Available online at www.sciencedirect.com

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

EUROPEAN RESUSCITATION COUNCIL

Clinical paper

Cut-off values of serum potassium and core temperature at hospital admission for extracorporeal rewarming of avalanche victims in cardiac arrest: A retrospective multi-centre study

Hermann Brugger [a,b,c,*], **Pierre Bouzat** [d], **Mathieu Pasquier** [c,e], **Peter Mair** [f], **Julia Fieler** [c,g,h], **Tomasz Darocha** [i], **Marc Blancher** [c,j,k], **Matthieu de Riedmatten** [l], **Markus Falk** [a], **Peter Paal** [c,m], **Giacomo Strapazzon** [a,c], **Ken Zafren** [c,n], **Monika Brodmann Maeder** [a,o]

[a] Institute of Mountain Emergency Medicine, EURAC research, Drususallee 1, 39100 Bolzano, Italy
[b] Medical University Innsbruck, Austria
[c] International Commission for Mountain Emergency Medicine ICAR MEDCOM
[d] Department of Anaesthesiology and Critical Care, Grenoble Alps Trauma Center, University Hospital of Grenoble- Alpes, 38043 Grenoble Cedex 09, France
[e] Emergency Service, Lausanne University Hospital Center, BH 09, CHUV, CH-1011 Lausanne, Switzerland
[f] Department of Anaesthesiology and Critical Care Medicine, Medical University Innsbruck, Anichstraße 35, 6020 Innsbruck, Austria
[g] Division of Surgical Medicine and Intensive Care, University hospital of North Norway, Tromsø, Norway
[h] Anaesthesia and critical care research group, The Artic University of Norway, 9037 Tromsø, Norway
[i] Department of Anaesthesiology and Intensive Care, Medical University of Silesia, Medykow 14, 40-752 Katowice, Poland
[j] Department of Emergency Medicine, University Hospital of Grenoble-Alpes, France
[k] French Mountain Rescue Association ANMSM, 38043 Grenoble Cedex 09, France
[l] Department of Emergency Medicine, Sion Hospital, Sion, Switzerland
[m] Department of Anaesthesiology and Intensive Care, Hospitallers Brothers Hospital, Paracelsus Medical University, Kajetanerplatz 1, 5020 Salzburg, Austria
[n] Department of Emergency Medicine, Stanford University School of Medicine, Stanford, California, USA
[o] Department of Emergency Medicine, Inselspital, Bern University Hospital, University of Bern, Freiburgstrasse 16C, 3010 Bern, Switzerland

* Corresponding author at: Institute of Mountain Emergency Medicine, EURAC research, Viale Druso 1, 39100 Bolzano, Italy.
E-mail addresses: hermann.brugger@eurac.edu (H. Brugger), PBouzat@chu-grenoble.fr (P. Bouzat), Mathieu.Pasquier@chuv.ch (M. Pasquier), p.mair@tirol-kliniken.at (P. Mair), juliafieler@gmail.com (J. Fieler), tomekdarocha@wp.pl (T. Darocha), MBlancher@chu-grenoble.fr (M. Blancher), matderied@yahoo.fr (M. de Riedmatten), falk@e-science.eu (M. Falk), peter.paal@icloud.com (P. Paal), giacomo.strapazzon@eurac.edu (G. Strapazzon), zafren@stanford.edu (K. Zafren), monika.brodmann@eurac.edu (M. Brodmann Maeder).

https://doi.org/10.1016/j.resuscitation.2019.04.025
Received 4 October 2018; Received in revised form 19 March 2019; Accepted 8 April 2019

Abstract

Aim: Evidence of existing guidelines for the on-site triage of avalanche victims is limited and adherence suboptimal. This study attempted to find reliable cut-off values for the identification of hypothermic avalanche victims with reversible out-of-hospital cardiac arrest (OHCA) at hospital admission. This may enable hospitals to allocate extracorporeal life support (ECLS) resources more appropriately while increasing the proportion of survivors among rewarmed victims.

Methods: All avalanche victims with OHCA admitted to seven centres in Europe capable of ECLS from 1995 to 2016 were included. Optimal cut-off values, for parameters identified by logistic regression, were determined by means of bootstrapping and exact binomial distribution and served to calculate sensitivity, rate of overtriage, positive and negative predictive values, and receiver operating curves.

Results: In total, 103 avalanche victims with OHCA were included. Of the 103 patients 61 (58%) were rewarmed by ECLS. Six (10%) of the rewarmed patients survived whilst 55 (90%) died. We obtained optimal cut-off values of 7 mmol/L for serum potassium and 30 °C for core temperature.

Conclusion: For in-hospital triage of avalanche victims admitted with OHCA, serum potassium accurately predicts survival. The combination of the cut-offs 7 mmol/L for serum potassium and 30 °C for core temperature achieved the lowest overtriage rate (47%) and the highest positive predictive value (19%), with a sensitivity of 100% for survivors. The presence of vital signs at extrication is strongly associated with survival. For further optimisation of in-hospital triage, larger datasets are needed to include additional parameters.

Keywords: Avalanche, Out-of-hospital cardiac arrest, Extracorporeal life support, Hypothermia, Serum potassium

Introduction

Between 1983 and 2015 about 165 avalanche deaths were recorded per year in Europe and in North-America.[1] Survival analyses suggest that most completely buried avalanche victims die by asphyxiation between 15 and 35 min after burial.[2,3] Special search strategies, electronic devices,[4] and shovelling techniques, may enable uninjured companions to extricate victims before asphyxia becomes irreversible. These measures, used immediately after an avalanche, are more effective than efforts by organised rescue teams.[5] Avalanche victims who are found in cardiac arrest during the early burial phase and who receive cardiopulmonary resuscitation are at risk of permanent neurological damage.[6]

Unlike asphyxia, hypothermia develops after long burial if the completely buried avalanche victim is able to breathe.[2,7] When hypoxia has not preceded hypothermia, patients presenting with vital signs should be rewarmed with minimally invasive methods[8,9] and patients in cardiac arrest with extracorporeal life support (ECLS).[10] These avalanche victims may recover without neurological sequelae.[11]

When avalanche victims present with cardiac arrest at hospital admission, it is difficult to determine the cause of cardiac arrest. Most of them are already dead from asphyxia, but a few avalanche victims may survive without neurological damage if rewarmed properly. Clinical and laboratory parameters can help to identify those victims at hospital admission who may benefit from ECLS rewarming.

Duration of burial, patency of the airway, core temperature at the time of extrication and serum potassium at hospital admission have been identified as prognostic markers for survival.[12–14] Recommendations for on-site triage of avalanche victims with out-of-hospital cardiac arrest (OHCA) have been developed since 1996 to help determine whether cardiac arrest in an avalanche victim is due to asphyxia or to hypothermia.[1,2,7,15–17]

Until 2015, a cut-off value of 12 mmol/L for serum potassium and core temperature of 32 °C were recommended by both the European Resuscitation Council (ERC) and American Heart Association (AHA). The most recent algorithm for the pre-hospital management of avalanche victims was proposed in 2015 by the ERC with a cut-off level 8 mmol/L for serum potassium and 30 °C for core temperature at extrication.[7] However, all recommendations were based on expert consensus and case series with, admittedly, low levels of evidence and have not previously been validated using a large dataset.

The aim of this study was to identify optimal cut-off values of serum potassium and core temperature for in-hospital triage of arrested avalanche victims by using collected data from hospitals that are capable of ECLS. We hypothesised that it would be possible to establish optimal cut-off values with a maximum rate of 5% undertriage (in need of treatment, but not treated) and 50% overtriage (no treatment indicated, but treated).[18] This may improve the ability to identify hypothermic avalanche victims with reversible OHCA, enabling hospitals to allocate ECLS resources more appropriately while increasing survival rates.

Methods

This was a retrospective multi-centre study. First we performed a literature search and inquiry among all 34 member countries of the International Commission of Mountain Emergency Medicine (ICAR MEDCOM) to identify hospitals that are capable of ECLS and have admitted avalanche victims with OHCA. These centres were invited and agreed to participate in the study.

Data

We included all avalanche victims with OHCA, independent of rewarming, who were admitted to the following hospitals capable of ECLS, from January 1, 1995 to December 31, 2016 (21 years): Bern (Switzerland), Grenoble (France), Innsbruck (Austria), Krakow (Poland), Tromsø (Norway), Lausanne and Sion (Switzerland). We excluded avalanche victims who were not in cardiac arrest at hospital admission. Approval by local institutional review boards was provided by the participating hospitals. No informed consent was required. Data collection followed the Utstein Style for studies of patients with OHCA.[19] All data were collected at the participating hospitals, transmitted to, stored and analysed at the coordinating entity EURAC research.

Out-of-hospital and in-hospital patient data were collected and analysed anonymously. No identifying elements remained which could serve to identify patients, in accordance with the Data Protection Directive of the European Union Agency for Fundamental Rights and the Council of Europe together with the Registry of the European Court of Human Rights.[20]

The following out-of-hospital data were collected: age and sex; duration of complete burial; airway status at extrication; air pocket (any space surrounding the mouth and nose, no matter how small, with a patent airway at extrication[15]); presence of vital signs at extrication; first cardiac rhythm; core temperature (°C) and method of measurement at the time of extrication; cardiopulmonary resuscitation (CPR) during transport; time from extrication to hospital admission. The following in-hospital data were collected: first recorded cardiac rhythm at admission; first recorded core temperature and method of measurement on admission; first recorded serum potassium at admission (mmol/L); injury severity score; rewarming method; pH; outcome at hospital discharge (dead, alive); if alive, neurological outcome (cerebral performance category (CPC), defining CPC 1–2 as good neurological outcome) at hospital discharge.

Statistical analysis

To assess possible cut-off values for hospital triage we used the following definitions (see Table 1): overtriage rate (underestimation of the severity) is defined as the false positive rate (1-specificity) including those that would not benefit from treatment; undertriage rate (overestimation of severity) is defined as the false negative rate (1-sensitivity) excluding those that require treatment. Maximum acceptable values for over- and undertriage rates were set to 50% and 5% respectively.[21] A sample size of 100 victims was needed to confirm at least one predictor in logistic regression for hospital triage, assuming 10% survivors, with alpha = 5% and 80% power. As this rule is rather conservative[22] one can expect that the most relevant predictors could be identified with the envisaged sample size. To identify parameters that contribute independently to survival and using only cases in which the patient was rewarmed, we performed a stepwise logistic regression on survival with respect to sex, age, duration of burial, core temperature, serum potassium and pH. For serum potassium and core temperature we visually assessed ability to discriminate by means of receiver operating curve (ROC) analysis. Due to the low number of survivors, standard methods cannot be used and respective cut-offs were assessed by means of non-parametric methods. Specifically, in using the observed maximum value in survivors, the percentage of the respective percentile in the overall sample (rewarmed and not rewarmed cases) was obtained and scaled up by a factor of 1.4. For this percentile the upper limit of the 95% confidence interval, calculated by means of bootstrapping and exact binomial distribution, was used as the cut-off value. A description of the method and a sensitivity analysis can be found in Data in Brief.[23]

Table 1 – Treatment decision according to cut-off value.

Cut-off	Treatment needed (survivors)	No treatment needed (nonsurvivors)
Below or equal cut-off-> treat	Correctly treated (true positive = sensitivity)	Overtriage (false positive = 1-specificity)
Above cut-off-> do not treat	Undertriage (false negative)	Correctly not treated (true negative)

Using this method, we established safe cut-off values for serum potassium and core temperature and calculated sensitivity, overtriage rate and predictive values using, firstly, only rewarmed cases, which correspond to the triage setting but may overestimate effects due to a possible preselection of cases, and secondly, using all cases, reflecting the worst possible scenario.

For logistic regression only, missing parameter values were replaced by their respective overall means. Otherwise, a case with only one missing value in one parameter would have been eliminated from analysis. For frequencies, binomial confidence intervals were estimated by means of the Jeffreys method[24] and comparisons between groups were performed by means of the Chi-Square-test or Fisher's exact test, as appropriate. For continuous data, and due to the non-normality distribution of some parameters, differences between groups were assessed by means of the Mann-Whitney-U test or the Kruskal-Wallis test. All p-values were two-sided. P-values below 0.05 were considered to be statistically significantly. SPSS 21 was used for statistical calculations and Matlab 2016 for Monte Carlo simulations.

Results

From January 1, 1995 to December 31, 2016 a total of 106 avalanche victims with OHCA were admitted to the participating centres (Fig. 1). Three patients were excluded (two nonsurvivors with missing potassium and core temperature values and one survivor who was hit by an avalanche while sitting in a snow plow that was swept into water). Of the remaining 103 cases, 61 (59%) were rewarmed, whilst 42 (41%) were not rewarmed, mostly due to having a serum potassium or a core temperature above the actual cut-offs of 8 mmol/L and 30 °C (n = 28, 67%).

Sex, age and values of out-of-hospital variables are shown in Table 2. The values of variables at hospital admission and rewarming methods are shown in Table 3. The respective values and neurological outcome of survivors are shown in Table 4. The mean age of the six survivors was 31 years (range 17–41). The median duration of burial for survivors was 120 min (range 45–420). Mean core temperature at hospital admission was 22.5 °C (range 16.9–27.8). The mean serum potassium was 3.6 mmol/L (range 2.7–4.8). The mean pH was 6.91 (range 6.48–7.26). In univariate analysis the parameters duration of burial ($p < 0.001$), core temperature ($p = 0.002$), serum potassium ($p = 0.004$) and pH ($p = 0.015$) were statistically, significantly related to survival, whilst sex ($p = 0.449$) and age ($p = 0.637$) were not. In multivariate analysis logistic regression confirmed core temperature ($p = 0.02$) as well as serum potassium ($p = 0.03$) but not duration of burial ($p = 0.481$) or pH ($p = 0.949$).

The observed maximum value for core temperature in survivors was 27.8 °C, corresponding to the 58th percentile of all observations. This would imply an overtriage rate above 50%, so the starting percentile for the cut-off calculation was set to the 50th percentile (scaled up by a factor of 1.4 to the 70th percentile), and 30 °C was calculated to be the cut-off value for core temperature (29.9 °C by bootstrapping and 29.8 °C by the binomial method). For serum potassium the observed maximum value in survivors was 4.8 mmol/L, corresponding to the 19th percentile (scaled up to the 26.6th percentile). The calculated cut-off value was 7 mmol/L (6.7 mmol/L by bootstrapping and 6.5 mmol/L by the binomial method). Sensitivity, overtriage rate and positive and negative predictive values are shown

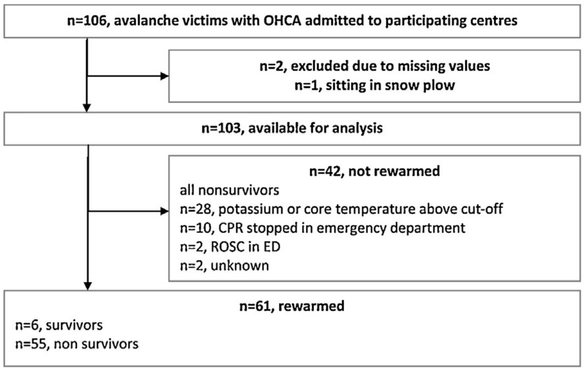

Fig. 1 – Flow chart of study.

in Table 5. Because cut-off values were chosen conservatively for safety, an undertriage rate of 0% (sensitivity of 100% for survivors) was achieved for each variable. When using only rewarmed cases, the use of 8 mmol/L as cut-off for serum potassium and 30 °C for core temperature resulted in an overtriage rate of 64% (95% CI 50%–75%), negative predictive value (NPV) of 100% (95% CI 88%–100%) and positive predictive value (PPV) of 15% (95% CI 6%–28%). The upper limit of the overtriage rate is 75%, which is sub-optimal. Using cut-offs of 7 mmol/L and 30 °C resulted in an overtriage rate of 47% (95% CI 35%–60%), NPV of 100% (95% CI 92%–100%) and PPV of 19% (95% CI 8%–35%). This improves PPV by 4% (absolute difference), indicating that at least 8% of rewarmed cases will survive with an overtriage rate of 60% with the possibility that up to 8% of patients who were not rewarmed may have been survivors. In comparison, 9 cases (22%) triaged to rewarming with cut-offs 8 mmol/L and 30 °C will not be rewarmed when using 7 mmol/L and 30 °C (McNemar Test, $p = 0.004$) and when using all cases PPV is slightly lower ranging from 7% to 35%.

Fig. 2 shows the serum potassium and core temperature of each patient; survivors are highlighted. Fig. 3 shows the ROC curves for serum potassium and core temperature with the optimal cut-off values. Serum potassium is the strongest predictor, but for safety reasons the cut-off value was estimated conservatively.

Table 2 – Sex, age, duration of burial, airway status, presence or absence of an air pocket, presence or absence of vital signs at extrication, first out-of-hospital cardiac rhythm and duration of CPR.

Parameter	Rewarmed			Not rewarmed
	Survivors	Nonsurvivors	Total (§)	
Survival	n = 6 (10)	n = 55 (90)	n = 61	n = 42
Center (†) (p = 0.029) (*1)	n = 6 (6)	n = 55 (53)	n = 61	n = 42
Bern (Switzerland)		3 (100)	3 (5)	6
Grenoble (France)	4 (15)	22 (85)	26 (43)	12
Innsbruck (Austria)	1 (8)	11 (92)	12 (20)	3
Krakow (Poland)	1 (100)		1 (2)	
Lausanne and Sion (Switzerland)		9 (100)	9 (15)	30
Tromsø (Norway)		10 (100)	10 (16)	10
Sex (†) (p = 0.599) (*1)	n = 6	n = 55	n = 61	n = 41
Female	2 (15)	11 (85)	13 (21)	4
Male	4 (8)	44 (92)	48 (79)	37
Age (years) (p = 0.725) (*2)	n = 6	n = 55	n = 61	n = 42
Mean ± SD	31 ± 9	34 ± 14	34 ± 13	36 ± 16
Range	17–41	2–67	2–67	14–75
Duration of burial (min) (p = 0.015) (*2)	n = 5	n = 49	n = 54	n = 32
Median	120	50	54	48
Range	45–420	15–320	15–420	15–150
Airway status (†) (p = 1.000) (*1)	n = 6	n = 42	n = 48	n = 23
Blocked/unknown		2 (100)	2 (4)	3
Patent/free	6 (13)	40 (87)	46 (96)	20
Air pocket (†) (p = 1.000) (*1)	n = 5	n = 39	n = 44	n = 19
Absent	2 (9)	20 (91)	22 (50)	15
Present	3 (14)	19 (86)	22 (50)	4
Vital signs at extrication (†) (p < 0.003) (*1)	n = 6	n = 41	n = 47	n = 31
Absent	1 (3)	34 (97)	35 (74)	31
Pulse/movement/respiration	5 (42)	7 (58)	12 (26)	
Duration of CPR (min) (p < 0.619) (*2)	n = 4	n = 36	n = 40	n = 19
Median	63	84	79	75
Range	40–372	10–300	10–300	22–235
First cardiac rhythm (†) (p = 0.065) (*1)	n = 6	n = 54	n = 60	n = 36
Asystole	2 (5)	39 (95)	41 (68)	32
Pulseless electrical activity	3 (27)	8 (73)	11 (18)	3
Pulseless ventricular tachycardia	1 (33)	2 (67)	3 (5)	
Ventricular fibrillation		5 (100)	5 (8)	1

(†) Number and row percentage (%), (*1) Chi-Square test or Fisher's exact test, (*2) Kruskal-Wallis test or Mann-Whitney-U test. Plus–minus values are means ± SD. Range is min to max, (§) Column percentages. CPR = cardiopulmonary resuscitation.

Table 3 – Cardiac rhythm, core temperature, serum potassium and pH at hospital admission and rewarming method for survivors and nonsurvivors.

Parameter	Rewarmed			Not rewarmed
	Survivors	Nonsurvivors	Total (§)	
Cardiac rhythm (†) ($p = 0.008$) (*1)	n = 5	n = 40	n = 45	n = 37
Asystole	1 (3)	33 (97)	34 (76)	29
Pulseless electrical activity	1 (20)	4 (80)	5 (11)	4
Pulseless ventricular tachycardia	1 (50)	1 (50)	2 (4)	
Ventricular fibrillation	2 (50)	2 (50)	4 (9)	4
Core temperature (°C) ($p = 0.012$) (*2)	n = 6	n = 53	n = 59	n = 37
Mean ± SD	22.5 ± 4.2	27 ± 3.0	26.6 ± 3.4	28.2 ± 5.7
Range	16.9–27.8	19.1–36.0	16.9–36.0	13.0–35.5
Serum potassium (mmol/L) ($p < 0.001$) (*2)	n = 6	n = 53	n = 59	n = 35
Mean ± SD	3.6 ± 0.9	7.5 ± 3.1	7.1 ± 3.2	10 ± 4.2
Range	2.7–4.8	2.3–17.5	2.7–17.5	3.4–19.0
pH ($p = 0.062$) (*2)	n = 6	n = 48	n = 54	n = 27
Mean	6.91 ± 0.34	6.63 ± 0.27	6.7 ± 0.29	6.57 ± 0.16
Range	6.48–7.26	6.1–7.25	6.1–7.26	6.2–6.9
Rewarming method (†) ($p = 0.392$) (*1)	n = 6	n = 55	n = 61	N/A
CPB	1 (4)	24 (96)	25 (41)	
ECMO	4 (13)	27 (87)	31 (51)	
Other	1 (20)	4 (80)	5 (8)	

(†) Number and row percentage (%), (*1) Chi-Square test. (*2) Mann-Whitney-U test. Range is min to max. (§) Column percentages. Injury severity score is not reported as documented in only three cases. CPB = cardiopulmonary bypass; ECMO = extracorporeal membrane oxygenation.

Discussion

In this retrospective multi-centre analysis, the characteristics of 103 avalanche victims with OHCA admitted to hospitals capable of ECLS were analysed to determine the optimal cut-off values for in-hospital triage. For serum potassium, the reduction from the previously proposed cut-off level of 12 mmol/L (until 2015) to 8 mmol/L (from 2015) can be confirmed and a further reduction to 7 mmol/L seems to be safe. The combined cut-offs 7 mmol/L for serum potassium and 30 °C for core temperature achieved the lowest overtriage rate (47%) and the highest PPV (19%), with a sensitivity of 100% for survivors.

Death from avalanches has been attributed to asphyxia in about 75–90% of cases, to trauma in 5–25%, and to hypothermia in only a few cases.[2,25–27] In previously reported cases, avalanche victims in cardiac arrest who survived neurologically intact, presented with ventricular fibrillation (VF) or pulseless electrical activity (PEA),[6,28] and rarely with asystole[29] at the time of extrication.

Recent studies have shown that the survival rate of avalanche victims with OHCA who were admitted for ECLS rewarming has

Table 4 – Sex, age, duration of burial, airway status, presence or absence of air pocket and vital signs at extrication, cardiac rhythm, core temperature, serum potassium and pH at hospital admission, rewarming method and neurological outcome of survivors.

ID	Sex	Age (years)	Duration of burial (min)	Airway status	Air pocket	Vital signs at extrication
20	Male	39	45	Patent	Absent	Non
21	Female	36	Unknown	Patent	Absent	Pulse
25	Male	17	360	Patent	Unknown	Pulse
30	Male	41	420	Patent	Present	Respiration
63	Male	29	90	Patent	Present	Pulse, respiration
64	Female	25	120	Patent	Present	Pulse, respiration, movement

ID	Cardiac rhythm at admission	Core temperature at admission (°C)	Serum potassium (mmol/L)	pH	Rewarming method	Outcome at discharge
20	Pulseless ventricular tachycardia	27.8	3.30	6.78	Peritoneal dialysis	CPC 3
21	Pulseless electrical activity	26.9	2.70	7.16	CPB	CPC 1
25	Ventricular fibrillation	21.1	3.91	7.26	ECMO	CPC 1
30	Asystole	22.0	2.75	7.19	ECMO	CPC 1
63	Pulseless electrical activity	20.0	4.80	6.48	ECMO	CPC 1
64	Ventricular fibrillation	16.9	4.30	6.60	ECMO	CPC 1

CPC = cerebral performance category; CPB = cardiopulmonary bypass; ECMO = extracorporeal membrane oxygenation.

Table 5 – Sensitivity, specificity, positive and negative predictive values with respective 95% confidence intervals according to triage criteria.

Criteria n = 103 (*)	Sensitivity		Overtriage rate (1-specificity)		Positive predictive value		Negative predictive value	
Exclude from rewarming when	R	A	R	A	R	A	R	A
K > 8 or core temperature > 30	6/6 (100%) 67–100		35/55 (64%) 50–75	41/97 (42%) 33–52	6/41 (15%) 6–28	6/47 (13%) 6–24	20/20 (100%) 88–100	56/56 (100%) 96–100
K > 7 or core temperature > 30			26/55 (47%) 35–60	31/97 (32%) 23–42	6/32 (19%) 8–35	6/37 (16%) 7–30	29/29 (100%) 92–100	66/66 (100%) 96–100

(*) Given values are counts/total and (percentages) with 95% Jeffrey's confidence interval. Total for sensitivity and overtriage rate are survivors and nonsurvivors, whilst positive and negative predictive values are based on cases with positive or negative rewarming criteria. R denotes the sample of rewarmed cases, A denotes all cases.

remained at about 12%.[28,30,31] This is substantially lower than survival rates from all-cause hypothermic cardiac arrest, which range from 23 to 100%.[32,33] The high rate of deaths due to asphyxia in avalanche victims is likely the reason for the substantially lower survival rate compared with hypothermic cardiac arrest from other causes.

The use of serum potassium level has been proposed to predict survival of patients presenting with hypothermic cardiac arrest from any cause,[12,13] and, specifically to predict survival of arrested avalanche victims.[2,7,14,15] Hyperkalaemia is a sign of cell death, but the underlying pathophysiology that leads to changes in serum potassium during cooling is not fully understood. In particular, the effect of deleterious cofactors such as trauma and asphyxia on the level of serum potassium is controversial. In a systematic review of the impact of accidental hypothermia on serum potassium, Buse et al.[34] found that among 50 studies 39 (78%) showed initial decreases of serum potassium levels, attributed to liver pooling and intracellular shift. In 11 (22%) studies serum potassium increased

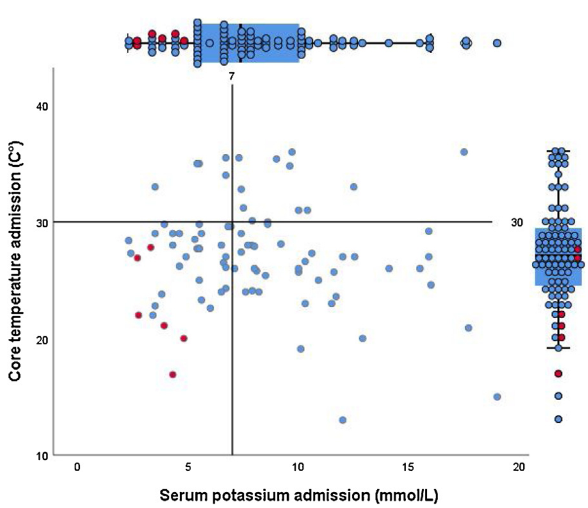

Fig. 2 – Scatter plot with border box-plots of serum potassium (x-axis and top) versus core temperature (y-axis and right side) of survivors (red) and nonsurvivors (blue) with respective reference lines at cut-off values (7 mmol/L for serum potassium and 30 °C for core temperature, n = 103). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

over time in severe hypothermia, attributed to a membrane leakage with passive efflux of electrolytes. The authors observed that "the irreversibility of cardiac arrest in deep hypothermia is admittedly difficult to assess and even more so given that underlying causes such as asphyxia can be associated." It appears that increases in serum potassium depend not only on hypothermia, but also on comorbidities such as trauma or asphyxia, due to damage of cell membranes.

The highest reported serum potassium levels in patients who were successfully rewarmed with good neurological outcome were in a hypothermic child who had an initial potassium of 11.8 mmol/L[35] and in an adult with 9.0 mmol/L,[36] both exposed to cold environments without asphyxiation. The highest level in an avalanche survivor was 6.4 mmol/L.[14] This difference between the highest recorded serum potassium levels in hypothermia from cold exposure and from avalanche burial also supports the assumption that the prognostic value of serum potassium depends on whether hypothermia is the sole cause of cardiac arrest or whether there is associated asphyxia or trauma.

Since 1996, several out-of-hospital recommendations have been developed for the on-site triage of avalanche victims presenting with cardiac arrest. The patency of the airway, duration of burial and core temperature have been proposed as decisive parameters. For example, if an avalanche victim is found after >60 min burial in asystolic cardiac arrest with a completely obstructed airway, hypothermia is unlikely to have been the cause of cardiac arrest. In that case, resuscitation can be withheld and death can be declared on site. If the airway is not completely obstructed, potentially reversible hypothermia cannot be excluded and the patient should be transported to a hospital for ECLS rewarming.[1,7]

After the dissemination of triage guidelines,[2,15] the use of ECLS rewarming of avalanche victims with OHCA decreased in some centres, but the adherence to the guidelines has remained suboptimal. A single-centre study has shown that a considerable number of avalanche victims were not selected for ECLS according to the established guidelines.[37] Of the investigated patients with a short duration of burial (≤35 min) 27% (4 of 15) patients were rewarmed with ECLS, while only 29% (14 of 49) patients with a long duration of burial (>35 min) and patent or unknown airways received CPR and were transported to a hospital with ECLS. The study indicates that the adherence to out-of-hospital recommendations can be poor, and insufficient transfer of information from the accident site to the hospital may partially

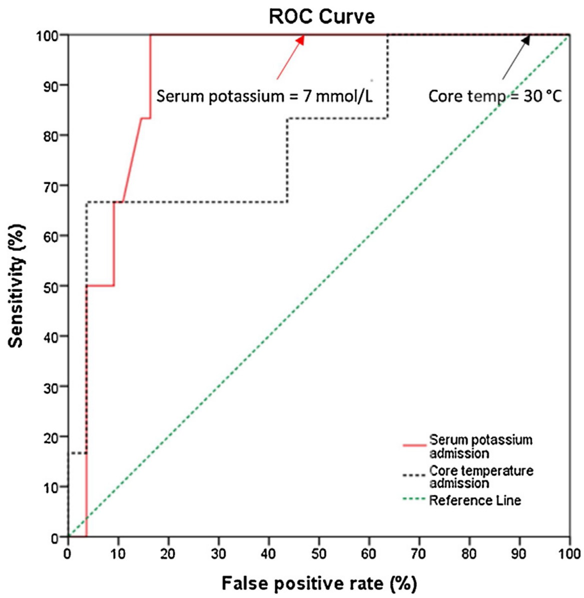

Fig. 3 – Receiver operating curve (ROC) for rewarmed avalanche victims (n = 61) with respect to serum potassium levels (red) and core temperature (black dotted). Areas under the curve for serum potassium AUC = 0.92 (95% confidence interval 0.85-0.99, p = 0.001) and for core temperature AUC = 0.80 (95% confidence interval 0.60-1.00, p = 0.015). When considering a serum potassium level of 7 mmol/L and core temperature of 30 °C as cut-offs, rate of overtriage (False positive rate = 1-specificity) is 47%. The respective cut-off values are marked by arrows, showing that the respective cut-offs were chosen conservatively, for safety reasons. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

explain the respective poor outcome of arrested avalanche victims treated with emergency cardiac care. To address these problems, a resuscitation checklist was published in 2014 by ICAR MEDCOM.[38] It is too early to draw any conclusions regarding whether this initiative will reduce the overall number of futile rewarming attempts of avalanche victims with OHCA, as many victims may still reach the hospital without out-of-hospital data or without meeting the criteria for ECLS rewarming. Some hospital centres have reported a financial loss by the implementation of ECLS according to the international guidelines.[39] It is desirable to establish criteria for additional in-hospital triage of avalanche victims with OHCA that can be used even when no out-of-hospital data are available.

In this study, we calculated and compared sensitivity, specificity and ROCs for in-hospital cut-off values. Due to the low number of survivors the ability to estimate sensitivity and undertriage rate are limited, whilst overtriage rate and predictive values can be estimated more accurately because nonsurvivors are also included. Our results show that serum potassium at hospital admission is an accurate predictor of survival and that prediction can be further improved if core temperature is also used. A potassium level of 7 mmol/L and core temperature of 30 °C seem to be the optimal cut-off values for triage of avalanche victims at hospital admission. Using these values, the rate of overtriage (false positive rate = 1- specificity) is 47% or 32% when using all cases (Table 5). Although lower cut-off values have been suggested[40] to decrease the overtriage rate, using a cut-off lower than 7 mmol/L may be unsafe.

The Hypothermia Outcome Prediction after ECLS (HOPE) score has been proposed for in-hospital triage of patients in cardiac arrest who are hypothermic from all causes.[41] In addition to serum potassium level and core temperature at hospital admission, the HOPE score includes the variables age, sex, mechanism of cooling and duration of cardiopulmonary resuscitation. In our study the presence of vital signs at extrication was, for example, strongly associated with survival. Survivors also had a lower core temperature and longer duration of burial than nonsurvivors. This may reflect that cardiac arrest was primarily caused by hypothermia and not by asphyxia. However, present data sets are too small to evaluate additional out-of-hospital parameters.

Limitations

This study is retrospective with all the usual limitations. The overall number of 103 included avalanche victims over the observation period of 21 years is very low, likely due to the fact that not all avalanche victims who are found in cardiac arrest are transported to ECLS hospitals. Moreover, the incidence of avalanche accidents varies considerably between the centres. This may reflect the regional differences in the incidence of avalanche accidents and very likely different rescue strategies. Cut-off values were estimated using data only from avalanche victims who were admitted to a hospital capable of ECLS. No data were available from avalanche victims with OHCA who were not admitted to a hospital capable of ECLS. The cohort is drawn from a 21-year time period between 1995 and 2016. It is possible that changes in the management of patients over time, such as advances in post-arrest care, had an impact on the results. The first recommendations for the out-of-hospital triage of avalanche victims in cardiac arrest were published in 1996. Since then, selected avalanche patients in cardiac arrest should have been rewarmed with ECLS according to these recommendations. In the investigated period all participating centres were equipped with ECLS facilities.

Conclusion

For in-hospital triage of avalanche victims admitted to hospitals in cardiac arrest, the serum potassium accurately predicted survival. The combined cut-offs 7 mmol/L for serum potassium and 30 °C for core temperature achieved the lowest overtriage rate (47%) and the highest PPV (19%), with a sensitivity of 100% for survivors. The presence of vital signs at the time of extrication was strongly associated with survival. For further optimisation of in-hospital triage, larger datasets are needed to include additional parameters.

Conflicts of interest

HB receives grants as the head of the Institute of Mountain Emergency Medicine from EURAC research, Bolzano, Italy. No author has any conflict of interest to disclose.

Acknowledgements

The authors thank the Department of Innovation, Research and University of the Autonomous Province of Bozen/Bolzano for covering the Open Access publication costs.

REFERENCES

1. Van Tilburg C, Grissom CK, Zafren K, et al. Wilderness medical society practice guidelines for prevention and management of avalanche and nonavalanche snow burial accidents. Wilderness Environ Med 2017;28:23–42.
2. Brugger H, Durrer B, Adler-Kastner L, Falk M, Tschirky F. Field management of avalanche victims. Resuscitation 2001;51:7–15.
3. Adler-Kastner L. Avalanche survival chances. Nature 1994;368:21.
4. Brugger H, Etter HJ, Zweifel B, et al. The impact of avalanche rescue devices on survival. Resuscitation 2007;75:476–83.
5. Mair P, Frimmel C, Vergeiner G, et al. Emergency medical helicopter operations for avalanche accidents. Resuscitation 2013;84:492–5.
6. Moroder L, Mair B, Brugger H, Voelckel W, Mair P. Outcome of avalanche victims with out-of-hospital cardiac arrest. Resuscitation 2015;89:114–8.
7. Truhlar A, Deakin CD, Soar J, et al. European Resuscitation Council Guidelines for Resuscitation 2015: Section 4. Cardiac arrest in special circumstances. Resuscitation 2015;95:148–201.
8. Strapazzon G, Nardin M, Zanon P, Kaufmann M, Kritzinger M, Brugger H. Respiratory failure and spontaneous hypoglycemia during noninvasive rewarming from 24.7 degrees C (76.5 degrees F) core body temperature after prolonged avalanche burial. Ann Emerg Med 2011;60:193–6.
9. Paal P, Gordon L, Strapazzon G, et al. Accidental hypothermia-an update: The content of this review is endorsed by the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). Scand J Trauma Resusc Emerg Med 2016;24:111.
10. Walpoth BH, Walpoth-Aslan BN, Mattle HP, et al. Outcome of survivors of accidental deep hypothermia and circulatory arrest treated with extracorporeal blood warming. N Engl J Med 1997;337:1500–5.
11. Oberhammer R, Beikircher W, Hormann C, et al. Full recovery of an avalanche victim with profound hypothermia and prolonged cardiac arrest treated by extracorporeal re-warming. Resuscitation 2008;76:474–80.
12. Mair P, Kornberger E, Furtwaengler W, Balogh D, Antretter H. Prognostic markers in patients with severe accidental hypothermia and cardiocirculatory arrest. Resuscitation 1994;27:47–54.
13. Boyd J, Brugger H, Shuster M. Prognostic factors in avalanche resuscitation: a systematic review. Resuscitation 2010;81:645–52.
14. Locher T, Walpoth BH. Differential diagnosis of circulatory failure in hypothermic avalanche victims: retrospective analysis of 32 avalanche accidents. Praxis 1996;85:1275–82.
15. Brugger H, Durrer B, Adler-Kastner L. On-site triage of avalanche victims with asystole by the emergency doctor. Resuscitation 1996;31:11–6.
16. Soar J, Perkins GD, Abbas G, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 8. Cardiac arrest in special circumstances: Electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. Resuscitation 2010;81:1400–33.
17. Brugger H, Durrer B, Elsensohn F, et al. Resuscitation of avalanche victims: Evidence-based guidelines of the international commission for mountain emergency medicine (ICAR MEDCOM): intended for physicians and other advanced life support personnel. Resuscitation 2013;84:539–46.
18. Davis JW, Dirks RC, Sue LP, Kaups KL. Attempting to validate the overtriage/undertriage matrix at a Level I trauma center. J Trauma Acute Care Surg 2017;83:1173–8.
19. Cummins RO, Chamberlain DA, Abramson NS, et al. Recommended guidelines for uniform reporting of data from out-of-hospital cardiac arrest: the Utstein Style. A statement for health professionals from a task force of the American Heart Association, the European Resuscitation Council, the Heart and Stroke Foundation of Canada, and the Australian Resuscitation Council. Circulation 1991;84:960–75.
20. Handbook on European data protection law. Brussels, Belgium: European Union Agency for Fundamental Rights, Council of Europe; 2014.
21. Committee on Trauma ACoS. Monitoring Overtriage and Undertriage. Resources for Optimal Care of the Injured Patient. Chicago: American College of Surgeons; 2014 p. 28.
22. Vittinghoff E, McCulloch CE. Relaxing the rule of ten events per variable in logistic and Cox regression. Am J Epidemiol 2007;165:710–8.
23. Brugger H, Bouzat P, Pasquier M, et al. Data and methods to calculate cut-off values for serum potassium and core temperature at hospital admission for extracorporeal rewarming of avalanche victims in cardiac arrest. Data in Brief 2019 in press.
24. Brown LD, Cai TT, Dasgupta A. Interval Estimation for a Binomial Proportion. Stat Sci 2001;16:101–33.
25. Boyd J, Haegeli P, Abu-Laban RB, Shuster M, Butt JC. Patterns of death among avalanche fatalities: a 21-year review. CMAJ 2009;180:507–12.
26. Hohlrieder M, Brugger H, Schubert HM, Pavlic M, Ellerton J, Mair P. Pattern and severity of injury in avalanche victims. High Alt Med Biol 2007;8:56–61.
27. McIntosh SE, Grissom CK, Olivares CR, Kim HS, Tremper B. Cause of death in avalanche fatalities. Wilderness Environ Med 2007;18:293–7.
28. Mair P, Brugger H, Mair B, Moroder L, Ruttmann E. Is extracorporeal rewarming indicated in avalanche victims with unwitnessed hypothermic cardiorespiratory arrest? High Alt Med Biol 2014;15:500–3.
29. Althaus U, Aeberhard P, Schupbach P, Nachbur BH, Muhlemann W. Management of profound accidental hypothermia with cardiorespiratory arrest. Ann Surg 1982;195:492–5.
30. Boue Y, Payen JF, Brun J, et al. Survival after avalanche-induced cardiac arrest. Resuscitation 2014;85:1192–6.
31. Hilmo J, Naesheim T, Gilbert M. “Nobody is dead until warm and dead”: Prolonged resuscitation is warranted in arrested hypothermic victims also in remote areas - A retrospective study from northern Norway. Resuscitation 2014;85:1204–11.
32. Ruttmann E, Weissenbacher A, Ulmer H, et al. Prolonged extracorporeal membrane oxygenation-assisted support provides improved survival in hypothermic patients with cardiocirculatory arrest. J Thorac Cardiovasc Surg 2007;134:594–600.
33. Wanscher M, Agersnap L, Ravn J, et al. Outcome of accidental hypothermia with or without circulatory arrest: experience from the Danish Praesto Fjord boating accident. Resuscitation 2012;83:1078–84.
34. Buse S, Blancher M, Viglino D, et al. The impact of hypothermia on serum potassium concentration: A systematic review. Resuscitation 2017;118:35–42.
35. Dobson J, Burgess J. Resuscitation of Severe Hypothermia by Extracorporeal Rewarming in a Child. J Trauma 1996;40:483–5.
36. Pasquier M, Darocha T, Husby P. Survival of a cardiac arrested victim with hypothermia despite severely elevated serum potassium (9.0 mmol/L). Cryobiology 2017;78:128–9.
37. Strapazzon G, Plankensteiner J, Mair P, et al. Prehospital management and outcome of avalanche patients with out-of-hospital cardiac arrest: a retrospective study in Tyrol, Austria. Eur J Emerg Med 2017;24:398–403.
38. Kottmann A, Blancher M, Spichiger T, et al. The Avalanche Victim Resuscitation Checklist, a new concept for the management of avalanche victims. Resuscitation 2015;91:e7–8.
39. Kosinski S, Darocha T, Jarosz A, et al. Difficulties in funding of VA-ECMO therapy for patients with severe accidental hypothermia. Anaesth Intensive Ther 2017;49:106–9.
40. Cohen JG, Boue Y, Boussat B, et al. Serum potassium concentration predicts brain hypoxia on CT after avalanche-induced cardiac arrest. Am J Emerg Med 2016;34:856–60.
41. Pasquier M, Hugli O, Paal P, et al. Hypothermia outcome prediction after extracorporeal life support for hypothermic cardiac arrest patients: the HOPE score. Resuscitation 2018;126:58–64.