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Clinical paper

Burial duration, depth and air pocket explain avalanche survival patterns in Austria and Switzerland☆

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ABSTRACT

Aim: To calculate the first Austrian avalanche survival curve and update a Swiss survival curve to explore survival patterns in the Alps.
Methods: Avalanche accidents occurring between 2005/06 and 2012/13 in Austria and Switzerland were collected. Completely buried victims (i.e. burial of the head and chest) in open terrain with known outcome (survived or not survived) were included in the analysis. Extrication and survival curves were calculated using the Turnbull algorithm, as in previous studies.
Results: 633 of the 796 completely buried victims were included (Austria $n = 333$, Switzerland $n = 300$). Overall survival was 56% (Austria 59%; Switzerland 52%; $p = 0.065$). Time to extrication was shorter in Austria for victims buried ≤60 min ($p < 0.001$). The survival curves were similar and showed a rapid initial drop in survival probability and a second drop to 25–28% survival probability after burial duration of ca. 35 min, where an inflection point exists and the curve levels off. In a logistic regression analysis, both duration of burial and burial depth had an independent effect on survival. Victims with an air pocket were more likely to survive, especially if buried >15 min.
Conclusion: The survival curves resembled those previously published and support the idea that underlying survival patterns are reproducible. The results are in accordance with current recommendations for management of avalanche victims and serve as a reminder that expedient companion rescue within a few minutes is critical for survival. An air pocket was shown to be a positive prognostic factor for survival.

Introduction

An avalanche survival curve is a graphical representation of the cumulative survival probability during complete avalanche burial as a function of time.[1] The step-wise decrease of survival probability with increasing duration of burial was first recognized in the original curve in 1994 using avalanche data from Switzerland.[1] Four distinct phases could be distinguished in the curve, which reflected patterns of death in victims extricated within that time period: trauma is the major cause of death in the first ("survival") phase, asphyxia in the second ("asphyxia") phase and a combination of severe hypothermia, hypoxia and hypercapnia in the third ("latent") and fourth ("long-term survival") phases. Characterising avalanche survival in this manner had a lasting practical impact on avalanche rescue. For example, these curves offered a way to quantify the importance of rapid extrication by companion rescuers, i.e. a victim must be extricated within ca. 15 min for a survival chance of >90%. Secondly, a threshold was identified at the end of the asphyxia phase (ca. 35 min) after which survival without a patent airway is unlikely. These aspects were later integrated into international guidelines on the management of avalanche victims[2,3] and resuscitation guidelines.[4]

To understand whether these survival patterns pertained to other regions, the first comparative study of survival curves was published in 2011 using data from Switzerland and Canada.[5] For the first time it was shown that these four phases in the survival curve seem to be universal, but that their duration and contribution to survival are modified by local factors. In this comparison,

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the incidence of fatal injuries and snow climate were decisive for survival in the early phase of burial, whereas response time of rescue services and transport time seem to influence survival after prolonged burial. However, because this was the only comparative study published to date, it is unclear which local factors affect survival patterns in other regions or how they contribute to understanding survival patterns in similar regions. The aim of this study was to calculate the first avalanche survival curve for Austria and compare it to an updated curve for Switzerland as a step towards exploring survival patterns in the Alps.

Methods

Data were collected from all reported avalanche accidents occurring in open areas between the winter season 2005/06 and 2012/13 from databases in Austria (Austrian Alpine Police) and Switzerland (WSL Institute for Snow and Avalanche Research SLF). Accidents involving completely buried victims (i.e. burial of the head and chest) with known outcome (survived or not survived) were included. *Survival* in these datasets refers to the victim's status either upon extrication from the snow or at hospital admission or discharge. Accidents occurring in buildings or on transport routes were excluded because survival patterns are not comparable to those of victims buried in open terrain. The variables included year, duration of burial, burial depth, presence of an air pocket (i.e. any space no matter how small in front of the mouth and nose with a patent airway) and survival. Accident data are compiled from different sources, including persons who witnessed the accident, rescue organizations and other authorities responsible for reporting accidents in these countries.

The Mann–Whitney *U* test was used to compare burial depth between countries and the Fisher's exact test to compare survival and extrication rates between countries. Extrication curves were compared using the Log-rank and Breslow tests for cases with burial ≤360 min. Survival curves were calculated with the estimation procedure of Turnbull[6] for doubly-censored data and compared using the procedure of Dümbgen et al.[7] Logistic regression was used to describe the effect of duration of burial, burial depth and winter season on survival for victims buried ≤180 min using a combined dataset from both countries. The analysis was limited to victims extricated within ≤180 min to reduce the influence of exceptionally long burial cases on the regression analysis, which (in contrast to survival analyses) addresses only final outcome. In a subsequent analysis, logistic regression was used to further investigate the association of burial depth on survival; this analysis included cases with at least two victims in the same avalanche but at least one victim buried ≤80 cm and at least one buried >80 cm (i.e. median burial depth as a cut-off). Burial duration and depth were entered into the model as ordinal (not continuous) variables. Tests were two-sided and $p < 0.05$ was considered statistically significant. SPSS (Version 23.0, SPSS Inc., Chicago, IL) was used for the analyses.

Results

There were 406 completely buried avalanche victims between the winter season 2005/06 and 2012/13 in Austria; 73 cases were excluded from further analysis because of missing information on duration of burial or survival. There were 390 completely buried avalanche victims between the winter season 2005/06 and 2012/13 in Switzerland; 90 cases were excluded from further analysis because of missing information on duration of burial or survival. The remaining 633 cases (Austria $n = 333$, Switzerland $n = 300$) were included in the analysis.

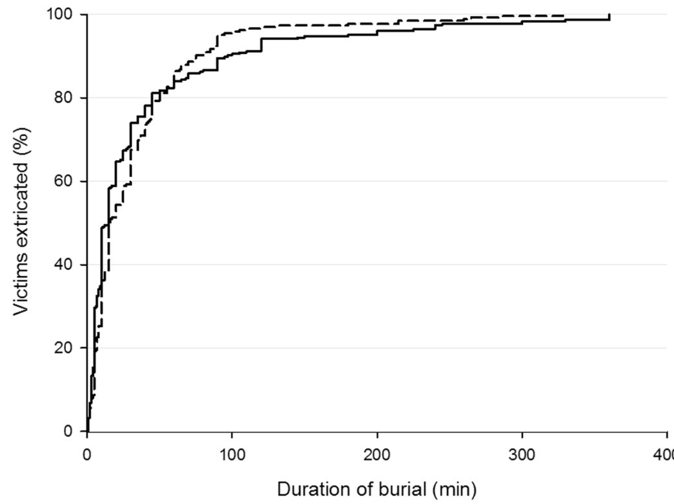

Fig. 1. Extrication curve shown as the proportion of victims extricated as a function of duration of burial in Austria (solid line) and Switzerland (dashed line) for completely buried victims between 2005 and 2013.

Duration of burial

Overall median time between burial and extrication was 15 min (25–75th quartile: 5–50 min) in Austria and 25 min (25–75th quartile: 10–60 min) in Switzerland. The proportion of all victims extricated as a function of duration of burial is shown in Table 1. The extrication curves are not proportional and intersect at ca. 60 min (Fig. 1). In Austria, 54% of victims were extricated within the first 15 min of burial and 78% within 60 min. In Switzerland, 44% of victims were extricated within the first 15 min of burial, significantly less with respect to Austria ($p = 0.021$), and 76% within 60 min, which is comparable to Austria ($p = 0.777$). Median time between burial and extrication for victims extricated within 60 min was 10 min in Austria and 15 min in Switzerland (Log-rank $p < 0.001$, $n = 487$); for victims extricated after 60 min median time between burial and extrication was 225 min in Austria and 330 min in Switzerland (Log-rank $p = 0.079$, $n = 146$). This was not due to differences in burial depth for victims buried ≤60 min ($p = 0.640$) or >60 min ($p = 0.335$).

Survival probability

Overall survival was 56% (Austria 59%; Switzerland 52%; $p = 0.065$). The survival curves, i.e. survival probability as a function of duration of burial, are shown in Fig. 2. In the Austrian curve, the major drop in survival probability occurs (i) within 7 min of burial

Table 1
Number of avalanche victims extricated in Austria and Switzerland.

Duration of burial (min)	Extricated (Austria)			Extricated (Switzerland)			*p*-value (Austria vs. Switzerland)
	n	%	Cumulative %	*n*	%	Cumulative %	Cumulative %
≤15	179	53.8%	53.8%	133	44.3%	44.3%	0.021
16–35	53	15.9%	69.7%	52	17.3%	61.7%	0.036
36–60	26	7.8%	77.5%	44	14.7%	76.3%	0.777
>60	75	22.5%	100.0%	71	23.7%	100.0%	
Total	333	100.0%		300	100.0%		

Table 2
Factors affecting survival in victims buried ≤180 min in Austria and Switzerland ($n = 500$) based on a logistic regression analysis.

Variable	Level	Austria and Switzerland ($n = 500$)		
		OR	95% CI	p-value
Duration of burial (min)	≤15 (reference)	–	–	<0.001
	16–35	8.7	5.01–15.10	<0.001
	36–60	18.11	8.72–37.62	<0.001
	>60	28.67	12.72–64.63	<0.001
Burial depth (cm)	≤40 (reference)	–	–	<0.001
	41–80	2.41	1.20–4.87	0.014
	81–120	4.05	2.01–8.17	<0.001
	>120	4.92	2.41–10.05	<0.001

OR, odds ratio; CI, confidence interval.

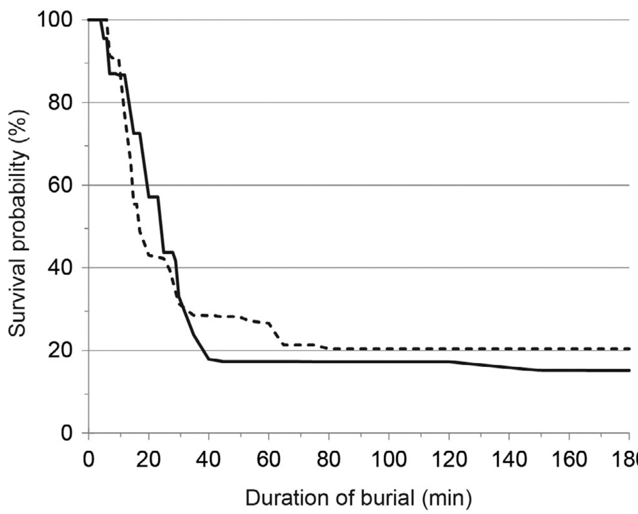

Fig. 2. Survival curve for Austria (solid line) and Switzerland (dashed line) for completely buried victims between 2005 and 2013.

to 87%, (ii) between 11 and 25 min to 44% and (iii) between 28 and 40 min to 18%; thereafter survival probability is relatively constant until 180 min. Similarly, in the Swiss curve, a rapid drop occurs (i) within 7 min of burial to 91%, (ii) between 10 and 20 min to 43%, (iii) between 20 and 35 min to 28% and (iv) between 35 and 64 min to 21%; thereafter, survival probability remains relatively constant at 21% until 180 min. Though the curves appear slightly different between 35 and 60 min, the Swiss survival curve does not differ from the Austrian survival curve based on the comparison method of Dümbgen et al.[7] ($p = 0.766$); similarly, the Swiss curve does not differ ($p = 0.096$) from the survival curve published previously using an older Swiss dataset (Oct. 1980–Sept. 2005).[5]

Factors affecting survival

Based on a logistic regression analysis of victims buried ≤180 min, both duration of burial and burial depth had an independent effect on survival (Table 2). The likelihood of mortality increased with increasing duration of burial and depth. Mortality was 18 times higher if buried 36–60 min and 29 times higher if buried >60 min compared to ≤15 min; mortality was almost 5 times higher if buried >120 cm compared to ≤40 cm.

A sub-analysis of the Austrian data showed that survival was higher in victims with an air pocket compared to those without (Table 3; $n = 273$, data unknown in 60 cases). Of the victims buried ≤15 min, 95% with an air pocket survived compared to 69% without ($p < 0.001$). Of the victims buried >15 min, 67% with an air pocket survived compared to 4% without ($p < 0.001$). Two of the three survivors buried >15 min without an air pocket were extricated within the threshold time of 35 min (20 and 25 min), whereas one was buried for 120 min at a depth of 2 m.

Table 3
Rate of survival with and without an air pocket for burial ≤180 min (Austrian data, $n = 273$).

Duration of burial (min)	Air pocket	Survived n (%)	Died n (%)	p-value
≤15	No	25 (69)	11 (31)	<0.001
	Yes	122 (95)	6 (5)	
>15	No	3 (4)	63 (96)	<0.001
	Yes	29 (67)	14 (33)	

Discussion

We calculated the first Austrian avalanche survival curve and updated an existing Swiss survival curve as a step towards exploring survival patterns in the Alps.[1,5] We found that the new curves show important similarities to existing survival curves, most importantly, the rapid drop in survival probability in the early phases of burial (up to 35–40 min) and more stable survival probability over long-term burial. The close resemblance to previous curves indicates that the general patterns of survival probability seem to be reproducible and have not changed significantly over time in Switzerland (compared to data from Switzerland between 1980 and 2005). Interestingly, though, we found that survival probability in the first phase dropped rapidly, i.e. similar to the initial drop reported for Canada (10 min) and faster than that reported for Switzerland (18 min).[5] This may indicate that fatal trauma was more often the cause of death in cases occurring after 1995 compared to previous datasets. The survival rate of victims buried ≤15 min was 90% in Austria and 85% in Switzerland. Both of these findings re-emphasize that rapid extrication within 15 min and prompt first aid by companion rescuers is live-saving, as stated in previous studies.[8] In the asphyxia phase, survival probability drops in both countries from ca. 90% to 25–28% at 35 min burial, where an inflection point exists and the curve begins to level off. It was based on a similar finding[1,5] that international recommendations adopted a threshold of 35 min to mark the burial time after which a patent airway is needed for long-term survival.[3] Our results support this recommendation.

The original decision algorithm for management of avalanche victims, published in 2001 and 2002, included presence/absence of an air pocket.[2,9] Recent publications and recommendations have also considered the presence of an air pocket a positive prognostic marker for survival, whereby airway patency is the preferred parameter and presence of an air pocket is ancillary information.[3] Air pocket data were available in the Austrian dataset in 82% of cases, but not reported in the Swiss data. This is the first survival analysis to include this variable and we found that victims with an air pocket had higher survival rates, especially if buried >15 min (Table 3). There was no information on the cause of death in the six victims with an air pocket buried ≤15 min (range 5–15 min; burial depth 30–450 cm), though it is likely that trauma was present in some cases. Survival in victims buried >15 min without an air pocket was very low (4%).

Previous studies have shown that geographic factors, climatic factors and prehospital care may partially explain specific differences in survival between countries.[5] Overall patterns of survival and absolute survival rates were comparable between these two datasets and comparable to existing curves. The finding that the Swiss curve did not change (compared to data from the period 1980–2005[5]) indicates that factors such as technical development of safety equipment (e.g. airbags that may prevent fatal trauma) or advances in medical care had little impact on the survival curve. This might be explained by low prevalence of safety devices among winter recreationists[10] and insufficient transfer of information from the accident site to the hospital according to guidelines.[11] It is unclear why the time between burial and extrication differed (Fig. 1), though it was not due to differences in burial depth. Given the available data it would be unjustified to make assumptions about better or poorer practices between these countries. However, it is plausible that safety equipment of bystanders (e.g. avalanche transceivers, shovels and probes), education and training influence how fast a victim can be extricated. Almost half (47%) of all cases with known burial depth were buried ≥100 cm. This high percentage of deep burials highlights that rapid as well as skilled companion rescue is required to perform extrication within reasonable time. Data from helicopter-based avalanche rescues in Austria show that the majority of victims have already been extricated by companion rescuers when emergency services arrived on site (63% [35/56] of victims).[12] Overall, our data and data from the literature[12] emphasize the importance of rapid location and extrication of a buried avalanche victim by all available means and provision of basic life support (if indicated) to improve survival. Despite that organized rescue can provide advanced prehospital care, victims extricated by organized rescue have lower survival rates because burial is longer.[12]

It has been hypothesized that deeper burial may be associated with trauma and thorax compression and thus higher mortality,[13] though the association between burial depth and survival has not been consistently demonstrated.[1,5] In the logistic regression we found that burial depth had an independent effect on survival in the combined dataset. To confirm this finding, we did the same analysis on a subset using only cases with at least two victims in the same avalanche (to reduce the variability of other avalanche-related factors), i.e. at least one victim buried ≤80 cm and at least one buried >80 cm. Again, burial depth was associated with survival ($p = 0.008$). The discrepancy between findings in previous studies may be partially due to incomplete data on avalanche size or other factors associated with burial depth and survival. There should be continued emphasis internationally on high-quality and comprehensive data collection of both accident and patient data to improve the comparability of datasets. Future survival analyses should include mountainous regions with varying topography and climate (e.g. Scandinavia, Pyrenees, Apennines, southern range of the Alps) to identify local differences that may be important for rescue strategies.

Limitations

Survival analyses have been calculated to date using data from completely buried victims only and do not represent survival probability for all avalanche victims. Similarly, because non-fatal accidents are commonly under-reported, poor outcome cases with lower survival probability may be over-represented in these datasets. Finally, we cannot exclude the possibility that there is systematic bias in collection and reporting of some variables. For example, duration of burial must be estimated retrospectively in many cases, and datasets show a concentration at the nearest estimated 5-min interval. Presence of an air pocket is required for triage and treatment decisions for victims buried >35 min and does not influence decisions for victims buried ≤35 min; thus, it is not mandatory to document it in all cases (though recommended) and we do not know if there is less emphasis on documenting this parameter in fatal cases. Finally, 20% of all accidents occurring in the observation period had to be excluded from the analysis because of missing data; data were also not available for other parameters that may influence survival (e.g. unwitnessed cardiac arrest at extrication, advanced in-hospital care).

Conclusions

The first survival curve ever calculated for Austria and an updated curve for Switzerland show that survival patterns resemble those previously published and support the idea that the underlying survival patterns are reproducible between countries. The results are also in accordance with previous findings that survival drops rapidly and reaches an initial minimum at ca. 35 min of burial and, for this reason, that expedient companion rescue within the first few minutes is critical for survival. The presence of an air pocket was shown to be a positive prognostic factor for survival, especially after 15 min of burial. In addition, the results show that not only duration of burial is associated with survival, but also burial depth. Survival analyses from different countries continue to be an important source of information for developing evidence-based management guidelines and for monitoring outcome of completely buried avalanche victims.

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Conflict of interest statement

None of the authors has any financial or personal relationship that could have inappropriately influenced the work.

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