ON THE EFFECTIVENESS OF AVALANCHE BALLOON PACKS

Pascal Haegeli[1,2*], Benjamin Zweifel[3], Frédéric Jarry[4], Spencer Logan[5], Hanno Bilek[6], Marek Biskupič[7], Hermann Brugger[8] and Markus Falk[9]

[1]School for Resource and Environmental Management, Simon Fraser University, Burnaby, BC, Canada
[2]Avisualanche Consulting, Vancouver, BC, Canada
[3]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
[4]National Association for Snow and Avalanche Studies (ANENA), Grenoble, France
[5]Colorado Avalanche Information Center, Boulder, CO, USA
[6]Österreichisches Kuratorium für Alpine Sicherheit, Innsbruck, Austria
[7]Avalanche Prevention Center, Jasna, Slovakia
[8]Institute of Mountain Emergency Medicine, European Academy, Bozen/Bolzano, Italy
[9]Inova Q Inc., Bruneck/Brunico, Italy

ABSTRACT: Even though avalanche balloon packs have been promoted in Europe since the early 1990s, they have only truly established themselves as an accepted avalanche safety device over the last five to ten years. This particularly applies to North America, where a stream of regulatory hurdles delayed the introduction of the new technology. The goal of the present study is to provide an independent, up-to-date perspective on the effectiveness of avalanche balloon packs to reduce the likelihood of critical burials and to improve avalanche survival. The dataset used for the analysis consists of well-documented avalanche accident records from Austria, Canada, France, Switzerland and the United States. To ensure a most appropriate dataset for the evaluation of avalanche balloon packs, the dataset was limited to only include avalanche involvement records that had the potential to result in complete burial. For the main analysis, the dataset was further reduced to include only accidents that involved both users and non-users of avalanche balloon packs to minimize the effect of a likely reporting bias. Using a multivariate approach to control for other factors contributing to avalanche survival, the present analysis offers a more comprehensive perspective and more accurately isolates the true impact of avalanche balloon packs than previous studies.

KEYWORDS: Avalanche accidents, avalanche safety equipment, avalanche balloon packs, avalanche airbags, avalanche survival

1. BACKGROUND

Avalanche balloon packs, also known as avalanche airbags, are a relatively new avalanche safety device that consists of a backpack or vest with one or two integrated inflatable balloons. Once caught in an avalanche, users of avalanche balloon packs can pull a ripcord to deploy the stowed balloon(s), which then instantly inflate to a total volume of roughly 150 liters. In comparison to other avalanche safety devices that aim to accelerate the search and extrication phase of an avalanche rescue (e.g., avalanche transceiver, probe, shovel), the goal of avalanche balloon packs is to prevent or reduce the severity of avalanche burial through the physical process of inverse segregation. Typical accident avalanches are gravitational granular flows that segregate in a way that larger particles are more likely to be found near the surface while smaller particles move towards the base of the flow (Kern, 2000). The effectiveness of this process primarily depends on the relative size difference of the particles within the flow. With the inflated balloon(s), an avalanche victim, who is already a rather large particle in an avalanche, becomes an even larger particle that can take full advantage of the segregation effect. As long as the user of the avalanche balloon pack is flowing freely within the avalanche debris, the separation effect will be moving the victim towards the surface despite its higher density. Since asphyxia through burial in snow is the primary cause of death in avalanches (Hohlrieder et al., 2007; McIntosh et al., 2007; Boyd et al., 2009) and the available time window for successful live recoveries is short (Brugger et al., 2001; Haegeli et al., 2011), staying on top of the avalanche has great potential for improving avalanche survival.

* *Corresponding author address:*
Pascal Haegeli, Avisualanche Consulting,
2-250 E 15 Ave, Vancouver BC,
Canada, V5T 2P9
Phone: +1 604 773 0854;
Email: pascal@avisualanche.ca

The initial concept for avalanche balloon packs was invented in the late 1970s in Europe (ABS, 2011). While the first commercial product was available the European market in 1991 (Brugger et al., 2007), the introduction of the safety device to the North American market was considerably delayed due to a stream of regulatory hurdles. To-date, there are four different manufacturers of avalanche balloon packs (ABS, Mammut/Snowpulse, Backcountry Access and Wary) and various companies are currently in the process of developing their own product (e.g., Arc'teryx and Black Diamond).

The effectiveness of avalanche balloon packs is supported by various credible scientific studies, which include the theoretical evaluation of the concept of inverse segregation in the context of avalanches (Kern, 2000, Kern et al., 2005; and Gray & Ancey, 2009), field experiments where crash test dummies with inflated avalanche balloon packs were exposed to artificially triggered avalanches (Tschirky & Schweizer, 1996; Kern et al., 2002; Meier & Harvey, 2010), statistical evaluations of accident records comparing the survival rates of users and non-users of avalanche balloon packs (Tschirky et al., 2000; Brugger & Falk, 2002; Brugger et al., 2003; and Brugger et al., 2007, Haegeli, 2012a), and most recently an examination of operational concerns and experiences with avalanche balloon packs among Canadian avalanche professionals (Haegeli, 2012b).

Building on the existing research that used accidents records to evaluate avalanche balloon packs, the present study aims to provide a comprehensive up-to-date perspective on the effectiveness of avalanche balloon packs using the latest available information.

We are currently still in the process of collecting relevant accident information for the final dataset of our analysis. To avoid possible confusion from having different statistical results published from the same study, we decided not to include any preliminary results in the present article. Instead, we focus on study design and describe how our research advances our understanding from previous studies. Final results of the study will soon be submitted for publication in a relevant peer-reviewed journal accessible to the avalanche community.

2. STUDY DESIGN

2.1 Research questions

Our study aims to answer the following three research questions:

- How effective are inflated avalanche balloon packs for reducing the likelihood of critical burials and improving the survival rate among individuals seriously involved in avalanches?
- How often do avalanche balloon packs fail to deploy and for what reasons?
- How effective are avalanche balloons when deployment failures are taken into account?

2.2 Increased sample size

Earlier studies on the effectiveness of avalanche balloon packs were limited considerably by the small amount of the available data on accidents involving avalanche balloon packs. In all but one study, the datasets used for the analysis were collected by the WSL Institute for Snow and Avalanche Research SLF in Switzerland and the total number of records of balloon pack users ranged from 35 (Brugger et al., 2007) to 60 (Brugger et al., 2003). As a consequence, the possibilities for advanced statistical analyses were quite limited and the extrapolation of the results to other geographic regions was questionable.

Due to the growth in avalanche balloon pack usage in recent years, the number of accidents involving avalanche balloon packs has also increased considerably. This trend is clearly reflected in national avalanche accident databases, which have accumulated a substantial amount of new information on these types of accidents since the publication of the last study on avalanche balloon packs.

For the present study, relevant avalanche accident records from Austria, Canada, France, Switzerland and the United States were combined to compile a large comprehensive dataset that offers new opportunities for statistical analyses. As of August 15, 2012, our dataset consisted of 164 avalanche accidents with a total of 266 seriously involved individuals. Seventy-five percent of these individuals (200 of 266) were wearing avalanche balloon packs during their involvements, while the other 25% (66 of 266) were not equipped with the de-

vice. The dataset includes self-reported accidents as well as accidents that were officially investigated (e.g., due to fatalities or organized rescue efforts).

2.3 Strict case definition

Even though an in-depth understanding of the type of avalanche involvements used in the analysis is crucial for the proper interpretation of derived performance measures, the majority of existing studies lack a description of the criteria used to include victim records in their datasets.

Since avalanche balloon packs are designed to prevent or reduce the severity of avalanche burials, the present study focused exclusively on avalanche involvements with the potential for complete burial. This requirement was implemented by employing the following two criteria during data collection. First, accidents were only considered for our dataset if the destructive size of the avalanche was 2.0 or larger according to the Canadian avalanche size classification (CAA, 2007). By definition, avalanches of size 1.5 or smaller are too small to bury a person. Second, individual victim records were only included in the dataset if they were seriously involved in the flow of the avalanche and/or partially or completely buried. Marginally involved individuals (e.g., only slightly moved at the edge of the avalanche, remained standing during their entire involvement, or managed to ride out of the avalanche) were excluded from the dataset. The combination of these two criteria together ensures a most meaningful dataset for the evaluation of avalanche balloon packs.

2.4 Control group selection

Most existing studies on the effectiveness of avalanche balloon packs drew their control groups of non-avalanche balloon pack users from large existing national avalanche accident databases and compared their survival rate to the survival rate of a considerably smaller sample of known avalanche balloon pack users (see, e.g., Brugger et al., 2003). While this type of comparison was the only possible approach to examine the effectiveness of avalanche balloon packs given the small amount of available data at the time, it is susceptible to a likely reporting bias towards non-serious involvements with avalanche balloon packs.

Since avalanche balloon packs are a relatively new avalanche safety device, it is likely that avalanche accidents involving avalanche balloon packs are reported more frequently than other avalanche accidents. This reporting bias is likely most pronounced for small avalanche accidents with non-serious outcomes that normally remain unreported. As a consequence, evaluations using this type of control group likely overestimate the effectiveness of avalanche balloon packs

To overcome this challenge of self-reported accident records, the avalanche balloon pack analysis of Brugger et al. (2007) only included accidents from Switzerland that were officially investigated and included in the accident database of the WSL Institute for Snow and Avalanche Research SLF. While this approach ensured the comparability of the user and non-user samples, it also reduced the sample size of users and limited the geographical extent of the dataset to Switzerland.

The present study uses a different approach to minimize the impact of the reporting bias. For the comparative analyses between users and non-users, the complete sample (all known accidents involving avalanche balloon pack with avalanches of size 2.0 or larger) is reduced to only accidents that involved both users and non-users of avalanche balloon packs. Users can either be defined as individuals with only deployed balloon packs to examine the impact of inflated balloon packs, or as individuals wearing avalanche balloon packs (deployed and not deployed) to examine for overall impact of avalanche balloon packs including non-deployments. In addition to avoiding the reporting bias, this approach also results in a more uniform and balanced dataset with respect to additional contributing factors. However, it also reduces the size of the dataset considerably and shifts it towards more serious accidents. These side effects have to be considered when interpreting the study results.

2.5 Multivariate perspective

The likelihood of a critical burial and the chance of survival for an individual involved in a serious avalanche clearly depends on more factors than just the use of an avalanche balloon pack. While Brugger et al. (2007) showed that avalanche balloon packs have a significant impact on avalanche survival in a European dataset, the survival rate also differed significantly with respect to degree of burial, depth of burial, slab width, year of accident and country. Similarly, survival rates varied with size of the avalanche, local terrain characteristics and location of the victim on the slab when the avalanche was triggered in the Canadian dataset

used by Haegeli (2012a). While the Canadian dataset did not include any trauma fatalities, one can assume that severity of personal injuries also has a significant effect on survival rates.

Despite these obvious additional contributing factors, all of the existing studies have only used univariate comparisons to examine the effectiveness of avalanche balloon packs as small samples of avalanche balloon pack users simply did not allow for more advanced statistical analyses. Due to the larger size of the present dataset, this study has the opportunity to use a multivariate approach to control for the effects of additional factors and properly isolate the effect of avalanche balloon packs on the likelihood of critical burials and avalanche survival.

2.6 Analysis approach

The three research questions are examined in the following steps. First, the effect of fully inflated avalanche balloon packs on the likelihood critical burials and the survival rate is examined using multivariate logistic regression models. Odds ratios and relative risk reduction values for significant contributing factors can be derived directly from the coefficients of the logistic regression models. As pointed out earlier, the dataset for this analysis only includes records of victims that were involved in accidents with both users and non-users of avalanche balloon pack to avoid issues from a likely reporting bias.

In addition to estimating the main effect of avalanche balloon packs, which describes the average impact of the safety device across the conditions covered in the dataset, the logistic regression analysis can also highlight conditions when avalanche balloon packs perform significantly better or worse than average (i.e., interaction effects). This information can provide a valuable perspective on the limitations of avalanche balloon pack applications.

The second step of the analysis uses the complete dataset of avalanche balloon pack users to calculate the frequency of deployment failures and to examine the underlying causes. This analysis can provide insights about possible design weaknesses of avalanche balloon packs and frequent users errors.

In the final step of the analysis, the frequency of non-deployments is used to scale the relative risk reduction values of fully inflated avalanche balloon packs derived in the first step. The adjusted relative risk reduction values provide an overall assessment of the effectiveness of avalanche balloon packs that takes non-deployments into account.

3. FUTURE

The present study offers an up-to-date perspective on the effectiveness of avalanche balloon packs based on the latest available data. However, the currently available dataset is still relatively small and only supports statistical analyses of limited complexity.

To further improve our understanding of how avalanche balloon packs and other factors affect avalanche survival, it is critical to systematically collect detailed avalanche accident information. Particular focus should be given to improve the collection of detailed information on victims who were unharmed with or without the use of avalanche balloon packs. Naturally, fatalities or victims with major injuries are investigated in greater detail, but detailed information on accidents with less serious outcomes is equally important for future studies.

Since insightful statistical analyses require large datasets, we also encourage international collaborations and the combination avalanche accident datasets. To ensure compatibility among the various datasets, it is important to develop consistent observation protocols and recording guidelines that facilitate the exchange of avalanche accident information worldwide.

CONFLICT OF INTEREST

This study was not supported financially or materially by any manufacturers of avalanche balloon packs. None of the authors are involved financially in the production or sale of avalanche balloon pack nor have they received any related grants or patents.

ACKNOWLEDGEMENTS

The authors would like to thank everybody who has contributed to the collection on high-quality avalanche accident information that made this research possible.

REFERENCES

ABS-Lawineneairbags, Peter Aschauer GmbH (2011), Company background. [available online at http://abs-airbag.de/us/meta/company/].

Gray, J., & Ancey, C. (2009). Segregation, recirculation and deposition of coarse particles near two-dimensional avalanche fronts. Journal of Fluid Mechanics, 629, 387-423.

Boyd, J., Haegeli, P., Abu-Laban, R. B., Shuster, M., & Butt, J. C. (2009). Patterns of death among avalanche fatalities: a 21 year review. Canadian Medical Association Journal, 180(5), 507–511.

Brugger, H., Durrer, B., Adler-Kastner, L., Falk, M., & Tschirky, F. (2001). Field management of avalanche victims. Resuscitation, 51, 7–15.

Brugger, H., Etter, H.-J., Zweifel, B., Mair, P., Hohlrieder, M., Ellerton, J., et al. (2007). The impact of avalanche rescue devices on survival. Resuscitation, 75, 476–483.

Brugger, H., & Falk, M. (2002). Analysis of Avalanche Safety Equipment for Backcountry Skiers. [available online at http://www.snowpulse.ch/v3/medias/ brugger_falk_report.pdf].

Brugger, H., Kern, M., Mair, P., Etter, H.-J., & Falk, M. (2003). Effizienz am Lawinenkegel: Notfallausruestung fuer Tourengeher und Variantenfahrer. Eine kritische Analyse. BergUndSteigen, 03/4, 60–65.

Canadian Avalanche Association. (2007). Observation Guidelines and Recording Standards for Weather, Snowpack, and Avalanches. Revelstoke, BC.

Haegeli, P. (2012a). On the effectiveness of avalanche balloon packs in Canadian avalanche incidents. Research report [available online at http://www. avalancheresearch.ca].

Haegeli, P. (2012b). Overview of existing concerns and operational experiences with avalanche balloon packs within the Canadian professional avalanche community. Research report [available online at http://www. avalancheresearch.ca].

Haegeli, P., Falk, M., Brugger, H., Etter, H.-J., & Boyd, J. (2011). Comparison of avalanche survival patterns in Canada and Switzerland. Canadian Medical Association Journal, 183(7), 789–795.

Hohlrieder, M., Brugger, H., Schubert, H. M., Palvic, M., Ellerton, J., & Mair, P. (2007). Pattern and severity of injury in avalanche victims. High Altitude Medicine and Biology, 8(1), 56-61.

Kern, M. (2000). Inverse grading in granular flow. PhD Thesis, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. [available online at http://biblion.epfl.ch/EPFL/theses/2000/2287/EPFL_TH2287.pdf].

Kern, M., Buser, O., Peinke, J., Siefert, M., & Vulliet, L. (2005). Stochastic analysis of single particle segregational dynamics. Physics Letters A, 336, 428-433.

Kern, M., Tschirky, F., & Schweizer, J. (2002). Field tests of some new avalanche rescue devices. Paper presented at the International Snow Science Workshop, Penticton, BC.

McIntosh, S. E., Grissom, C. K., Olivares, C. R., Kim, H. S., & Tremper, B. (2007). Cause of Death in Avalanche Fatalities. Wilderness and Environmental Medicine, 18, 293-297.

Meier, L., & Harvey, S. (2011). Feldversuche mit Lawinen-Notfallgeraeten Winter 2010/11. Draft report. WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland.

Tschirky, F., & Schweizer, J. (1996). Avalanche Balloons—Preliminary Test Results. Paper presented at the International Snow Science Workshop, Banff, AB.

Tschirky, F., Brabec, B., & Kern, M. (2000). Avalanche rescue systems in Switzerland: Experience and limitations. Paper presented at the International Snow Science Workshop, Big Sky, MT.