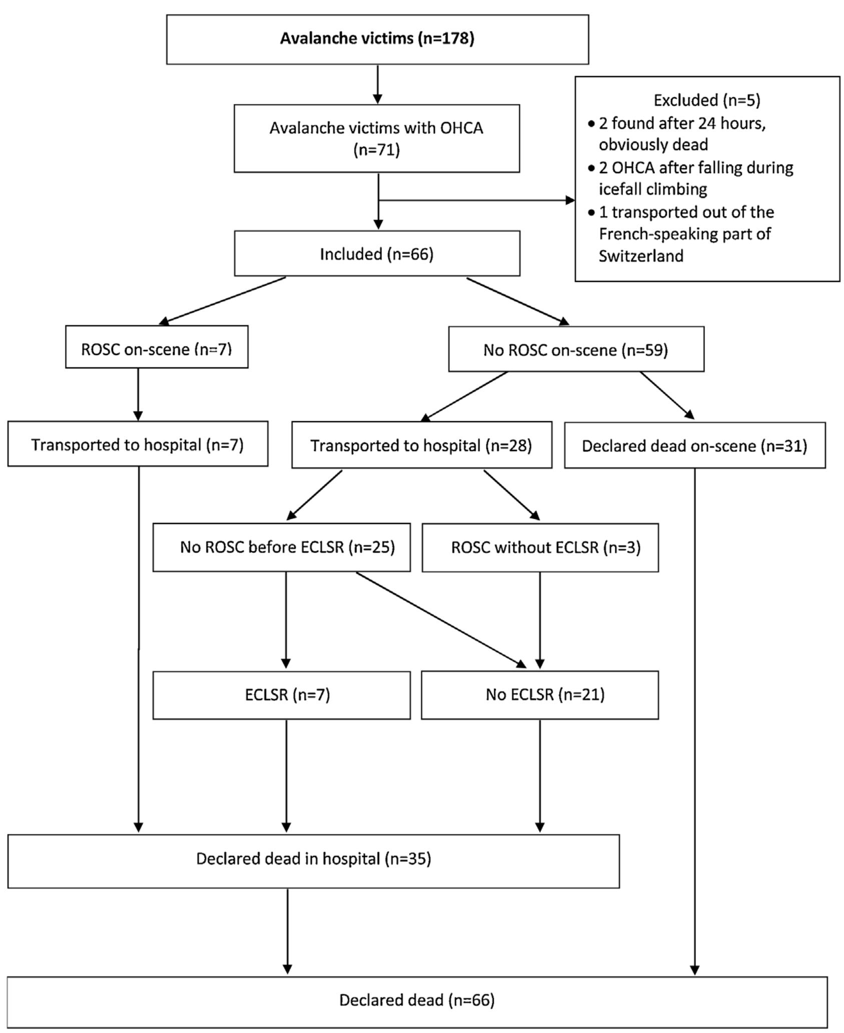

Fig. 1 – Flowchart of patient inclusion. Helicopter primary rescue missions of Air-Glaciers, Sion and Collombey, Switzerland between 1st January 2004 and 1st June 2016. Abbreviations: CA, cardiac arrest; ECLSR, extracorporeal life support rewarming; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation.

buried), initial core temperature and site of measurement, airway patency, presence of an air pocket, presence of lethal trauma, completely frozen body or unacceptable risk for the rescue team, the first CA rhythm, and whether the CA was witnessed. Complete burial was defined as at least burial of the head. Hospital data included core temperature, cardiac rhythm, and potassium value at admission. We registered whether the patient was rewarmed with ECLS. The follow-up included survival, neurological outcome at hospital discharge and organ donation. A Cerebral Performance Category (CPC) of 1 or 2 was considered a favourable neurological outcome.[13,14]

Primary outcome

Our **primary outcome** was to assess whether patient management followed the specific dedicated guidelines for CPR, decision to transport the patient to hospital whilst undergoing CPR, and ECLSR for patients still in CA at hospital admission. The guidelines used for assessing a given case were those applicable at the time of the rescue mission.[7,8] The 2015 ERC Guidelines for Resuscitation were not yet implemented in practice during the 2015–2016 winter season. We classified each decision according to whether the management was correct, incorrect, or indeterminate (i.e., elements were lacking to

Table 1 – Characteristics of the study population and exhaustiveness of "avalanche-specific" information according to the medical chart.

	Total (n = 66)	Dead on-scene (n = 31)	Transported to hospital (n = 35)	P
Males, n (%)	54 (82)	25 (81)	29 (83)	0.82
Median age, years (IQR)[a]	37 (26–50)	37 (26–51)	36 (23–49)	0.41
Degree of burial, n (%)				0.22
Completely buried	59 (89)	26 (84)	33 (94)	–
Partially buried	1 (1.5)	0	1 (2.9)	–
Not buried	5 (7.6)	4 (13)	1 (2.9)	–
Not documented	1 (1.5)	1 (3.2)	0	–
Burial duration for completely buried patients[b]				
Exact duration documented, n (%)	40 (68)	15 (58)	25 (76)	–
Median duration, min (IQR)	35 (20–73)	40 (10–90)	35 (30–70)	0.80
Only cut-off duration documented, n (%)	5 (8.5)	1 (3.8)	4 (12)	–
≤35 min, n (%)[c]	22 (37)	7 (27)	15 (46)	–
>35 min, n (%)[c]	23 (39)	9 (35)	14 (42)	–
Not documented, n (%)	14 (24)	10 (39)	4 (12)	–
Airways patency for completely buried patients, n (%)				<0.001
Free	11 (19)	2 (7.7)	9 (27)	–
Obstructed	2 (3.4)	2 (7.7)	0	–
Not documented but patient intubated or ventilated	37 (63)	13 (50)	24 (73)	–
Not documented, not intubated	9 (15)	9 (35)	0	–
Air pocket for completely buried patients, n (%)				0.59
Absent	10 (17)	4 (15)	6 (18)	–
Present	7 (12)	2 (7.4)	5 (15)	–
Documented unknown	1 (1.7)	0	1 (3.0)	–
Not documented	41 (70)	20 (77)	21 (63)	–
Prehospital core temperature in °C				
Median (IQR)[a]	28.4 (24.7–31.5)	29.8 (20.0–31.9)	28.3 (27.0–30.8)	0.67
<32, n (%)[c]	29 (44)	10 (32)	19 (54)	–
≥32, n (%)[c]	8 (12)	3 (9.4)	5 (14)	–
Not documented, n (%)	29 (44)	18 (58)	11 (31)	–
First cardiac arrest rhythm, n (%)				0.13
Asystole	31 (47)	14 (45)	17 (49)	–
Pulseless electrical activity	6 (9.1)	2 (6.5)	4 (11)	–
Ventricular fibrillation	4 (6.1)	0	4 (11)	–
Not documented	25 (38)	15 (48)	10 (29)	–
Trauma, n (%)				0.10
Any trauma documented	30 (46)	18 (58)	12 (34)	–
Lethal trauma documented	2 (3.0)	2 (6.5)	0	–
"No trauma" documented	2 (3.0)	0	2 (5.7)	–
Not documented	34 (52)	13 (42)	21 (60)	–
CPR[a], n (%)				<0.001
CPR provided	54 (82)	19 (61)	35 (100)	–
No CPR provided	6 (9.1)	6 (19)	0	–
Not documented	6 (9.1)	6 (19)	0	–

[a] IQR and CPR denote interquartile range and cardiopulmonary resuscitation, respectively.
[b] Data are only for completely buried victims. The exact values are sometimes unknown but cut-offduration is mentioned. Median duration of burial and temperature were calculated from exact values.
[c] The 2015 ERC Guidelines for Resuscitation that proposes different cut-offs for triage was not yet implemented in practice during the 2015–2016 winter season.

conclude that the management was correct). In the absence of persistent ventricular fibrillation (VF), pulseless electrical activity (PEA), or prehospital return of spontaneous circulation (ROSC), the following reasons were considered valid for deciding not to provide CPR or transport a patient to the hospital whilst undergoing CPR: body completely frozen, obvious fatal injuries or unacceptable risk for the rescuers, on-site core temperature ≥32 °C, incomplete burial or short burial (i.e., ≤35 min) without hypothermia, long burial (i.e., >35 min) with asystole plus an obstructed airway (or, before 2013, unequivocal absence of an air pocket).[7,8] We considered the following reasons as valid for deciding not to initiate ECLSR for a persistent CA patient at hospital admission: any of the reasons mentioned above, or if serum potassium was >12 mmol/L (guidelines for 2001–2012)[8] or >8 mmol/L (guidelines for 2013–2015).[7] In the absence of any of the above criteria, CPR, transport to the hospital, and ECLSR were considered to be indicated. If no information was documented, airways were considered patent if the patient was intubated, ventilated or if the temperature could be measured oesophageally. The records and critical decisions were reviewed by the two main authors (JM and MP) and jointly discussed in case of difficult judgement, which was the case in 19 (14%) of these decisions. A third author (AK) who was unaware of the conclusions of the two first experts independently reviewed these 19 decisions and confirmed the allocated appropriateness for 17 of them. A disagreement occurred for two decisions, which led to discussion and consensual modification of the initially allocated appropriateness.

Secondary outcomes

Our **secondary outcomes** were the quality of the documentation in the prehospital medical records of specific items needed to guide decisions according to the guidelines, and the survival to hospital discharge.

This study was approved by the Human Research Ethics Committee of the State of Vaud, Switzerland, on 22 August 2016 (No 2016-01038).

Statistical analysis

The collected data were entered into an Excel spreadsheet (Microsoft, Redmond, WA, USA) and then exported to Stata version 14 (Stata Corporation, College Station, TX, USA). Continuous data were expressed as means and standard deviations (SDs) or medians and interquartile ranges (IQRs) according to the data distribution. Comparisons were performed using Student's t-test or Mann–Whitney U test, as appropriate. Categorical data were expressed as numbers and percentages and compared by Pearson's chi-squared test or Fisher's exact test as appropriate. A bilateral p-value < 0.05 was considered significant.

Results

A total of 71 patients suffered CA in an avalanche accident during the study period. Sixty-six victims were included in this study, (Fig. 1) 31 (47%) of whom were declared dead on scene. Fifty-four (82%) victims were male. The median age was 36.5 years (range 14–75, IQR 26–50). Activities during avalanche accidents were ski touring (n = 28, 42%), backcountry activities (n = 24, 36%), alpinism (n = 7, 11%) and unknown (n = 7, 11%). The 66 victims were rescued by 24 different doctors, which represents a median of 2 (range 1–12, IQR 1–3) avalanche victims in CA per doctor during the study period. The information specifically needed to guide the critical decision that is found in the prehospital medical chart is presented in Table 1. The characteristics of the 25 patients still in CA at hospital admission are presented in Table 2. Seven (28%) victims underwent ECLSR.

Table 2 – Characteristics of patients in persistent cardiac arrest at hospital according to the information provided in the medical chart. Abbreviations: ECLSR, Extracorporeal life support rewarming. ROSC, return of spontaneous circulation.

	Total n = 25[a]	ECLSR[b] n = 7 (28%)	No ECLSR n = 18 (72%)	P
Overall characteristics				
Males, n (%)	21 (84)	5 (71)	16 (89)	0.29
Median age, years (IQR)[b]	36 (23–48)	47 (17–49)	35 (23–48)	1.00
Avalanche-specific information				
Burial degree, n (%)				0.66
Completely buried	23 (92)	7 (100)	16 (89)	–
Not/partially buried	2 (8.0)	0	2 (11)	–
Not documented/unknown	0	0	0	–
Burial duration for completely buried patients[c]				
Exact duration documented, n (%)	16 (70)	5 (71)	11 (69)	–
Median, min (IQR)	45 (30–83)	70 (45–75)	35 (20–90)	0.43
Only cut-off documented, n (%)	4 (17)	0	4 (25)	–
≤35 min, n (%)	8 (35)	1 (14)	7 (44)	–
>35 min, n (%)	12 (52)	4 (57)	8 (50)	–
Not documented/unknown, n (%)	3 (13)	2 (29)	1 (6.2)	–
Airway patency for completely buried patients, n (%)	–	–	–	0.86
Free	6 (26)	2 (29)	4 (25)	–
Obstructed	0	0	0	–
Not documented but patient intubated or ventilated	17 (74)	5 (71)	12 (75)	–
Not documented, not intubated	0	0	0	–
Air pocket for completely buried patients, n (%)				0.74

Table 2 (continued)

	Total n = 25[a]	ECLSR[b] n = 7 (28%)	No ECLSR n = 18 (72%)	P
Present	4 (17)	2 (29)	2 (13)	–
Absent	3 (13)	1 (14)	2 (13)	–
Documented as unknown	1 (4.3)	0	1 (6.2)	–
Not documented	15 (65)	4 (57)	11 (69)	–
Prehospital core temperature in °C				
Median (IQR)	28.0 (27.0–29.6)	29 (28.2–29.6)	27.7 (25.0–29.2)	0.40
<32, n (%)	15 (60)	5 (71)	10 (56)	–
≥32, n (%)	2 (8.0)	0	2 (11)	–
Not documented, n (%)	8 (32)	2 (29)	6 (33)	–
First prehospital cardiac arrest rhythm, n (%)				0.82
Asystole	14 (56)	4 (57)	10 (56)	–
Ventricular fibrillation	2 (8.0)	1 (14)	1 (5.6)	–
Pulseless electrical activity	1 (4.0)	0	1 (5.6)	–
Not documented/unknown	8 (32)	2 (29)	6 (33)	–
Witnessed cardiac arrest, n(%)	1 (4.0)	1 (14.3%)	0	0.10
Trauma, n (%)				0.05
Any trauma documented	10 (40)	3 (43)	7 (39)	–
« No trauma » documented	2 (8.0)	2 (29)	0	–
Not documented	13 (52)	2 (29)	11 (61)	–
Hospital patient characteristics				
First hospital core temperature in °C				–
Median (IQR)	29.2 (27.3–33.0)	27.4 (25.0–28.8)	32 (29.0–34.3)	0.02
<32, n (%)	14 (56)	7 (100)	7 (39)	–
≥32, n (%)	8 (32)	0	8 (44)	–
Not documented/unknown, n (%)	3 (12)	0	3 (17)	–
First hospital cardiac rhythm, n (%)				0.72
Asystole	17 (68)	5 (71)	12 (67)	–
Ventricular fibrillation	5 (20)	2 (29)	3 (17)	–
Pulseless electrical activity	1 (4.0)	0	1 (5.5)	–
Not documented/unknown	2 (8.0)	0	2 (11)	–
Serum potassium at admission in mmol/L				
Median (IQR)	7.4 (6.5–12)	6.5 (5.5–8.6)	9.1 (6.8–14)	0.09
>12, n (%)	5 (20)	0	6 (33)	–
≤12, n (%)	18 (72)	7 (100)	10 (56)	–
>8, n (%)	11 (44)	2 (29)	9 (50)	–
≤8, n (%)	13 (52)	5 (71)	8 (44)	–
Not documented[d], n (%)	2 (8.0)	0	2 (11)	–
Any trauma documented pre- and in-hospital, n (%)				0.17
Any trauma documented	12 (48)	4 (57)	8 (44)	–
« No trauma » documented	1 (4.0)	1 (14)	0	–
Not documented/unknown	12 (48)	2 (29)	10 (56)	–

Values are expressed in n (%) or medians (interquartile ranges, IQR).
[a] Excluding three patients who sustained in-hospital return of spontaneous circulation before extracorporeal life support rewarming.
[b] ECLSR and IQR denote extracorporeal life support rewarming and interquartile, respectively.
[c] Data are only for completely buried victims. The exact values are sometimes unknown but cut-off duration is mentioned. Median duration of burial and temperature are calculated from exact values.
[d] One value was expressed as >10 mmol/L, and was considered as not documented (guidelines 2001–2012).

A total of 138 **critical decisions** were analysed, including 66 decisions regarding CPR, 47 transport of a CA patient to a hospital (excluding patients with no or unknown CPR status or with ROSC), and 25 ECLSR for patients still in CA at hospital admission. Due to the absence of information in the prehospital chart, the appropriateness of management could not be determined for 12 (9%) of these 138 critical decisions. The prehospital management was correct (71%) or indeterminate (15%) in most of 66 patients regarding CPR and patient transport (Table 3 and Supplementary Table 1 for details). All 35 patients transported to a hospital had prehospital CPR on scene or during transport. Seven patients (all with short burial) had prehospital ROSC. Twenty-eight patients were transported whilst undergoing CPR, including one patient who experienced CA in the helicopter. Three of them had hospital ROSC without ECLSR (see Supplementary Table 1 for details). The detailed hospital appropriateness regarding ECLSR initiation is presented in Supplementary Table 2. A summary of the appropriateness of the overall (prehospital and hospital) management of avalanche victims with CA is presented in Table 4.

Overall, the information documented in the patients' medical charts allowed adequacy of the critical decisions to be determined; 117 of the 126 (93%) decisions were correct. The management was judged incorrect in at least one of the three critical decisions for 9 (14%) of the 66 patients, with potential undertreatment in 7 (11%) patients and potential futile treatment in 2 (3%) patients.

None of the 66 patients was discharged alive (survival rate 0% [95% CI; 0–5.4]). Seven of them (11%) were organ donors, five with

Table 3 – Detailed prehospital appropriateness and compliance of cardiac arrest patient's management to the retrospective prehospital medical chart review (n = 66). Abbreviations: CA, cardiac arrest; CPR, cardiopulmonary resuscitation; DNRO, do not resuscitate order; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; VF, ventricular fibrillation.

Clinical scenario	N (%)
Management considered as correct	**47 (71)**
CPR not provided on-site, patient not transported to hospital	3
Lethal trauma[a]	2
Completely frozen body	1
CPR provided, no ROSC, patient not transported to hospital	**13**
Short burial, core temperature not documented	6
Short burial, core temperature ≥32 °C	1
Unknown duration of burial, core temperature ≥32 °C	2
Long burial, asystole, obstructed airways	1
Not buried, CA of presumed traumatic cause	3
CPR provided, no ROSC, patient transported to hospital whilst undergoing CPR	**23**
Short burial or unknown duration of burial, any core temperature, persistent VF or PEA	6
Long burial, core temperature unknown, no obstructed airways documented	4
Long burial, core temperature <32 °C (unknown site or not oesophageal), no obstructed airways documented	5
Any grade or duration of burial, core temperature <32 °C (oesophageal), no obstructed airways documented	5
Short burial, core temperature <32 °C (not oesophageal), no obstructed airways documented[b]	2
High risk for rescuers ("load and go")[c]	1
No initial CA, CA and CPR during transport to hospital	**1**
Rescue collapse	1
CPR provided, ROSC, patient transported to hospital	**7**
Management considered as incorrect	**9 (14)**
CPR not provided on-site despite indication	**2**
Long burial or oesophageal core temperature <32 °C. None of the following documented: lethal trauma, completely frozen body, high risk for rescuers, valid DNRO	2
CPR provided but patient not transported to hospital despite indication	**5**
Unknown duration of burial, core temperature <32 °C (unknown site), no obstructed airways documented	1
Long burial, core temperature <32 °C (unknown site or oesophageal), no obstructed airways	4
CPR provided (indicated) but patient transported to hospital without indication	**2**
Any duration of burial, core temperature ≥32 °C, asystole	2
Insufficient data to draw conclusion	**10 (15)**
CPR not provided	**1**
Missing documented argument not to provide CPR	1
No documentation whether CPR was provided on-site, patient not transported to hospital	**6**
Absence of pertinent clinical data to consider that the management was correct or not	6
CPR provided, patient not transported to hospital	**1**
Missing documented argument to terminate CPR	1
CPR provided, patient transported to hospital	**2**
Missing documented argument to transport patient to hospital	2

[a] Physicians documented trauma incompatible with life.
[b] Decision to transport the patients is debatable, given the concomitant short duration of burial and hypothermia, but no oesophageal temperature measurement.
[c] The critical information were not available before transporting the patient to the hospital, given the risk for the rescuers.

prehospital or hospital ROSC and 2 after ECLSR (Supplementary Table 1 and Table 2). A summary of the main characteristics and outcomes of avalanche victims in CA included in this study compared to similar studies is presented in Table 5.[10,11,15]

Discussion

To the best of our knowledge, the present study is one of the largest to date to assess the medical management of avalanche victims in CA. The prehospital chart review allowed assessment of the adequacy of management in most (91%) cases; the management regarding critical decisions was correct in 93% of them. Even if indeterminate decisions were classified as incorrect (worst-case scenario), most decisions (117/138; 85%) would still be classified as correct. Despite high adherence to international guidelines, this study highlights the poor prognosis of patients who suffer CA due to avalanche burial. Our results also provide further information regarding the on-site management of avalanche victims in CA. In particular, analysis of the situations in which patients may have been undertreated is important in order to detect cases that could have survived with proper treatment.

The overall rate of **CPR on site** was 82%, which is approximately twice as high as in similar studies from Tyrol.[10,11] This difference could be related to the higher rate of lethal trauma in these studies,[10,11] sporadic presence of an emergency physician on site,[11] or different inclusion criteria between studies. Burial times were also different, as 49% of patients in our study with documented duration had short burials compared to 26% (34/129) in Strapazzon et al.[11] The CPR rate for victims declared dead on scene was higher in our study than a similar study from Switzerland (61% vs. 36%; p = 0.012).[1] When only victims with a short burial duration were considered, the CPR rate was

Table 4 – Summary of appropriateness of the 126 critical decisions regarding the prehospital and hospital management of avalanche patients in cardiac arrest and for which sufficient information was available in the medical chart to judge adequacy of recommendations. Insufficient data was available in 12 (8.6%) critical decisions (7 regarding CPR, 3 regarding transport of patients in cardiac arrest and 2 regarding hospital rewarming). The detailed hospital appropriateness and compliance of patients with cardiac arrest at hospital regarding ECLSR is presented in the Supplementary Table 2. Data are provided in n (%). Abbreviations: CA, cardiac arrest; CPR, cardiopulmonary resuscitation; ECLSR, Extracorporeal life support rewarming; ROSC, return of spontaneous circulation.

Indication according to the guidelines	Actual patient's management	
	Correct	Incorrect
Overall (n = 126 critical decisions), n (%)	117 (93)	9 (7)
CPR (n = 59)	57 (97)	2 (3)
Indicated, n (%)	54 (92)	2 (3.4)[a]
Not indicated, n (%)	3 (5)	0
Transport of patients in CA[b] (n = 44)	37 (84)	7 (16)
Indicated, n (%)	24 (55)	5 (11)[a]
Not indicated, n (%)	13 (30)	2 (5)[c]
ECLSR of patients in persistent CA (n = 23)	23 (100)	0
Indicated, n (%)	7 (30)[d]	0
Not indicated, n (%)	16 (70)	0

[a] Situations with potential undertreatment (n = 7).
[b] Patients with no CPR, unknown CPR or prehospital ROSC are excluded (n = 19).
[c] Situations without consequence for the patient (overtreatment) (n = 2).
[d] The patient who sustained a rescue collapse suffered from abdominal and thoracic injuries and died from haemorrhage during ECLSR.

Table 5 – Summary of the main characteristics and outcomes of avalanche victims with cardiac arrest from the four main studies on this topic. Abbreviations: CA, cardiac arrest; CPC, Cerebral Performance Category; CPR, cardiopulmonary resuscitation; ECLSR, extracorporeal life support rewarming; ROSC, return of spontaneous circulation.

	Métrailler et al.	Moroder[10]	Strappazzon[11]	Boué [15],[a]	Overall
On-scene CA n (%)	**66**	**55**	**170**	**48**	**339**
Lethal/frozen	3 (4.5)	6 (11)	28 (17)	–	37 (11)
Partial/not buried	6 (9.1)	9 (16)	–	–	15 (4.4)
Long burial	23 (35)	37 (67)	112 (66)	–	–
First decision					
On-scene CPR, n (%)	54 (82)	23 (42)	75 (44)	48 (100)	**200 (59)**
Declared dead on-scene	31 (47)	38 (69)	134 (79)	–	203 (70)
Prehospital ROSC	7 (11)	10 (18)	6 (3.5)	18 (38)	41 (12)
Second decision					
Transported whilst undergoing CPR, n (%)	28 (42)	7 (13)	30 (18)	30 (63)	**95 (28)**
% long burial	14 (21)	6 (11)	20 (12)[b]	19 (40)	59 (17)
Third decision					
ECLSR for CA, n (%)	7 (11)	3 (5.5)	8 (4.7)	19 (40)	**37 (11)**
Survival					
After prehospital ROSC	0 (0)	5 (9.1)[c]	0 (0)	5 (10)[d]	10 (2.9)
Among ECLSR patients	0 (0)	0 (0)	1 (0.6)[e]	3 (6.3)[f]	4 (1.2)
Overall, n (%)	0 (0)[g]	5 (9.1)	1 (0.6)	8 (17)	**14 (4.1)**[h]
CPC 1-2	0 (0)	2 (3.6)	1 (0.6)	3 (6.3)	6 (1.8)[i]
CPC 3-4	0 (0)	3 (5.5)	0 (0)	5 (10)	8 (2.4)

[a] In Boué[15], only patients transported to hospital are included. In our study and in Moroder[10], patients not or partially buried are also included. In Strapazzon[11] and in Boué[15], only fully buried patients are included.
[b] Include long and unknown duration of burial.
[c] All short burial and ROSC on-site, 2 CPC 1 and 3 CPC 4.
[d] No air pocket, all asystole, 4 short burial (20 min) and 1 long burial (45 min), 1 survivor with CPC 3, 4 with CPC 4.
[e] CPC 1, long burial with rescue collapse, T = 22 °C.
[f] All with air pocket, rescue collapse and then pulseless electrical activity, 2 long burial and 1 unknown duration of burial, all CPC 1.
[g] 95% CI.(0–5.4%).
[h] 95% CI (2.3–6.8%).
[i] 95% CI (0.7–3.8%).

100% in both our study and that of Moroder et al.[10] However, the proportion of ROSC in this subgroup was much lower in our study (32% vs. 100%). This may be due to differences in mean burial duration (22.4 ± 9.7 min for this study vs. 18.3 ± 5.6 min for the nine patients in Moroder et al.) or the rate of immediate bystander CPR.[10] Extrication by companions and the provision of immediate basic life support are especially important in avalanche burial, as survival is dependent on the burial time.[7,8] Among the 23 victims with a long burial duration, 4 (17%) did not benefit from CPR. In one case, the decision to withhold CPR was classified as incorrect. Four patients with long burial time, hypothermia, and patent airways, benefited from CPR on site but were not transported to a hospital with ECLSR capabilities despite an apparent indication. These five cases of potential undertreatment suggest room for improvement. As these cases may include patients with potentially reversible hypothermic CA who could survive with good neurological outcome,[11,15,16] the justifications for declaring an avalanche victim dead on scene after a long burial have to be documented in detail.

For two patients in the present study, trauma was the **reason for declaring a patient dead on scene** and occurred at higher rate in other settings,[10,11] but may be over-diagnosed during clinical examination.[17] Rigor mortis, which was mentioned in one of our patients, or fixed dilated pupils should also not be considered as reliable signs of death in accidental hypothermia.[18,19] Similarly, death should not be assumed only on the basis of a very low core temperature or a very long burial duration,[20] as survival with good neurological outcomes occurs in such situations.[21–23] In case of any doubt, when safely possible, patients should be resuscitated and, in the presence of hypothermia, transported to a hospital where further investigation may be performed and multidisciplinary decision-making done using tools such as the HOPE score.[6,24]

The proportion of **patients transported** is higher in our study than as reported by Moroder[10] and Strapazzon[11]. The combination of clinical characteristics (patient in asystole with a long burial duration and obstructed airway) that justified ceasing resuscitation efforts on site according to the recommendations[7,9] was documented in the medical chart in only one victim in our study, compared to 59 out of 108 (54.6%) patients in Strapazzon et al.[11] This difference may reflect different clinical approaches to assessing airway patency. In our experienced HEMS, the pragmatic definition of a blocked airway requires both the nose and mouth to be sealed with compact snow or debris. This definition may not be shared by all rescuers.

In two of our cases, patients were transported to the hospital with a core temperature $\geq$32 °C. Underlying external conditions may have influenced the decision to transport these patients, such as subjective factors (e.g., young CA victims with relatives present on site) or safety concerns precluding the on-site provision of standard ALS as recommended.[9]

In our study, 28% of patients still in CA at hospital admission underwent **ECLSR** according to the guidelines.[8] Differences in patient characteristics or prehospital triage[7,25] may explain the higher rates reported by others (50% and 63%).[10,15] The HOPE score predicts the probability of survival after ECLSR and helps clinicians decide when to start ECLSR.[6,26] We were able to retrospectively calculate this score for 15 of the 18 CA patients who had not been rewarmed.[6] All but one had HOPE survival probability $\leq$2%, suggesting ECLSR should be withheld.

The duration of complete burial and airway patency were described less frequently in our study than similar studies.[10,11] These other studies used both medical charts and accident reports to determine the burial duration.[10,11] The core temperature was documented in 56% of our patients, and the site of measurement was oesophageal (i.e., as recommended)[7,27] in only 13 of the 23 patients (57%) for whom the measurement site was documented. The cardiac rhythm was also infrequently documented (52%) for the 31 patients declared dead on scene. This is suboptimal, as the triage algorithm applies to victims in asystole. Accurate determination of cardiac rhythm is important, not only for quality control or research, but also for forensic purposes. The dedicated avalanche victim resuscitation checklist[28] was implemented at our HEMS in 2016. This may improve both the documentation of this critical information as well as guideline adherence, together with the presentation of this study to the physicians of our HEMS.

No patient in our study survived. Among 339 avalanche victims with OHCA pooled from the four main studies on this topic[10,11,15] (Table 5), the overall survival was 4.1% (95% CI; 2.3–6.8%) and the rate of survival with good outcome 1.8% (95% CI; 0.7–3.8%). Survivors are either avalanche victims with short burial time and prehospital ROSC[11] or patients with long burial time still in CA at hospital admission and rewarmed with ECLS.[15] These examples and some historical cases[23] suggest that adherence to guidelines could theoretically improve survival.

Limitations

One limitation of this study pertains to the retrospective design. The analysis relied on the quality and extent of information documented in the prehospital and hospital charts. This assessment, however, was one of the study goals. Information missing from the medical charts (e.g., lethal trauma) and external conditions, such as multi-victim accidents,[29] logistic issues, shortage of resources, meteorological conditions, and safety concerns are likely to have influenced management decisions. Therefore, our classification of some decisions as "incorrect" may suffer from classification bias.

Another limitation is based on the avalanche algorithm itself. The algorithm has a simplistic dichotomous structure, which in some situations allows following two opposite branches for the same patient (e.g., patient with short burial duration with core temperature <32 °C). This constitutes a real problem in the field management of such patients. Thus, we decided to prioritise the core temperature, which we assumed to be more physiological and objective, rather than burial duration when deciding the appropriateness of management.

Finally, this analysis focuses on a single HEMS. The number of CA patients per doctor is notably higher than in other settings,[1] and the rescue teams are specifically field trained before every winter season from the practical approach of the avalanche victim to the application of the most recent guidelines. Geographical disparities may exist in avalanche-related morbidity and mortality[30] and, as such, our findings may therefore not reflect practices elsewhere.

Conclusions

The management of avalanche victims in CA seems to be correct in our system, and the overall adherence to international guidelines is good to excellent. The presence of a few cases with incorrect management and potential undertreatment suggests some room for improvement. This study finally confirms the very poor prognosis of patients that suffer from OHCA due to an avalanche accident, as approximately half of the patients were declared dead on scene and none survived after transportation to an ECLSR-capable hospital.

Conflict of interest

None to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.05.037.

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