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Clinical paper

Survival probability in avalanche victims with long burial (≥60 min): A retrospective study

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Abstract

Background: The survival of completely buried victims in an avalanche mainly depends on burial duration. Knowledge is limited about survival probability after 60 min of complete burial.

Aim: We aimed to study the survival probability and prehospital characteristics of avalanche victims with long burial durations.

Methods: We retrospectively included all completely buried avalanche victims with a burial duration of ≥60 min between 1997 and 2018 in Switzerland. Data were extracted from the registry of the Swiss Institute for Snow and Avalanche Research and the prehospital medical records of the physician-staffed helicopter emergency medical services. Avalanche victims buried for ≥24 h or with an unknown survival status were excluded. Survival probability was estimated by using the non-parametric Ayer–Turnbull method and logistic regression. The primary outcome was survival probability.

Results: We identified 140 avalanche victims with a burial duration of ≥60 min, of whom 27 (19%) survived. Survival probability shows a slight decrease with increasing burial duration (23% after 60 min, to <6% after 1400 min, p = 0.13). Burial depth was deeper for those who died (100 cm vs 70 cm, p = 0.008). None of the survivors sustained CA during the prehospital phase.

Conclusions: The overall survival rate of 19% for completely buried avalanche victims with a long burial duration illustrates the importance of continuing rescue efforts. Avalanche victims in CA after long burial duration without obstructed airway, frozen body or obvious lethal trauma should be considered to be in hypothermic CA, with initiation of cardiopulmonary resuscitation and an evaluation for rewarming with extracorporeal life support.

Keywords: Avalanche, Cardiac arrest, ECMO, ECPR, Hypothermia, Accidental, Resuscitation, Triage

Introduction

About 150 people die every year in an avalanche accident in North America and Europe. In Switzerland, more than 200 people are caught in avalanches annually. Approximately 25 of these people die.[1,2] Most avalanche victims who are completely buried are subjected to asphyxia. The survival of a completely buried victim mainly depends on burial duration.[3,4] Based on data from individual victims, Falk et al. reported in 1994 a step-wise decrease of avalanche survival probability with increasing burial duration.[5] The authors hypothesized that traumatic injuries were the main cause of death in the first phase; asphyxia in the second phase; and a combination of hypoxia, hypercapnia and

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hypothermia in the third phase. This was followed by a fourth phase, called the "long-term survival" phase.[5–8] Much is known about the first phases of the survival curve, in which survival probability drops dramatically to 21% after 60 min of full burial, but less is known about the fourth phase, which shows a flattening of the curve at 21% from 60 to 180 min.[4,5] Our aim was to study the prehospital characteristics, management and outcomes of avalanche victims who had undergone a long burial duration (≥60 min).

Methods

Data collection

We screened all avalanche accidents that occurred in Switzerland between October 1, 1997, and September 30, 2018, and involved at least one victim. We defined the winter season as the period between November 1 and May 31.[9] The data were extracted from the Swiss Institute for Snow and Avalanche Research (SLF) registry in Davos, Switzerland. The SLF has collected data on every reported avalanche accident that has occurred in Switzerland since 1936. The registry includes the following information: date and location of avalanche accident, sex and age of victim, type of burial (complete or partial, where complete burial is defined as the burial of at least the head and chest after the avalanche comes to a standstill), burial duration and burial depth, presence of an air pocket (defined as any space surrounding the mouth and nose), airway patency (obstructed airway being defined as both the mouth and the nose obstructed with compact snow or debris), and survival status (alive or dead).[3,10–13] The survival status was attributed at hospital discharge for victims who were transported to a medical facility, or on site for victims not transported.

We included every completely buried victim with a burial duration of ≥60 min who was rescued by one of the two physician-staffed helicopter emergency medical services (HEMS): Rega (13 bases distributed over Switzerland) or Air-Glaciers (Sion and Collombey). We excluded avalanche victims who were buried for ≥24 h, rescued by another HEMS or had an unknown survival status.

We searched the prehospital medical charts for the following information: presence of an avalanche transceiver, presumptive diagnosis, initial core temperature, presence of cardiac arrest (CA), first cardiac rhythm in the case of CA, medical management on site and final hospital destination. We also extracted the eight-level NACA score for each victim. The NACA score is graded by the prehospital emergency physician at the end of every mission and provides an estimation of the severity of the patient's condition.[14]

For avalanche victims with trauma who did not survive, two of the authors (D.E. and M.P.) reviewed the accident descriptions and independently judged the cause of death (asphyxia, trauma or undetermined). In cases of disagreement, the cause of death was considered "undetermined".

Our primary outcome was survival probability. Secondary outcomes included the description of the characteristics and prehospital management of the victims.

The study and data collection were approved by the local Ethics Committee "*Commission cantonale d'Ethique de la Recherche sur l'être humain* – Vaud" (CER-VD), Switzerland (project number 2018-01-01995).

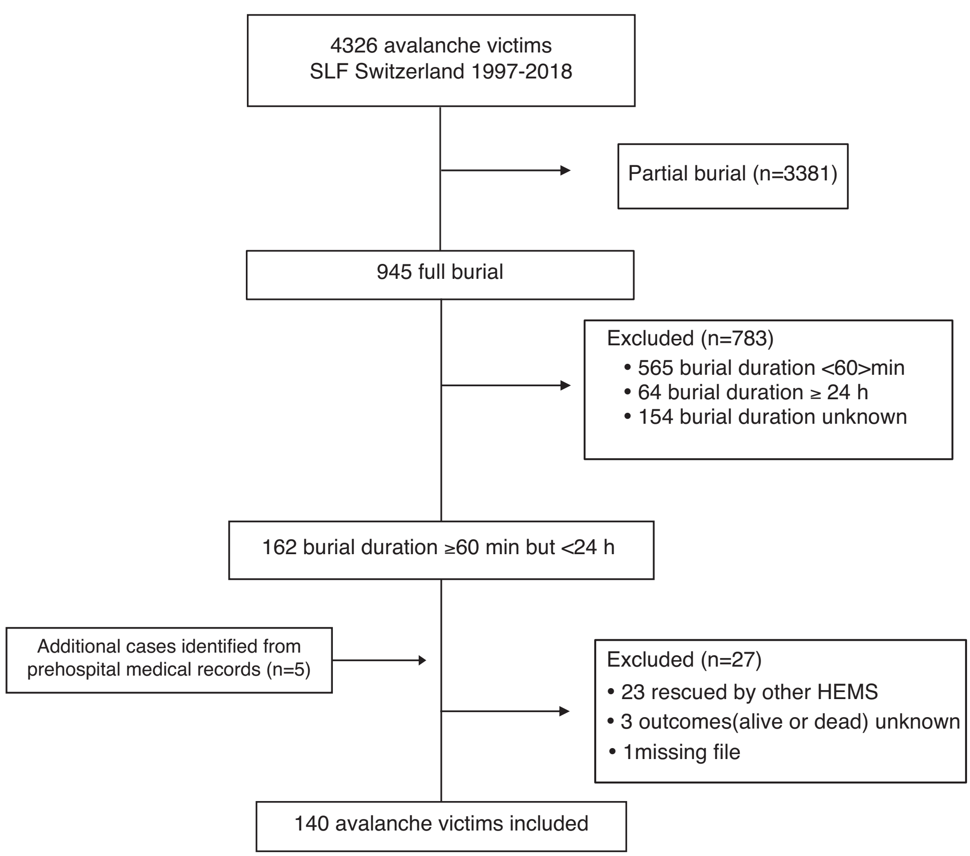

Fig. 1 – Flowchart of patient inclusion. HEMS: helicopter emergency medical service; SLF: Institute for Snow and Avalanche Research, Davos, Switzerland.

Table 1 – Patient characteristics and assessment. Completely buried avalanche victims with a burial time of ≥60 min but <24 h, Switzerland, 1997–2018. IQR: interquartile range; NACA: National Advisory Committee for Aeronautics.

	Total n = 140	Alive n = 27 (19%)	Dead[a] n = 113 (81%)	p Value
Sex, n (%)	n = 138	n = 25	n = 113	
Males	113 (82)	19 (76)	94 (83)	0.40
Age, median (IQR)	n = 138	n = 25	n = 113	
Years	38 (27–49)	44 (34–50)	35 (25–49)	0.10
Activity, n (%)	n = 100	n = 19	n = 81	0.06
Ski touring	35 (35)	4 (21)	31 (38)	
Off-piste skiing	24 (24)	3 (16)	21 (26)	
Hiking	10 (10)	4 (21)	6 (7)	
Other[b]	31 (31)	8 (42)	23 (29)	
Avalanche transceiver, n (%)	n = 65	n = 5	n = 60	
Carried	48 (74)	3 (60)	45 (75)	0.46
Airway patency, n (%)	n = 140	n = 27	n = 113	0.02
Free	20 (14)	8 (29)	12 (11)	
Obstructed	16 (12)	1 (4)	15 (13)	
Not documented but intubated or ventilated	20 (14)	0 (0)	20 (18)	
Not documented, not intubated or ventilated	84 (60)	18 (67)	66 (58)	
Air pocket, n (%)	n = 65	n = 17	n = 48	
Present	39 (60)	17 (100)	22 (46)	<0.001
Median prehospital core temperature, °C (IQR)	n = 22	n = 4	n = 18	
	27.8 (23.0–32.0)	33.7 (28.2–34.6)	27.1 (18.0–30.8)	0.09
Main diagnosis[c], n (%)	n = 84	n = 17	n = 67	<0.001
Asphyxia	41 (49)	0 (0)	41 (62)	
Hypothermia	25 (30)	16 (94)	9 (13)	
Trauma	10 (12)	1 (6)	9 (13)	
Other/unknown	8 (9)	0 (0)	8 (12)	
Cardiac arrest[d], n (%)	n = 133		n = 133	
Present	106 (80)	0 (0)	106 (100)	<0.001
Cardiac arrest rhythm, n (%)	n = 23		n = 23	<0.001
Asystole	21(91)	0 (0)	21 (91)	
Pulseless electrical activity	1 (4.5)	0 (0)	1 (4.5)	
Ventricular fibrillation	1 (4.5)	0 (0)	1 (4.5)	
NACA score, n (%)	n = 100	n = 19	n = 81	<0.001
3	4 (4)	4 (21)	0 (0)	
4	8 (8)	8 (42)	0 (0)	
5	7 (7)	7 (37)	0 (0)	
6	17 (17)	0 (0)	17 (21)	
7	64 (64)	0 (0)	64 (79)	

[a] Nine of the 113 dead victims were described as having a completely frozen body.
[b] Skiing, snowboarding, off-piste snowboarding, alpinism.
[c] A victim can have multiple injuries. Only the main diagnosis is reported.
[d] In 7 patients with missing data for cardiac arrest, five were described as "in critical condition" on site, and declared dead later at hospital.

Statistical analysis

We entered the data into an Excel spreadsheet (Microsoft, Redmond, WA, USA) and exported the data to Stata version 13 (Stata Corporation, College Station, TX, USA) and R version 3.3.3. (R Foundation for Statistical Computing, Vienna, Austria). We present continuous data as means and SD when normally distributed or medians and interquartile ranges (IQRs) when not normally distributed. We report categorical data as numbers and percentages. We used Student's t-test to compare continuous and normally distributed data, and the Mann–Whitney two-sample statistic for continuous and non-normally distributed data. We used Pearson's chi-squared test and Fisher's exact test for categorical variables. We defined a two-tailed p-value of <0.05 as statistically significant. We investigated the relationship between survival probability and burial duration non-parametrically using the maximum likelihood non-parametric estimation procedure for doubly censored data (Ayer–Turnbull method) and parametrically via logistic regression.[15,16]

Results

Of the 4326 victims involved in avalanche accidents in Switzerland during the study period, 945 (22%) were completely buried. Of these, 140 with a burial time of ≥60 min but <24 h met the inclusion criteria (Fig. 1). Most avalanches involving these 140 victims (139/140, 99%) occurred during the winter season. The median altitude was 2250 m (IQR 1900–2430). The characteristics of the victims and their diagnoses are presented in Table 1. The majority were male (n = 113, 82%). The median age was 38 years (IQR 27–49). The main activities were ski touring (n = 35, 35%) and off-piste skiing (n = 24, 24%). Forty-eight (74%) of the 65 patients for whom this information was available carried an avalanche transceiver.

The median burial depth was 100 cm (IQR 50–160; range 5–500) and was significantly deeper for the patients who did not survived (100 cm; IQR 65–170) compared to those who survived (70 cm; IQR 50–100) (p = 0.008) (Fig. 2).

Twenty-seven (19%) of the 140 patients survived. Survival probability as a function of burial duration, estimated with the non-parametric method and with logistic regression analysis, is shown in Fig. 3. While the non-parametric fit did not assume any particular form of the relation (other than monotonically decreasing) and resulted in a step function, the logistic fit provided a smooth, gradually decreasing function, the estimated survival probability dropping from 23% after 60 min of burial duration, to less than 6% after 1400 min. The odds ratio of the decrease was 0.93 per hour (95% CI: 0.85–1.02), meaning that the odds of being alive is multiplied by 0.93 for each additional buried hour. This decrease is not statistically significant (p = 0.13). Among the survivors, the two longest burial duration were 10 h and 17 h.

Medical management and hospital destinations are presented in Table 2. None of the patients with CA on site survived. Among the non-survivors with trauma (n = 20), death was attributed to the trauma in nine cases (45%), to asphyxia in six cases (30%) and remained undetermined in five cases (25%). The most frequently reported trauma diagnosis was traumatic brain injury (n = 20, 62 %) (Appendix 1). Among the victims in CA who did not benefit from CPR and were not transported to hospital facilities, the reasons were not documented in 31 of 55 (56%) cases. When documented, the reasons to consider not starting CPR were a frozen body (n = 9), obstructed airways (n = 8) or lethal trauma (n = 7). Among the nine victims with confirmed severe hypothermia and CA, eight received cardiopulmonary resuscitation (CPR) and were transported to an extracorporeal life support centre (ECLS).

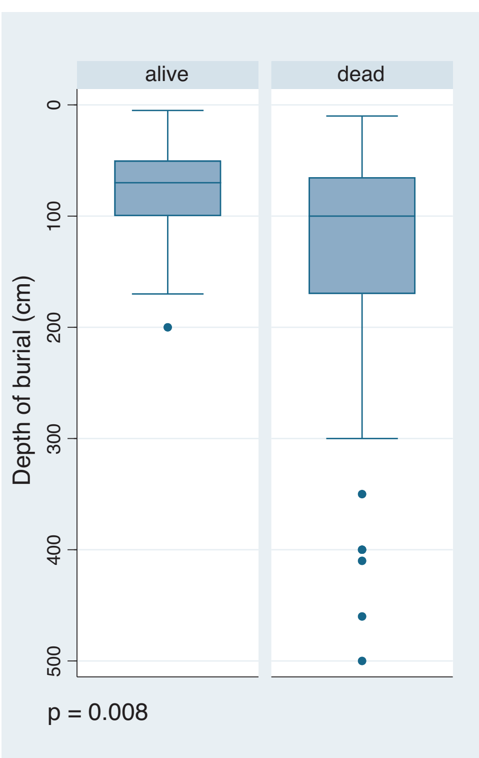

Fig. 2 – Survival and depth of burial of completely buried avalanche victims with a burial time of ≥60 min but <24 h, Switzerland, 1997–2018.

The individual characteristics of the survivors are presented in Table 3. The median NACA score was 4 (IQR 4–5). All survivors except one had patent airways. An air pocket was reported in all cases of survival for which this information was available (n = 17). The main diagnosis among the survivors was hypothermia (n = 16, 94%), followed by trauma (n = 1, 6%) (Table 1).

Discussion

Survival probability

This study focused on survival probability of completely buried avalanche victims with a long burial (≥60 min but <24 h). Based on the estimation of the avalanche survival probability curves described in 1994 and then updated, the survival probabilities of fully buried avalanche victims fall to about 21% at 60 min. This is followed by a plateau, with the curve remaining at about 21% between 60 and 180 min.[4–6,8] The important survival rate of 19%, with two survivors with exceptional burial duration of 10 and 17 h, highlights the importance of pursuing search and rescue efforts, even in prolonged burials.

The survival probability curves estimated with the non-parametric method and with logistic regression analysis were similar, indicating that the parametric fit (logistic regression) was a convenient approximation. While the use of the non-parametric Ayer–Turnbull method necessarily results in a step decreasing function of the estimated survival probability with an increasing burial duration, a logistic regression model provides with a smooth function and an explicit formula to estimate survival probability in function of burial duration. With the logistic regression model, the survival probability dropped from 23% at 60 min to ≤6% after 1400 min. Although this decrease was not statistically significant, this suggests that survival probability continues to decrease after 60 min of complete burial, but at a much slower rate than in the first hour of burial. Because of possible duplication of cases, we did not compare the survival curves we obtained with previously published curves that included Swiss data.[4] Avalanche victims with a burial >24 h were excluded, these cases still being most often managed in a “body recovery mission” approach in our setting, rather by traditional rescue teams. Similar studies focusing on the management of avalanche victims excluded burial durations ≥24 h.[17,18]

The survival rate of patients in CA caused by accidental hypothermia (secondary to exposure, immersion, submersion and avalanche) who were rewarmed with ECLS was 37% in a recent study.[19] In that study, the subgroup of avalanche victims had a lower survival rate (12%). The authors attributed the lower survival rate to asphyxia. A study of 339 avalanche victims in CA after burial duration of 7–1035 min found a survival rate of 4.1%.[17] The survivors had either short burial durations or prehospital return of spontaneous circulation. The fact that none of the patients in our study who had CA survived supports the hypothesis that avalanche victims with CA after a long burial have poor prognoses. However, in some cases, undertreatment may have led to a poor outcomes.[17,20]

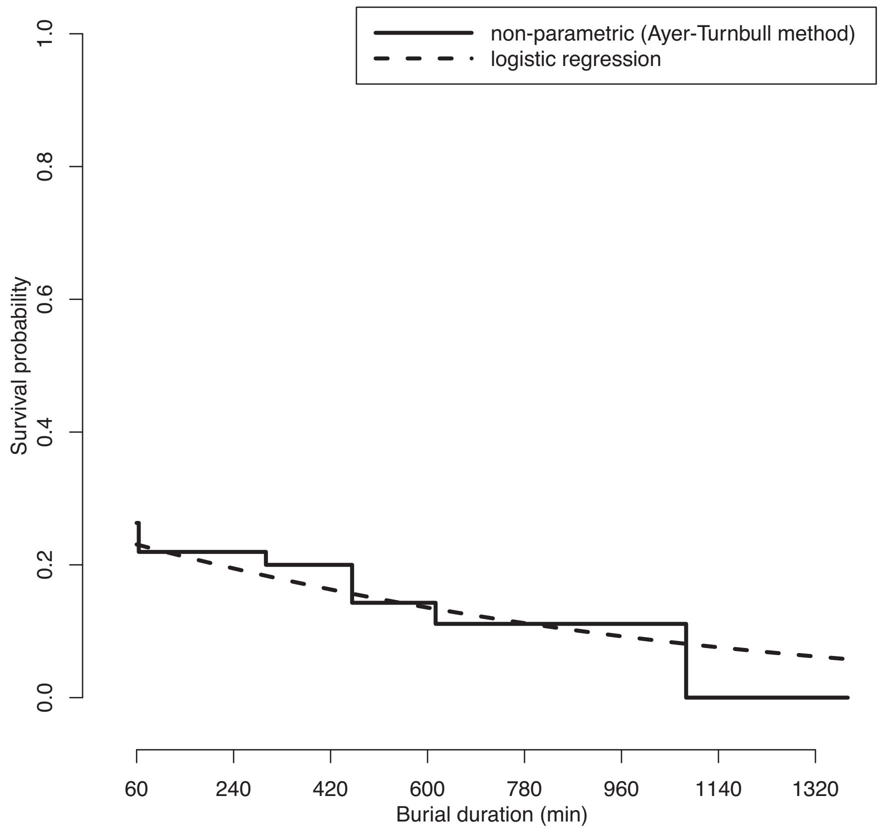

Fig. 3 – Survival probability as a function of burial duration of completely buried avalanche victims with a burial time of ≥60 min but <24 h, Switzerland, 1997–2018, estimated using either a non-parametric method or via logistic regression.

Table 2 – Medical management, including destination hospitals of completely buried avalanche victims with a burial time of ≥60 min but <24 h, Switzerland, 1997-2018. CPR: cardiopulmonary resuscitation; ECLS: extracorporeal life support.

	Total n = 140	Alive n = 27 (19.3%)	Dead n = 113 (81%)	p Value
CPR provided, n (%)	n = 103	n = 19	n = 84	
	39 (38)	0 (0)	39 (46)	<0.001
Intubation, n (%)	n = 98	n = 19	n = 79	
	30 (21)	0 (0)	30 (38)	0.001
Defibrillation, n (%)	n = 97	n = 19	n = 78	
	2 (2)	0 (0)	2 (3)	0.48
Adrenaline (Epinephrine), n (%)	n = 60	n = 12	n = 48	
	12 (20)	0 (0)	12 (25)	0.053
External rewarming, n (%)	n = 97	n = 19	n = 78	
	10 (10)	8 (42)	2 (3)	<0.001
Hospital destination, n (%)	n = 101	n = 19	n = 82	<0.001
No transport	6 (6)	0 (0)	6 (7)	
Non-medical facilities	37 (36)	0 (0)	37 (45)	
Medical practice	1 (1)	0 (0)	1 (1)	
Non-ECLS non-trauma centre	21 (21)	6 (32)	15 (18)	
Non-ECLS trauma centre	7 (7)	5 (26)	2 (3)	
ECLS trauma centre	29 (29)	8 (42)	21 (26)	

CA management

Among the victims with CA and patent airways, confirmed or suspected hypothermia was the main diagnosis. One of the victims was declared dead on scene and only half were transported to hospitals with ECLS facilities. It is challenging to distinguish between a hypothermic patient in CA who would benefit from ECLS rewarming and a cold and dead patient. Although the terms “rigor mortis” or “fixed dilated pupils” were mentioned in one patient, they should not be considered as reliable signs of death in accidental hypothermia.[21]

Table 3 – Detailed characteristics of 27 completely buried avalanche victims with a burial time of ≥60 min but <24 h who survived, Switzerland, 1997–2018.

Activity	Burial time (min)	Burial depth (cm)	Avalanche transceiver	Patent airway	Air pocket	GCS	Trauma	Medical diagnosis	Destination
NA	90	60	NA	NA	NA	NA	NA	NA	NA
NA	90	100	NA	NA	NA	NA	NA	NA	NA
NA	90	100	NA	NA	NA	NA	NA	NA	NA
NA	90	100	NA	NA	NA	NA	NA	NA	NA
NA	61	50	NA	NA	NA	NA	NA	NA	NA
NA	135	50	NA	NA	Yes	NA	NA	NA	NA
Skiing	200	5	NA	Yes	Yes	6	Yes (hip, legs)	Suspected hypothermia	Non-ECLS non-trauma
Alpinism	210	20	NA	NA	Yes	15	Yes (arm)	Suspected hypothermia	Non-ECLS non-trauma
Ski touring	90	20	NA	NA	Yes	15	No	Suspected hypothermia	Non-ECLS trauma centre
Ski touring	125	60	NA	NA	Yes	4	No	Suspected hypothermia	Non-ECLS trauma centre
NA	140	30	NA	NA	Yes	NA	NA	Confirmed hypothermia (30.2°)	NA
NA	180	100	NA	NA	Yes	NA	NA	(37.2 °C)	NA
Hiking	265	100	NA	NA	Yes	11	Yes (contusion)	Suspected hypothermia	ECLS and trauma centre
Skiing	215	160	NA	NA	Yes	9	No	Suspected hypothermia	ECLS and trauma centre
Off-piste skiing	600	150	NA	NA	Yes	15	Yes (pelvis)	Suspected hypothermia	ECLS and trauma centre
Off-piste skiing	60	NA	NA	Yes	NA	14	No	Suspected hypothermia	Non-ECLS non-trauma
Skiing	60	200				7	Yes (head)	Suspected hypothermia	ECLS and trauma centre
Off-piste skiing[a]	1020	20	No	Yes	Yes	15	No	Confirmed hypothermia (34 °C)	ECLS and trauma centre
Ski touring	450	50	No	Yes	Yes	7	No	Confirmed hypothermia (23 °C)	Non-ECLS non-trauma
Skiing	60	15	NA	No[b]	Yes	9	Yes (head)	Suspected hypothermia	Non-ECLS trauma centre
Off-piste snowboarding	420	50	Yes	Yes	Yes	15	Yes (head)	Confirmed hypothermia (33.5 °C)	Non-ECLS non-trauma
Hiking	60	70	NA	NA	NA	7	Yes (spine)	Suspected hypothermia	ECLS and trauma centre
Hiking	90	70	NA	NA	NA	15	Yes (contusion)	Suspected hypothermia	ECLS and trauma centre
Hiking	90	120	NA	NA	NA	15	Yes (contusion)	Suspected hypothermia	Non-ECLS non-trauma
Off-piste snowboarding	78	170	No	Yes	Yes	11	No	Suspected hypothermia	Non-ECLS trauma centre
Ski touring	150	80	Yes	Yes	Yes	15	No	Suspected hypothermia	Non-ECLS trauma centre
Other	180	150	Yes	Yes	Yes	15	No	Suspected hypothermia	ECLS and trauma centre

GCS: Glasgow Coma Scale, ECLS: extracorporeal life support. NA: not available.

[a] Case classified as a complete burial by the SLF, although a small upper part of the helmet was visible at the snow surface during rescue (head not completely buried under the snow) allowing the victim to breathe fresh air during burial.

[b] An error in understanding of the term "patent airway" by the emergency physician is suspected in this case, in which nasal oxygen therapy was administered during transport.

Although survival probability for avalanche victims in CA is low, full recovery after resuscitation and ECLS rewarming has been observed in victims with long burial and severe hypothermia.[19,17,22–25] In our study, none of the survivors sustained CA. We suspect that hypothermia may not have always been recognized as one of the possible causes of CA, and therefore that some patients may have been undertreated.[17] The management of avalanche victims with possible hypothermic CA consists in CPR, transport to hospital and ECLS rewarming when indicated. Optimal management of such patients with CPR and transport to an ECLS centre may be critical, as undertreatment (absence of ECLS rewarming) of the victims with possible reversible hypothermic CA may lead to avoidable deaths.

CA is unlikely to be caused by hypothermia if core temperature is >30 °C.[26] Hypothermia is mostly mild (35–32 °C) to moderate (<32–28 °C) among survivors and tends to be more severe (<28 °C) in non-survivors. Most deaths of avalanche victims who are completely buried for ≥60 min are attributed to asphyxia, with secondary cooling of the body occurring after CA. Nevertheless, hypothermic CA should be suspected in an avalanche victim with patent airways, whose body is not completely frozen and who has no obvious lethal trauma, including decapitation or transection of the trunk.[27]

If CA is confirmed in a victim without obvious lethal trauma or a frozen body but with a burial duration of ≥60 min, continuous or intermittent CPR should be started.[28] In 56% of cases the CPR was not started because the body was frozen, the airway was obstructed or there was lethal trauma.

Description of the survivors

The burial depth was significantly and inversely related to survival. It is unclear whether burial depth is an independent factor for survival in fully buried avalanche victims, or is instead linked to burial duration. It usually takes longer to extricate a deeply buried victim than a victim who is more shallowly buried. Existing evidence that a shallow burial depth is an independent factor in favour of survival is weak and contradictory.[4,8]

An avalanche victim with complete burial for ≥60 min cannot survive without a patent airway. The presence of an air pocket is a positive prognostic factor for survival of victims buried for ≥15 min.[6,22,29] In our study, victims with an air pocket had a significantly higher survival rate. Although the presence of an air pocket might be a positive survival marker, assessing for an air pocket during extrication of the victim is challenging, limiting clinical use.

Practical implications for avalanche rescue

A careful assessment of the victim, including the evaluation of airway patency with examination of the nose and the mouth, and the detection of vital signs (including, if available, an early ECG monitoring) should be performed before extrication for recognition of hypothermic CA.[30] If lethal trauma is excluded and the airway is patent, an avalanche victim with a long burial who is in CA may have a good outcome if rescuers recognise accidental hypothermia as a possible cause of the CA and treat the patient accordingly. A dedicated checklist (Avalanche Victim Resuscitation Checklist) has been developed by the International Commission for Mountain Emergency Medicine (ICAR MEDCOM) to help identify avalanche victims in hypothermic CA, to guide rescuers, and to increase adherence to life-saving algorithms.[31,32]

Limitations

The study was retrospective with a potential information bias caused by missing data and only a brief description of some of the rescues. Misclassifications related to the main diagnosis, cause of death and management of the avalanche victims cannot be excluded. We did not have access to hospital or post-mortem data. The data were collected from a period of 20 years, a time during which international guidelines for management and resuscitation of avalanche victims evolved. Finally, rescue missions can also be influenced by the circumstances, including safety concerns, weather conditions and logistics.

Conclusions

The overall survival probability in fully buried avalanche victims for more than 60 min is 19%. This illustrates the importance of continuing search and rescue efforts in completely buried avalanche victims. It is critical to find and to treat victims of long burial. Among the avalanche survivors in this study, none was in CA on site. This suggests the potential for improvement in detecting the avalanche victims who sustain a long burial with CA from hypothermia. An avalanche victim in CA after a long burial (≥60 min) with a patent airway, whose body is not completely frozen and who does not have obvious lethal trauma should be considered to be in hypothermic CA. Cardiopulmonary resuscitation should be started and the victim should be transported to a hospital capable of providing ECLS.

Conflicts of interest

None.

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Emergency Department, Lausanne University Hospital.

CRediT authorship contribution statement

David Eidenbenz: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft. **Frank Techel:** Data curation, Writing - review & editing. **Alexandre Kottmann:** Data curation, Writing - review & editing. **Valentin Rousson:** Formal analysis, Writing - review & editing. **Pierre-Nicolas Carron:** Writing - review & editing. **Roland Albrecht:** Data curation, Writing - review & editing. **Mathieu Pasquier:** Supervision, Conceptualization, Methodology, Writing - original draft.

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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.2021.05.030.

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