Available online at ScienceDirect

Resuscitation

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

Clinical paper

Avalanche survival depends on the time of day of the accident: A retrospective observational study

Simon Rauch[a,b], *Joachim Koppenberg*[c,d], *Dario Josi*[d,e], *Lorenz Meuli*[f], *Giacomo Strapazzon*[b,g], *Mathieu Pasquier*[h], *Roland Albrecht*[i,k], *Hermann Brugger*[b,g], *Benjamin Zweifel*[j], *Urs Pietsch*[i,k,l,*]

Abstract

Introduction: We aimed to investigate the relationship between the time of the day and the probability of survival of completely buried avalanche victims. We explored the frequency of avalanche burials occurring after sunset, and described victims' characteristics, duration of burial and rescue circumstances compared to daytime avalanches.

Methods: In this retrospective, observational study, we analysed avalanche data from the registry of the Swiss Institute for Snow and Avalanche Research, from 1998 to 2020.

Results: A total of 3892 avalanche victims were included in the analysis, with 72 of the accidents (1.85%) occurring in the nighttime. Nearly 50% of the victims involved in nighttime avalanche accidents were completely buried, compared to about 25% of victims in daytime avalanches. Completely buried victims were rescued by a companion less often at night than in the daytime (15% vs. 51%, p <.001). The search and rescue of completely buried avalanche victims took longer during the nighttime compared to the daytime (median 89 min vs 20 min, p =.002). The probability of survival decreased as the day progressed; it was highest at around midday (63.0%), but decreased at sunset (40.4%) and was the lowest at midnight (28.7%).

Conclusions: Avalanche accidents at night are a rare event, and probability of survival after complete burial is lower during the nighttime compared to the daytime. The most relevant reason for this is the longer duration of burial, which is explained in part by the lower rate of companion rescue and the lower rate of victim localisation with an avalanche transceiver.

Keywords: Avalanche, Triage, Night, CPR, Resucitation

Introduction

Avalanche accidents are common in mountain regions and approximately 100 fatalities are counted in Europe each year.[1] The probability of survival after complete burial, i.e. head and chest buried under snow, is about 50%.[2–4] Factors that have been shown to influence survival include duration of burial,[3,5] airway patency and presence of an air pocket,[6,7] snow characteristics[8] and severity of traumatic lesions.[4,9] Currently, it is unknown to what extgent the timing of the avalanche affects the survival probability.

Here, we investigate the relationship between the time of day and the survival probability of completely buried avalanche victims. We explored the frequency of avalanche burials occurring after sunset and described victim's characteristics, burial duration and rescue circumstances compared to daytime avalanches.

Methods

Material

We analysed avalanche data from November, 1998 to September, 2020 collected by the WLS Institute for Snow and Avalanche Research (SLF) in Davos, Switzerland. The Institute collects all avalanche data in Switzerland. For each avalanche the date and time of the event, duration of burial and survival status (alive or dead) were

* Corresponding author at: Department of Anaesthesiology and Intensive Care Medicine, Cantonal Hospital St, Gallen, St. Gallen, Switzerland.
E-mail addresses: simon.rauch@eurac.edu (S. Rauch), joachim.koppenberg@cseb.ch (J. Koppenberg), Dario.josi@iee.unibe.ch (D. Josi), lorenz.meuli@usz.ch (L. Meuli), giacomo.strapazzon@eurac.edu (G. Strapazzon), Mathieu.Pasquier@chuv.ch (M. Pasquier), Roland.Albrecht@rega.ch (R. Albrecht), hermann.brugger@eurac.edu (H. Brugger), zweifel@slf.ch (B. Zweifel), urs.pietsch@kssg.ch (U. Pietsch).
https://doi.org/10.1016/j.resuscitation.2022.03.023
Received 7 February 2022; Received in Revised form 15 March 2022; Accepted 18 March 2022
Available online xxxx

recorded. The survival status was recorded at hospital discharge for victims who were transported to a medical facility, or on site for victims not transported.[10] For the survival analysis, only completely buried victims were included while non-buried or partially buried victims were excluded because the survival rates are not comparable (50% for completely buried vs approximately 95% for partially buried victims).[2] To determine the survival rate in relation to the time of day only avalanches for which the time of the event was recorded with an accuracy of ±1 h were selected. 223 victims were excluded from the analysis of search and rescue times due to missing and inaccurate data regarding the duration of burial (accuracy deviated more than ±30 min). Additionally, only victims which were rescued within the first 8 h of burial were considered (excluding other additional 54 victims). This rescue-time limit was chosen because we found a clear difference in the median rescue times at night below (median 89 min [range: 7–460]) and above (median 2693 min [range: 1140–18,393]) this cut-off, i.e., either a victim was found within 8 h or the search and rescue times prolonged to days. Such long avalanche rescue missions are often temporarily interrupted and are hardly comparable to shorter rescue missions. Moreover, we found no victim that survived a burial duration of >8 h at night.

To distinguish avalanches that occurred at daytime from avalanches that occurred at the nighttime, the time of sunrise and sunset for each first day of the month was extracted from the database quoted in Appendix A. An avalanche was classified as a daytime avalanche when it occurred between sunrise and sunset. Avalanches occurring between sunset and sunrise were classified as night avalanches.

The institutional review board of the cantonal ethics committee (EKOS) reviewed the study design and granted permission for the use of patient data without individual consent, according to the federal act on research involving human beings, and the ordinance on human research with the exception of clinical trials. The permission covers the use of anonymized patient data (EKOS Ostschweiz, February 7th, 2021, reference number 2021–00145).

Statistical analysis

All analyses were done with the software R, version 4.1.1.[11] The generalised linear mixed model (GLMM) was fitted with the package lme4.[12] Continuous variables were skewed and analyzed using Mann-Whitney U tests. Categorical variables were summarized with counts and compared with a Fisher's exact test. P-values are two-sided with an alpha-level of 5%. To estimate the survival rate in relation to the time of day, a GLMM with a binomial error distribution was fitted with survival (yes/no) set as response variable. The time point of the avalanche was transformed into seconds of the day. These values were entered into following formulas $\sin(2*\pi*\text{time}/86400)$ and $\cos(2*\pi*\text{time}/86400)$ which were included as predictors (for circular data) in the GLMM. Because avalanches buried more than one person in many cases, we included the identification number of the avalanche as a random effect. To investigate whether possible differences in survival were related to the different burial duration of the victims during day and night we used a Man-Whitney-U test.

Results

During the 22-year time period, a total of 2499 avalanches with 4270 victims were recorded. 378 victims were excluded from the analysis due to a lack of information on their extent of burial. The remaining 3892 avalanche victims were included in the analysis: 957 victims were completely buried, 1501 partially buried and 1434 were not buried by the avalanche (Fig. 1). Demographics of the victims, accident circumstances, rescue details, as well as duration of burial and depth of burial were subdivided between night and day are reported in Table 1.

Seventy-two out of 3892 avalanche victims (1.85%) accrued at nighttime. Nearly half of the victims involved in a night avalanche (48.8%) were completely buried and approximately one quarter (24.2%) was either partially or not buried (Fig. 1). While about 80% of the completely buried victims died, nearly all partially or non-buried victims survived the night avalanche accident (Fig. 1).

Survival probability in relation to the time of day

Of the 957 completely buried victims, 5 were excluded from the analysis due to missing survival data. The survival probability changed over the time of the day. The predicted survival probability was the highest around midday at 63.0% (95% CI: 58.2–67.5), and decreased to 40.4% (95% CI: 30.3–51.4) at sunset. At midnight the survival probability was only 28.7% (95% CI: 11.9–54.4) which is 2.2 times lower compared to midday. Survival probability as a function of the time of day of the avalanche is shown in Fig. 2.

Search and rescue at day-versus nighttime

Completely buried victims were less often rescued by a companion during night (5/33) compared to during day (471/924), p <.001, and were less likely to be localized with an avalanche transceiver during night (8/33) compared to daytime (405/924), p =.03. This can partially be explained by a significant association between the time of day and whether victims were ski touring/hiking or not (Fisher's exact test: p = 0.06). 62% (573/914) of all victims who were buried from avalanches during daytime were ski touring/hiking compared to only 45% (15/33) during the night.

The duration of search and rescue operations was analysed on a subset of 680 of 957 completely buried victims for whome the relevant time information was available. 666 victims were buried during daytime and 14 during the nighttime. The search and rescue of completely buried avalanche victims at night took significantly longer than during the day (median 89 min [IQR: 25–248] at night vs 20 min [IQR: 9–45] during the day, p =.002).

Discussion

In our study we show for the first time that survival probability after complete avalanche burial changes based on the time of day with midday being the time with the highest probability of survival. Most avalanche accidents happen during daytime; avalanche burial at night is a rare event (slightly less than 2% of all burials in our study) and complete burial at night is associated with a longer duration of burial and lower survival probability compared to daytime.

The survival probability is the highest around midday, declines towards sunset and is the lowest at midnight. The most likely explanation for this finding is the longer duration of burial during the nighttime compared to the daytime (median 89 vs 20 min), as survival from avalanche burial strongly depends on burial duration.[5,3,7] The longer duration of burial during the nighttime could have several reasons. First, the rate of companion rescue is lower during the night because the accident might not be observed or because orientation on the avalanche site and visual search (i.e., looking for visual clues

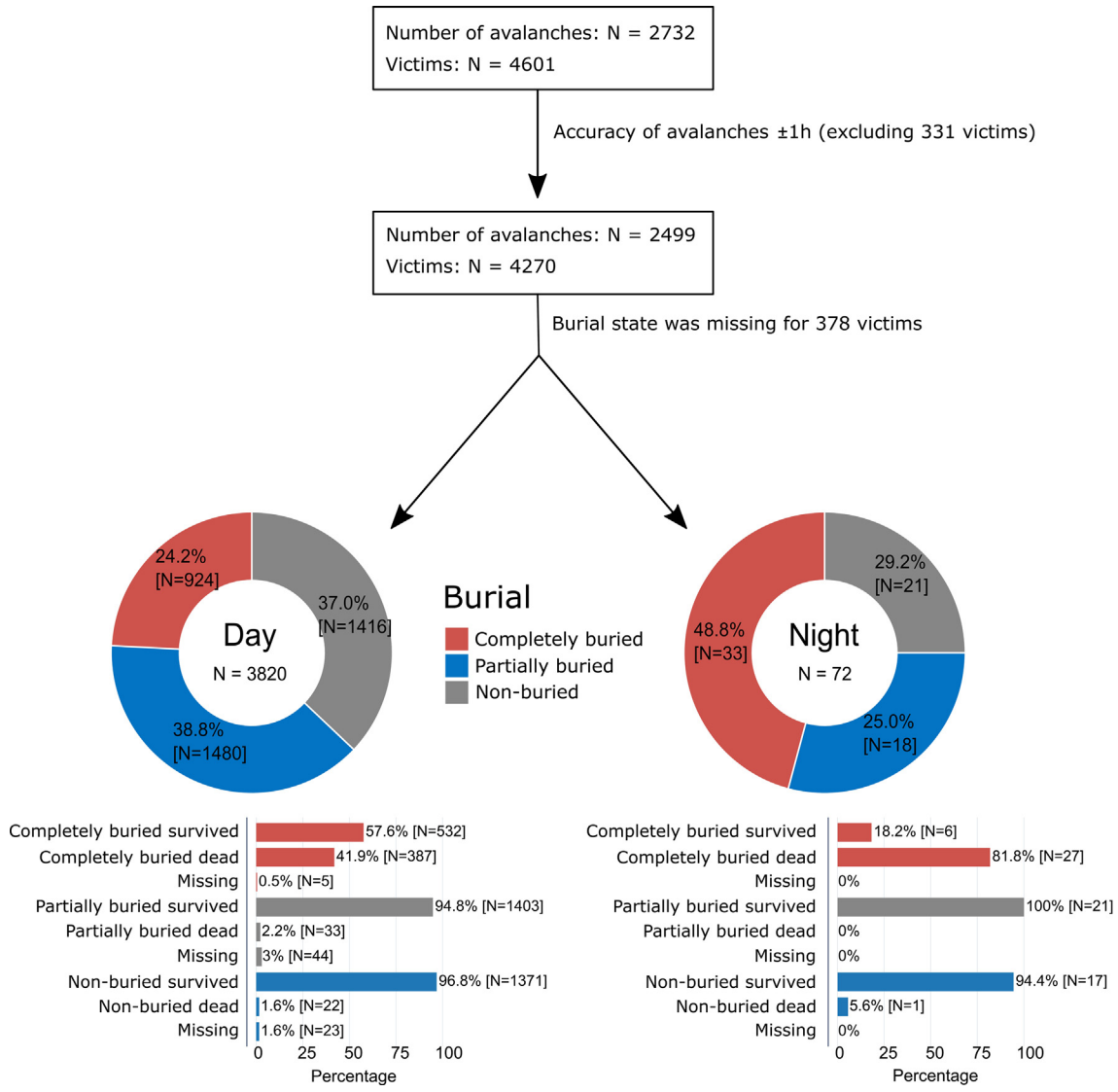

Fig. 1 – Data selection and degree of avalanche burial (%) and survival rate (%) at day- and nighttime.

on the surface of the avalanche) is more difficult. Search and rescue by uninjured companions is faster than organized rescue for obvious reasons and the likelihood of survival was found to be four times higher if the victim is rescued by companions compared to organized rescue.[13] Second, fewer victims of night avalanches wore an avalanche transceiver. An avalanche transceiver helps in localising the buried avalanche victims and might reduce the duration of burial. Third, the time from emergency call to arrival of the rescue team is longer during the night.[14] Helicopter emergency medical systems (HEMS) play a major role during avalanche accidents as they can bring rescue teams to the avalanche site very rapidly.[13] Yet, not all helicopters are equipped for night flying operations and even where search and rescue helicopters are available 24/7 like in Switzerland, activation and flight times are longer.[14] This is due to additional safety procedures for night flying operations and because picking up rescue specialists or avalanche dogs takes longer at night.[14] Fourth, once the rescue team is on site, the search for the buried avalanche victim might take longer, e.g. because additional materials such as illumination of the avalanche site must be set up and environmental conditions are often harsher during the night, making search and rescue operations more difficult. Fifth, the depth of burial was greater in night avalanches. A previous study found that burial depth is most likely not an independent factor determining survival, however, depth was closely related to the duration of burial.

Limitations

The main limitation of our study is the small number of avalanche accidents during nighttime, which makes it more difficult to estimate survival probabilites with a high degree of certainty.

Our study has a long (22 years and largest ever analysed dataset on this topic) observation period which could cause an attenuation of the differences in mortality between day and night through improvements of search and rescue techniques over the study period. However, a low incidence of an event calls for long observation periods to obtain a reasonable sample size.

In addition, information on the duration of burial was missing for a substantial proportion of the victims. It was assumed that this lack of information was completely random. However, this cannot be verified and therefore might carry the risk of selection bias.

Table 1 – Baseline data of avalanche victims in Switzerland between 1998 and 2020 (n = 3892).

Survival	Completely buried N = 957					Partially buried N = 1501					Non-buried N = 1434				
	Night		Day			Night		Day			Night		Day		
	Dead N = 27	Alive N = 6	Dead N = 387	Alive N = 532	Missing N = 5	Dead N = 0	Alive N = 21	Dead N = 33	Alive N = 1′403	Missing N = 44	Dead N = 1	Alive N = 17	Dead N = 22	Alive N = 1′371	Missing N = 23
Sex					238					1023					1074
m	20 (74%)	4 (100%)	314 (82%)	227 (74%)		0 (NA%)	5 (83%)	29 (91%)	347 (81%)		1 (100%)	2 (100%)	20 (91%)	275 (84%)	
Age [years]					305					1159					1224
Median (IQR)	41 (28,48)	38 (35,41)	39 (30,50)	40 (29,50)		NA	30 (24,33)	25 (22,35)	36 (27,48)		50 (50,50)	26 (26,26)	37 (30,43)	35 (26,45)	
N	27	4	371	250		0	4	32	297		1	1	22	185	
Activity					7					36					26
Village / Street / Hut	14 (52%)	0 (0%)	11 (2.8%)	17 (3.2%)		0 (NA%)	9 (43%)	1 (3.0%)	54 (3.9%)		0 (0%)	8 (47%)	1 (4.5%)	107 (7.9%)	
Rescue team	2 (7.4%)	1 (17%)	1 (0.3%)	2 (0.4%)		0 (NA%)	4 (19%)	0 (0%)	3 (0.2%)		0 (0%)	1 (5.9%)	0 (0%)	1 (<0.1%)	
Ski touring/Hiking	10 (37%)	5 (83%)	247 (64%)	326 (62%)		0 (NA%)	8 (38%)	24 (73%)	892 (65%)		1 (100%)	7 (41%)	18 (82%)	842 (63%)	
Off-pist skiing	1 (3.7%)	0 (0%)	128 (33%)	182 (35%)		0 (NA%)	0 (0%)	8 (24%)	421 (31%)		0 (0%)	1 (5.9%)	3 (14%)	397 (29%)	
Rescue					52					930					1129
Companion	3 (11%)	2 (40%)	110 (29%)	361 (72%)		0 (NA%)	1 (17%)	2 (11%)	133 (25%)		0 (NA%)	0 (0%)	0 (0%)	11 (3.8%)	
Rescue team	24 (89%)	2 (40%)	261 (70%)	111 (22%)		0 (NA%)	0 (0%)	16 (89%)	35 (6.5%)		0 (NA%)	0 (0%)	8 (100%)	31 (11%)	
Self	0 (0%)	1 (20%)	3 (0.8%)	27 (5.4%)		0 (NA%)	5 (83%)	0 (0%)	371 (69%)		0 (NA%)	6 (100%)	0 (0%)	249 (86%)	
Tracing agent					144					1372					1386
Observation - Digging	21 (78%)	1 (33%)	164 (46%)	208 (49%)		0 (NA%)	0 (NA%)	18 (95%)	100 (92%)		0 (NA%)	0 (NA%)	5 (100%)	41 (95%)	
LVS	6 (22%)	2 (67%)	188 (53%)	217 (51%)		0 (NA%)	0 (NA%)	1 (5.3%)	9 (8.3%)		0 (NA%)	0 (NA%)	0 (0%)	2 (4.7%)	
other	0 (0%)	0 (0%)	3 (0.8%)	3 (0.7%)		0 (NA%)	0 (NA%)	0 (NA%)	0 (NA%)		0 (NA%)	0 (NA%)	0 (NA%)	0 (NA%)	
Burial duration [min]					170					1501					1434
Median (IQR)	885 (152, 3′518)	96 (11,240)	45 (30,120)	10 (5,20)		NA	NA	NA	NA		NA	NA	NA	NA	
N	26	4	366	391		0	0	0	0		0	0	0	0	
Burial depth [cm]					218					1501					1434
Median (IQR)	150 (50,400)	50 (50,50)	100 (60,170)	50 (30,100)		NA	NA	NA	NA		NA	NA	NA	NA	
N	25	5	347	362		0	0	0	0		0	0	0	0	

This table includes all data where the time point of the avalanche has an accuracy of ±1 h and the burial state is known.

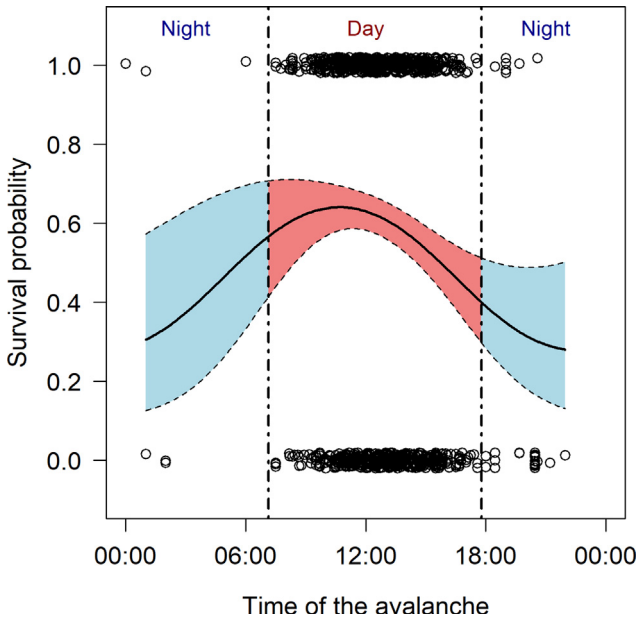

Fig. 2 – Avalanche survival probability as a function of the time of day of the accident of 952 victims (intercept: −0.190; sinus: mean ± SE: 0.256 ± 0.184; p = 0.16; cosinus: mean ± SE: −0.722 ± 0.298; p = 0.01). Black line represents the predicted regression line and dashed lines indicated the 95% confidence intervals. Nighttime (light blue) was classified between sunset and sunrise and daytime is indicated in red.

Last, the time interval from the emergency call to the arrival on scene of the rescue team is unknown for a relevant number of rescue missions. This time interval is relevant as avalanche emergencies are time critical, and it should therefore be recorded and investigated in detail in further studies.

Conclusions

Avalanche accidents during the night are a rare event, and probability of survival after complete burial is lower during the nighttime compared to the daytime. The most relevant reason for this is the longer duration of burial, which is in part explained by the lower rate of companion rescue and the lower rate of victim localisation with an avalanche transceiver. Outdoor activities in potential avalanche areas should therefore never be practiced alone and avalanche safety equipment should always be worn, especially at night.

Funding source

None.

Conflicts of interest

None.

CRediT authorship contribution statement

Simon Rauch: Conceptualization, Methodology, Investigation, Writing – original draft. **Joachim Koppenberg:** . **Dario Josi:** Formal analysis, Data curation. **Lorenz Meuli:** Formal analysis, Data curation. **Giacomo Strapazzon:** Writing – review & editing. **Mathieu Pasquier:** Writing – review & editing. **Roland Albrecht:** Data curation, Writing. **Hermann Brugger:** Supervision. **Benjamin Zweifel:** Formal analysis, Data curation. **Urs Pietsch:** Supervision, Conceptualization, Methodology, Writing – original draft.

Acknowledgements

We acknowledge Ms. Jeannie Wurz and Pascal Doppmann, who served as English language editors for this manuscript.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2022.03.023.

Author details

[a]*Department of Anaesthesiology and Intensive Care Medicine, F. Tappeiner Hospital, Merano, Italy* [b]*Institute of Mountain Emergency Medicine, Eurac Research, Bozen, Italy* [c]*Department of Anaesthesiology, Pain Therapy and Emergency Medicine, Lower Engadine Hospital and Health Centre, Scuol, Switzerland* [d]*Aquatic Ecology, Institute of Ecology and Evolution, University of Bern, Bern, Switzerland* [e]*Department of Fish Ecology and Evolution, EAWAG Swiss Federal Institute of Aquatic Science and Technology, Center for Ecology, Evolution and Biogeochemistry, Kastanienbaum, Switzerland* [f]*Department of Vascular Surgery, University Hospital Zurich, Zurich, Switzerland* [g]*Department of Anaesthesiology and Intensive Care Medicine, Innsbruck Medical University, Innsbruck, Austria* [h]*Emergency Department, Lausanne University Hospital, Lausanne, Switzerland* [i]*Swiss Air-Ambulance, Rega (Rettungsflugwacht/Guarde Aérienne), Zurich, Switzerland* [j]*WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland* [k]*Department of Anaesthesiology and Intensive Care Medicine, Cantonal Hospital St, Gallen, St. Gallen, Switzerland* [l]*Department of Emergency Medicine, Inselspital, Bern University Hospital, University of Bern, Bern, Switzerland*

REFERENCES

1. Techel F, Jarry F, Kronthaler G, et al. Avalanche fatalities in the European Alps: long-term trends and statistics. Geogr Helvetica 2016;71:147–59.
2. Brugger H, Durrer B, Adler-Kastner L, Falk M, Tschirky F. Field management of avalanche victims. Resuscitation 2001;51:7–15.
3. Haegeli P, Falk M, Brugger H, Etter HJ, Boyd J. Comparison of avalanche survival patterns in Canada and Switzerland. CMAJ 2011;183:789–95.

4. 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.
5. Falk M, Brugger H, Adler-Kastner L. Avalanche survival chances. Nature 1994;368:21.
6. Procter E, Strapazzon G, Dal Cappello T, et al. Burial duration, depth and air pocket explain avalanche survival patterns in Austria and Switzerland. Resuscitation 2016;105:173–6.
7. Strapazzon G, Brugger H, Paal P, Brown D. Reconsidering the air pocket around mouth and nose as a positive outcome predictor in completely buried avalanche victims. Resuscitation 2020;152:208–9.
8. Strapazzon G, Paal P, Schweizer J, et al. Effects of snow properties on humans breathing into an artificial air pocket – an experimental field study. Sci Rep 2017;7:17675.
9. Hohlrieder M, Brugger H, Schubert HM, Pavlic M, Ellerton J, Mair P. Pattern and severity of injury in avalanche victims. High Altitude Med Biol 2007;8:56–61.
10. 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.
11. Team R Core. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2021.
12. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. J Stat Softw 2015;67:1–48.
13. Mair P, Frimmel C, Vergeiner G, et al. Emergency medical helicopter operations for avalanche accidents. Resuscitation 2013;84:492–5.
14. Pietsch U, Knapp J, Mann M, et al. Incidence and challenges of helicopter emergency medical service (HEMS) rescue missions with helicopter hoist operations: analysis of 11,228 daytime and nighttime missions in Switzerland. Scand J Trauma, Resuscit Emergency Med 2021;29:92.