The impact of avalanche rescue devices on survival☆

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Avalanche rescue devices

Summary

Background: Within Europe and North America, the median annual mortality from snow avalanches between 1994 and 2003 was 141. There are two commonly used rescue devices: the avalanche transceiver, which is intended to speed up locating a completely buried person, and the avalanche airbag, which aims to prevent the person from being completely buried.

Objective: This retrospective study aimed to evaluate whether these avalanche rescue devices had an effect on mortality.

Methods: The study population was 1504 persons who were involved in 752 avalanches either in Switzerland from 1990 to 2000 and from 2002 to 2003 (1296 persons, 86.2%) or in Austria from 1998 to 2004 (208 persons, 13.8%).

Results: Persons equipped with an avalanche airbag had a lower chance of dying (2.9% versus 18.9%; \( P = 0.026, \) OR 0.09, \( n = 1504 \)). In persons who were completely buried, without visible or audible signs at the surface and who did not rescue themselves (\( n = 317 \)), we found a lower median duration of burial (25 min versus 125 min; \( P < 0.001 \)) and mortality (55.2% versus 70.6%; \( P < 0.001, \) OR 0.26) in those using an avalanche transceiver than in those not using the device.

Conclusions: Our data showed that both the avalanche airbag and the avalanche transceiver reduce mortality. However, to improve the evaluation of rescue devices in the future, the data collection procedures should be reviewed and prospective trials should be considered, as the reliability of retrospective studies is limited.

KEYWORDS
Avalanche; Avalanche transceiver; Avalanche airbag; Mountain rescue; Mortality; Prevention; Rescue devices; Safety

Introduction

In the 17 member countries of the International Commission for Alpine Rescue (ICAR) in Europe and North America, the median annual mortality from snow avalanches registered between 1994 and 2003 was 141 (range 111—199). Most avalanche accidents are sports-related and involve skiers, snowboarders and, especially in the USA, snowmobilers, in open, i.e. non-controlled, areas away from ski resorts. If caught in an avalanche, the chance of survival depends on: (a) the grade of burial; (b) the duration of burial; (c) the presence of an air pocket and a clear airway and (d) the severity of mechanical injuries.

A Swiss analysis of avalanche accidents between 1981 and 1998 showed an overall mortality rate of 23.0%. This rose to 52.4% for those victims who were completely buried but in only 4.2% of persons who were partially or not buried. A "complete burial" is defined as where snow covers the victim’s head and chest; otherwise the term "partial burial" applies.

For completely buried victims, survival is related to the duration of burial. The calculated survival function for avalanche burials in open areas, presented by Brugger et al. in 2001, shows a precipitous drop in survival probability from 91% at 18 min after burial to 34% at 35 min (acute asphyxiation of victims without an air pocket), a flattening of the curve between 35 and 90 min ("latent phase" for victims with an air pocket), followed by a second drop to only 7% at 130 min (death of victims with a "closed" air pocket from slow asphyxia and hypothermia). Victims completely buried under an avalanche cannot survive beyond 35 min without an air pocket. An air pocket is defined as any air space surrounding the mouth or nose, no matter how small, with a patent airway.

The significance of major trauma in causing death in avalanche accidents is controversial, as the incidence of fatal injury in the published studies has varied between 48 and 50%. A recent study on 105 avalanche victims in Austria (1996—2005) reports 5.6% died from injury.

From these studies, it is inferred that death from an avalanche is attributable primarily to asphyxiation, whereas hypothermia and fatal injuries are of lesser importance. All rescue devices for skiers and snowboarders currently on the market aim to avoid acute asphyxiation by (a) reducing the depth of burial, (b) reducing the duration of burial or (c) by prolonging survival after complete burial.

There are two commonly used rescue devices: the avalanche transceiver, which is intended to speed up locating a completely buried person, and the avalanche airbag, which aims to prevent the person from being completely buried.

1. The avalanche transceiver, developed in 1968 in the USA, is capable of transmitting and receiving an electromagnetic signal at 457 kHz. The device is intended for the search for completely buried persons, who have no visible or audible sign at the surface; both the buried person and the searching companion have to be equipped with a transceiver. In a retrospective analysis...
of 328 complete burials in Switzerland between 1981 and 1994, Brugger et al. showed that using an avalanche transceiver to locate a buried victim reduced the median extrication time significantly from 120 to 35 min, but the decrease in the mortality rate was not significant (76—66%; \( P = 0.054 \)). A subsequent study by Hohlrieder et al. on 278 complete burials in the Austrian Alps between 1994 and 2003 showed a significant reduction in median burial time from 102 to 20 min, as well as a significant reduction in mortality from 68.0 to 53.8% \( (P = 0.011) \). In the last decade, transceivers have been developed further, using multiple antennae and optical displays, so that in ideal conditions they will give an accurate indication of the search direction and distance to the buried person. This appears to have improved location efficiency. It has also been recognized that the rescuer must have an avalanche probe and a shovel to dig out the victim(s) from the snow as quickly as possible if the reduced location time achieved with a transceiver is to be translated into a significant reduction in mortality.

2. The avalanche airbag came to the market in 1991. It consists of two balloons integrated into a backpack. By pulling a string, the balloons fill with 120—150 l of a mixture of nitrogen from a cartridge and environmental air. In an avalanche, the skier avoids being completely buried by using the physical effect of "inverse segregation"; the skier remains on the surface of the snow or is only partially buried.

To date, no study has been made to compare the efficiency of these avalanche rescue devices. It is the aim of this study to evaluate the influence of both avalanche rescue devices on mortality during avalanche accidents.

Materials and methods

Data collection

A retrospective data analysis was performed of all recorded avalanche accidents involving persons buried in open areas, excluding persons buried in buildings and vehicles, from Switzerland winter 1990/1991 to 2003/2004 (without 2001/2002) and Austria from 1998/1999 to 2004/2005 \( (n = 2337) \). In Switzerland, data is collected by the Swiss Institute for Snow and Avalanche Research, Davos, Switzerland; data from 2001/2002 have been omitted as the records for this winter were incomplete. In Austria, data is collected by the Austrian Board for Mountain Safety, Innsbruck, Austria.

Data analysis

The data collected were highly heterogeneous so several cofactors correlated with mortality had to be considered in the evaluation of a rescue device. To test if a cofactor influenced mortality we used first loglinear regression analysis to identify cofactors and cofactor interactions. We followed this by a backward-likelihood ratio logistic regression \( (\text{exclusion criteria } P > 0.1) \) on mortality that included the cofactors and interactions identified by the loglinear analysis. In order to adjust for possible disturbance variables we considered the following, sufficiently documented cofactors: width (at the break) and length of the avalanche, year of accident (in 5-year intervals 1990—1994, 1995—1999, 2000—2004), grade of burial (coded as completely buried, i.e. head covered by snow versus partially or not buried, i.e. head remains out), depth of burial (i.e. head of the victim), type of group (coded as one person, a group of persons or a group with the presence of a mountain guide), activity (ski tourers in open, non-controlled areas versus off-piste skiers, who use mechanical ascent and then ski downhill away from the piste), and country (Switzerland or Austria). Due to skewness of the distribution of width and length of avalanche as well as burial depth these variables have been log transformed for the analysis.

Subgroup analysis

We checked each record to ascertain the use of rescue devices. The presence of an avalanche airbag was well documented in all avalanched persons. However, in Switzerland the avalanche transceiver was only reliably documented for completely buried persons who were located by using the transceiver; whereas in Austria, it was documented if the person had a transceiver regardless of whether it was used for location or not. Hence, we used two different datasets for the analysis. For the airbag analysis \( (n = 1504) \) we included the presence or absence of an avalanche airbag and, for the avalanche transceiver analysis we included the presence or absence of a transceiver \( (\text{excluding the cofactors grade of burial and the presence of an airbag}) \). In the transceiver analysis, the dataset was further reduced because self extricated persons, not completely buried persons or persons with visible or audible signs (an airbag was regarded as a visible sign) \( (n = 1187) \) were excluded, leading to a total of 317 cases (Figure 1).
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Figure 1 Flowchart describing inclusion and exclusion criteria.

Data is presented as frequencies or mean/median, minimum, maximum and standard deviation as appropriate. Comparisons of single groups for counted data were carried out by means of the Chi-square test and for continuous data the Kruskal–Wallis H-test or the Mann–Whitney U-test was applied. A p-value ≤ 0.05 was considered statistically significant and SPSS 13 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Results

Of the 2337 persons, we excluded 833 (35.6%) because of missing data on the width and length of the avalanche; the remaining 1504 persons who were involved in 752 avalanches were included in this study (Figure 1). 1296 (86.2%) persons were involved in an avalanche in Switzerland, and 208 (13.8%) in Austria. The mortality of persons excluded (150 out of 833, 18%) was not significantly different from those included (279 out of 1504, 18.6%; P = 0.75 Chi-square test) hence missing data did not introduce a bias.

Table 1 shows the mortality rate of the total study population and its relationship to the grade of burial. The mortality rate (57 of 208, 27.4% versus 222 of 1296, 17.1%; P < 0.001) as well as the rate of complete burial (92 of 208, 44.2% versus 414 of 1296, 31.9%; P < 0.001) was higher in the Austrian cohort compared with the Swiss cohort. Similarly, we found a deeper burial depth in Austria than in Switzerland (75th percentile 95 cm versus 30 cm, interquartile range 95 cm versus 30 cm; P = 0.027, Mann–Whitney U-test).

Table 2 shows the mortality rate in the two groups that we used for analysing the two rescue devices—the avalanche airbag (n = 1504) and the electronic avalanche transceiver (n = 317). The mortality rate for the cofactors grade and depth of burial; activity of the persons involved (ski

Table 1  Mortality of persons involved in avalanches in relation to the grade of burial

<table>
<thead>
<tr>
<th>Country</th>
<th>Survivorsa</th>
<th>Non-survivorsa</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland\textsuperscript{b}</td>
<td>Completely buried\textsuperscript{c}</td>
<td>224 (54.1%)</td>
<td>190 (45.9%)</td>
</tr>
<tr>
<td></td>
<td>Partially or non-buried</td>
<td>850 (96.4%)</td>
<td>23 (3.6%)</td>
</tr>
<tr>
<td></td>
<td>Total\textsuperscript{e}</td>
<td>1074 (82.9%)</td>
<td>222 (17.1%)</td>
</tr>
<tr>
<td>Austria\textsuperscript{f}</td>
<td>Completely buried\textsuperscript{c}</td>
<td>36 (39.1%)</td>
<td>56 (60.9%)</td>
</tr>
<tr>
<td></td>
<td>Partially or non-buried</td>
<td>115 (99.1%)</td>
<td>1 (0.9%)</td>
</tr>
<tr>
<td></td>
<td>Total\textsuperscript{e}</td>
<td>151 (72.6%)</td>
<td>57 (27.4%)</td>
</tr>
<tr>
<td>Total</td>
<td>Completely buried</td>
<td>260 (51.4%)</td>
<td>246 (48.6%)</td>
</tr>
<tr>
<td></td>
<td>Partially or non-buried</td>
<td>965 (96.7%)</td>
<td>33 (3.3%)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1225 (81.4%)</td>
<td>279 (18.6%)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Status on extrication or at hospital discharge.

\textsuperscript{b} From 1990 to 2000 and from 2002 to 2003.

\textsuperscript{c} Comparison between countries for survivors in completely buried persons; \( P < 0.01 \).

\textsuperscript{d} Comparison between countries for burial grade; \( P < 0.001 \).

\textsuperscript{e} Comparison between countries for survivors independent of burial grade; \( P < 0.001 \).

\textsuperscript{f} From 1998 to 2004.
## Table 2  Avalanche survival in relation to cofactors and rescue devices

<table>
<thead>
<tr>
<th>Total persons</th>
<th>Survivors</th>
<th>Non-survivors</th>
<th>Total</th>
<th>P (OR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1225 (100%)</td>
<td>121 (38.2%)</td>
<td>196 (61.8%)</td>
<td>317 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

### Grade of burial
- Completely buried: 260 (51.4%) 246 (48.6%) 506 (33.6%) <0.001 (44.23)
- Partially or not-buried: 965 (96.7%) 33 (3.3%) 998 (66.4%)

### Depth of burial (cm)
- 0 (0—700): 0 (0—700) 0.003
- 100 (0—650): 100 (0—650)

### Activity
- Ski tourers: 769 (81.1%) 179 (18.9%) 948 (63.0%) n.s.
- Off-piste skiers: 456 (82.0%) 100 (18.0%) 556 (37.0%)

### Group
- 1 member: 110 (74.7%) 38 (25.3%) 148 (9.8%) n.s.
- ≥2 members without guide: 769 (82.2%) 167 (17.8%) 936 (62.5%)
- ≥2 members with guide: 346 (82.4%) 74 (17.6%) 420 (27.9%)

### Avalanche
- Width (m) (at the break): 93.5 (137.82) 123.8 (114.02) 99.1 (134.21) n.s.
- Length (m): 297.9 (276.38) 513.3 (441.30) 337.8 (324.41) <0.001

### Year
- 1990—1994: 243 (73.6%) 87 (26.4%) 330 (21.9%) 0.005
- 1995—1999: 534 (82.9%) 110 (17.1%) 644 (42.8%)
- 2000—2004: 448 (84.5%) 82 (15.5%) 530 (35.2%)

### Country
- Switzerland: 1074 (82.9%) 222 (17.1%) 1296 (86.2%) 0.004 (2.11)
- Austria: 151 (72.6%) 57 (27.4%) 208 (13.8%)

### Avalanche airbag
- Equipped: 34 (97.1) 1 (2.9%) 35 (2.3%) 0.026 (0.09, 95% CI 0.01—0.75)
- Not equipped: 1191 (81.1%) 278 (18.9%) 1469 (97.7%)

### Avalanche transceiver
- Used for location: 81 (44.8%) 100 (55.2%) 181 (57.1%) <0.001 (0.26, 95% CI 0.14—0.48)
- Not used for location: 40 (29.4%) 96 (70.6%) 136 (42.9%)

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a For the analysis of persons who were equipped, or not, with an avalanche airbag we included all persons who where caught by avalanches, irrespective of the grade of burial (n = 1504).
b For the analysis of persons who were located by using, or not, an electronic avalanche transceivers, only completely buried persons out from the same dataset were included, except self-rescued persons or persons who were located by visible or audible signs (n = 317).
c On extrication or at hospital discharge.
e Median values in centimetres (minimum-maximum).
f Mean values in metres (standard deviation). OR = odds ratio. CI = Confidence interval.
tourers, off-piste skiers); type of group (alone, group, guided group); the width and length of the avalanche, year (1990—1994, 1995—1999, 2000—2004) and country is shown. Furthermore, the interactions between length and width, and, type of group and grade of burial, where included in the model (data not shown).

**Airbag analysis**

In the group used for the avalanche airbag analysis, the mortality rate was significantly lower in those who were equipped with an airbag compared with those without (2.9% versus 18.9%; $P = 0.026$; odds ratio [OR] 0.09, corresponding to a relative reduction in mortality of 91% with a 95% confidence interval ranging from 25 to 99%). Deeply buried persons ($P = 0.003$) and completely buried persons had a higher mortality than partially or not buried persons ($P < 0.001$, OR completely buried 44.23). Moreover, mortality increased with the length of the avalanche ($P < 0.001$). Accident year showed a decrease in mortality from 1990—1994 to 1995—1999 and 2000—2004 ($P = 0.005$, OR 0.66 and 0.46, respectively). A marginal influence on mortality was found comparing ski tourers and off-piste skiers ($P = 0.059$, OR 1.42). Although the grade and depth of burial were compensated in the model we still found a higher mortality in Austria ($P = 0.004$, OR 2.11).

Thirty-five persons had an avalanche airbag in this study; thirty-four (97.1%) survived; the one who (2.9%) that died was an off-piste skier who was crushed against a tree and was fatally injured during the avalanche. In 7 of 35 cases (20%), the balloons had not inflated either due to a technical failure (two cases—in one case, the balloons were ripped off the rucksack, and in another the cartridge was empty) or because the user was not able to activate the balloons by pulling the string (five cases). Six of 28 (21.4%) persons who achieved fully inflated balloons had been completely buried but in all cases the balloon was visible on the surface of the avalanche and all these persons survived.

**Avalanche transceiver analysis**

In the subgroup used for the analysis of avalanche transceivers, we found a significant lower duration of burial (25 min versus 125 min; $P < 0.001$ Mann—Whitney U-test) and mortality (55.2% versus 70.6%; $P < 0.001$; OR 0.26, corresponding to a relative reduction in mortality of 74% with a 95% confidence interval ranging from 52 to 86%) in persons who were located by using an avalanche transceiver than without. Burial depth was not significantly different between those groups ($P = 2.44$). The length of the avalanche ($P < 0.001$) had a significant impact on mortality. Only a marginal influence could be found for avalanche width ($P = 0.096$), accident year ($P = 0.074$, OR 1995—1999 0.46, 2000—2004 0.62) and the variable of skitourers versus off-piste skiers ($P = 0.089$, OR 1.69). The type of group ($P = 0.738$) and country ($P = 0.406$) showed no influence on mortality. Overall, the median burial duration of complete burials decreased from 1990—1994 (64 min, range 5 min—80 h) to 1995—1999 (35 min, range 2 min—500 h) and 2000—2004 (30 min, range 3 min—1000 h; $P = 0.001$) whereas burial depth of completely buried victims was not significantly different ($P = 0.434$). No interaction effect was observed in this subgroup.

No person in either of the data sets was equipped with newer rescue devices such as Avalung™ or Avalanche Ball.22—24

**Discussion**

The higher mortality rate in Austria compared with Switzerland is partially due to the higher rate of complete burial and the higher burial depth in the Austrian Alps. However, even after compensation of the grade and depth of burial mortality still remained significantly higher in Austria. This might be caused by topographic and logistic differences.

In this study, persons equipped with an avalanche airbag who were caught by an avalanche had a greatly reduced mortality rate; the relative risk of being killed was reduced by 91%. However, the analysis shows that in 20% of the avalanche accidents where an airbag was worn, the balloons did not inflate either due to technical failure or because the user was unable to activate the airbag by pulling the string. Moreover, in 21.4% of cases in which the airbag inflated correctly, the user’s head and chest was still buried. Fortunately, a prompt extrication from the snow by unburied companions was possible in all these cases. After the end of the study period, the producer of the airbag has improved the mechanism of activation. However, the high rate of complete burial suggests that improving the buoyancy system with the aim of reducing snow coverage of the head would be worthy of consideration.

Search of a completely buried person with an electronic avalanche transceiver significantly reduced the duration of burial and the mortality rate; the relative risk of being killed in a complete
burial was reduced by 74%. Our findings confirm the results of a previous study carried out in Austria that found a similar reduction of burial time from 102 to 20 min and decrease in mortality from 68.0 to 53.8%. In both the studies, however, the benefit of a transceiver is demonstrable only in persons who are completely buried.

During the observed period from 1990 to 2004 we found a significant decrease of mortality in persons involved in avalanches in Switzerland and in Austria, and a concomitant decrease of the median burial duration of complete burials, over time. This finding suggests that rescue devices may have become an increasingly important factor in preventing cardiac arrest.

Limitations

This study is a retrospective analysis of rescue data aimed at determining the influence of rescue devices on mortality rate. Such observational studies are frequently subject to systematic errors that may adulterate any statistical calculation. A major problem is that the records of avalanches are not designed to evaluate rescue devices, and hence the records continue to be incomplete. While being equipped with an avalanche airbag is well documented in all persons involved in avalanches, the avalanche transceiver is mostly documented in completely buried persons who were found by using the transceiver. Thus, in this study, partially or not buried persons who were found by visible or audible signs might not be documented in the dataset, even though they were equipped with an avalanche transceiver. It should also be taken into consideration that some avalanche accidents would not have been documented at all, especially when those involved were only partially or not buried and the rescue services not contacted. In order to avoid these problems we used different datasets for the analysis. By this procedure we were able to reduce the risk of bias, but the aim of comparing avalanche rescue devices within the same study population was not possible and, with regard to the avalanche transceiver, the results cannot be simply transferred to the whole population of ski tourers and off-piste skiers. The statistical model was primarily used to evaluate rescue devices with a secondary analysis for possible cofactors. As a consequence, the possible influence of these cofactors on mortality should be interpreted with care. Moreover, this study reflects the specific situation of avalanche accidents in the European Alps and should not simply be transferred to other regions, where a different set of risk factors may operate. These systematic limitations should be taken into account when the results of this study are interpreted.

Conclusions

In conclusion, this study showed a favourable assessment of both the avalanche airbag and avalanche transceiver in reducing the mortality rate of ski tourers and off-piste skiers. We suggest that further technical development and the use of rescue devices with a buoyant effect should be encouraged. Due to statistical limitations, it was not possible to make a direct comparison between the devices. For a reliable statistical evaluation of rescue devices, it is essential, in future, to document with accuracy the rescue equipment of all persons involved in avalanches at the site of the accident. Moreover, prospective trials to evaluate rescue devices should be considered, as the reliability of retrospective studies will always be limited.

Conflict of interest

This study was not supported financially or materially by any producer of avalanche rescue devices. The authors are not involved in any financial interest and did not receive any grants or patents concerning the devices.

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References