PRACTICAL IMPLICATIONS OF REGIONAL AVALANCHE SURVIVAL CURVES

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ABSTRACT: An avalanche survival curve is a graphical illustration of survival probability during complete avalanche burial as a function of time. The purpose of calculating these curves is not only to illustrate that survival is time-dependent, but to deduce practical information from the course of the curve. The step-wise decrease of survival over time was first recognized in the original curve in 1994 using avalanche data from Switzerland; four distinct phases were identified in which the subsequent drop in survival probability could be attributed to a specific pathology. These results have had lasting practical implications for avalanche rescue and international guidelines. More recently, region-specific curves have been used to understand the factors contributing to differences in survival probability. In this paper, we summarize the background to calculating and interpreting survival curves and discuss practical implications of regional survival curves, referring to preliminary results from the first Austrian curve.

KEYWORDS: survival probability, Austrian survival curve, extrication curve, Turnbull estimation

1. INTRODUCTION

An avalanche survival curve represents cumulative survival probability during complete burial as a function of time. The first survival curve was calculated in 1992 using a Swiss dataset (Brugger & Falk, 1992). The results were published for a wider audience in English in 1994 (Falk et al., 1994). To explore whether these results were applicable to other regions, the first regional comparison was published in 2011 using updated Swiss data and Canadian data (Haegeli et al., 2011). As expected the two curves showed similar patterns, but also marked differences that were valuable for exploring factors associated with differences in survival probability between these regions.

Despite widespread interest in the avalanche community, an in-depth explanation of avalanche survival curves has never been published and additional regional comparisons are still in progress. The aim of this paper is to review the background to calculating and interpreting survival curves and discuss practical implications of regional survival curves, referring to preliminary results from the first Austrian curve.

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2. CALCULATING SURVIVAL CURVES

Avalanche survival curves have been calculated to date using the non-parametric estimation procedure of Turnbull (1974) for completely buried avalanche victims. The minimum requirement is complete data on duration of burial and survival status at extrication.

Because the exact time of death of a victim during burial is not known this method uses so-called *interval censoring*—a victim dead at extrication died anytime between burial and extrication (left-censored); a victim alive at extrication may have died anytime after extrication (right-censored) (Fig. 1). One advantage of the Turnbull method is that intervals can be defined dynamically and based on the level of information in the dataset.

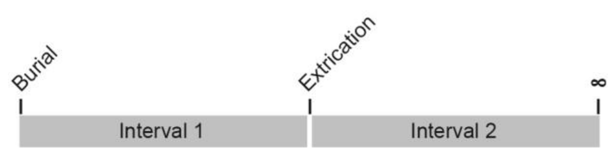

Fig. 1: Interval censoring applied to avalanche burial. A victim dead at extrication died in interval 1; a victim alive at extrication may have died in interval 2.

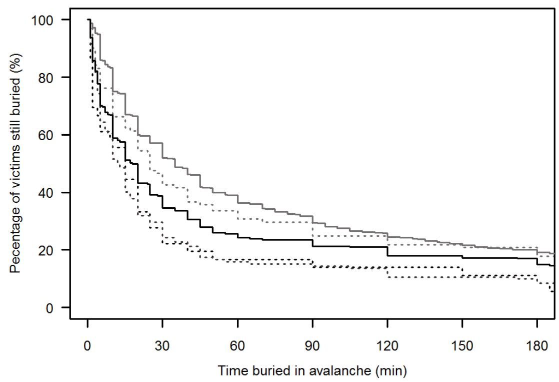

Fig. 2: Extrication curves for a Canadian (black) and Swiss (grey) dataset (adapted from Brugger et al., 2011).

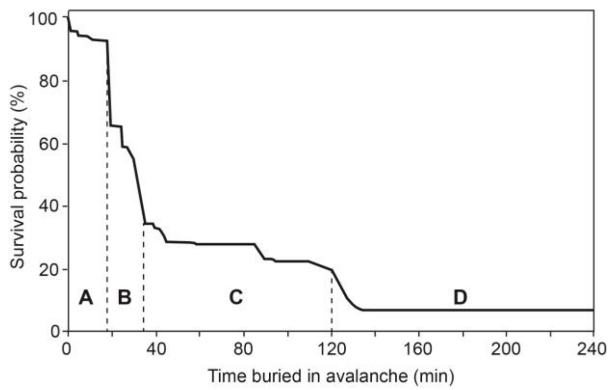

Fig. 3: An example survival curve showing the survival phase (A), asphyxia phase (B), latent phase (B) and long-term burial phase (D).

3. CALCULATING EXTRICATION CURVES

An extrication curve shows the cumulative percentage of victims extricated as a function of duration of burial (Fig. 2). This is produced by ordering the cases by duration of burial and calculating the percentage of victims still buried. The results are useful for comparing differences in burial time between datasets.

4. INTERPRETING SURVIVAL CURVES

4.1 Phases of survival

Avalanche survival curves have a characteristic shape with four distinct phases (Fig. 3):

- Survival phase (0–18 min)
- Asphyxia phase (19–35 min)
- Latent phase (36–120 min)
- Long-term burial phase (>120 min)

where the time intervals are from the Swiss curve but may vary slightly in other datasets. In the *survival phase*, survival remains high and deaths occur primarily from trauma. In the *asphyxia phase*, there is a rapid drop in survival and deaths occur primarily from asphyxia. In the *latent phase*, survival does not change drastically and reflects the survival of victims with patent airways for a limited time. Afterwards, survival gradually decreases and deaths occur from severe hypothermia complicated by progressive hypoxia and hypercapnia, also referred to as the “triple H syndrome” (hypothermia, hypoxia, hypercapnia). In the *long-term burial phase*, long-term survival is possible in a very low percentage of victims if oxygen support is sufficient (e.g. with an open air pocket).

4.2 Comparing regional curves

The first step is to compare sample size, overall survival rate, mean duration of burial and mean burial depth in each dataset. Optimally data should stem from a similar period (range of years) and contain the same type of accidents/recreationists. It is only possible to compare curves that have been calculated with the same statistical method. The most interesting parameters to compare are the absolute rate of survival at a given time, the rate of decrease in survival over a specified interval and factors associated with these differences.

It is essential to report when survival status was collected. If survival status was determined immediately upon extrication survival reflects the effect of burial; if it was determined after extrication, during transport or at hospital survival actually reflects the combined effect of both burial and rescue and treatment procedures.

This is not necessarily a limitation for making comparisons, but it must be clearly stated. In the Swiss and Canadian curves, for example, survival status was recorded at hospital discharge (Haegeli et al., 2011). Differences in long-term survival were thus probably not due to differences in avalanche survival per se but to external factors (long distance transportation of patients, different pre-hospital medical care).

The survival curve results from a mixture of potential causes of deaths, i.e. immediate death by trauma, asphyxia in the second phase and hypothermia (combined with hypoxia and hypercapnia) at the end of the latent phase. Therefore, differences in survival probability can be related to the proportion of trauma-related deaths (Bilek & Würtl, 2011; Haegeli et al., 2011), snow characteristics and snow climate (Haegeli et al., 2011) and other undefined individual factors.

4.3 Data quality

The shape of an avalanche survival curve is highly dependent on the underlying dataset. It is important to explain the source data and define variables. The results can be influenced by the distribution of data within the dataset (across years and duration of burial intervals), the number of missing cases for a variable and how missing cases are statistically handled. Results should be interpreted cautiously in intervals with significantly fewer cases. The more accurately the duration of burial is recorded, the smoother the curve becomes, as it is the use of wide time intervals that creates the step-wise decrease in the curve.

5. PRACTICAL IMPLICATIONS

Since the first publication, avalanche survival curves have had lasting practical implications for avalanche rescue and have formed the basis of international guidelines on management of avalanche victims (Brugger et al., 2013). We propose that comparing regional survival curves is valuable to uncover regional factors that account for differences in survival, both environmental and human factors. The long-term aim is to define region-specific practical recommendations. We calculated the first Austrian survival curve for complete avalanche burials between 2005/06 to 2013/14. The complete results will be published elsewhere, but the implications given below refer to preliminary results of this curve and the existing Swiss and Canadian curves.

5.1 Companion rescue

The most important practical implication is the emphasis on rapid extrication and the potential impact of companion rescue on survival compared to organized rescue (Mair et al., 2013). Every minute in the early phase counts to reduce the risk of death by asphyxiation and improve the prognosis of traumatized patients. Interestingly, the threshold for maximum duration of burial with “acceptably” high survival probability (i.e. survival phase) differs between regions, up to 8 min between the Swiss and Canadian data (Haegeli et al., 2011).

In the datasets analyzed, duration of burial was often missing in cases with companion rescue. This information should be reported by companion rescuers whenever possible, as it is decisive for treatment and triage decisions made later by the organized rescue team.

5.2 Organized rescue

The most important practical implication is the threshold for the end of the asphyxia phase, which is approximately 35 min in all curves. This defines the theoretical time after which victims cannot survive without patent airways. Treatment guidelines are currently based on this threshold and seem to be supported by the Austrian dataset as well.

If survival is not collected immediately upon extrication but after extrication or during transport, there is a chance that rescue procedures and onsite medical treatment have affected the victim’s status (e.g. if a patient presents with cardiac arrest induced from rough handling at extrication, survival may depend on whether immediate cardiopulmonary resuscitation was provided). Cardiac monitoring of the patient promptly after extrication is therefore recommended.

As a consequence, differences in long-term survival may reflect not only geographic differences but also differences in pre-hospital medical care. This underlines the importance of evaluating these factors.

6. LIMITATIONS OF SURVIVAL CURVES

The main limitation of survival curves is the nonreporting bias, i.e. datasets do not contain all avalanche accidents and non-serious accidents are likely underreported. This may bias the results towards more serious accidents, though it is plausible that this limitation influences all datasets similarly. Secondly, the definition of survival depends on when survival status of the victim is collected and this should be clearly reported. Thirdly, survival curves have only been calculated for complete burials and the definition of this may also differ between countries.

CONFLICT OF INTEREST

None of the authors has a conflict of interest.

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