

Analysis of Avalanche Safety Equipment for Backcountry Skiers

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Abstract

This review aims to evaluate and compare avalanche safety equipment for downhill and off-piste skiers on the basis of published rescue data. A new classification for avalanche rescue devices is proposed. With respect to the different mechanisms of action we distinguish the following categories rescue devices:

- A) devices aiming to prevent or reduce the extent of burial (ABS Avalanche Airbag, Avagear);
- B) devices aiming to shorten the duration of burial (avalanche beacon, K2 avalanche ball); and,
- C) devices with the aim to prolong survival time during complete burial (AvaLung TM).

The reduction of mortality is essential for the assessment of efficiency, representing the main criterion for the evaluation. The ABS Avalanche Airbag lowers mortality significantly from 23.0% to 2.5% ($p=0.001$) and is considered as acceptable, safe and useful (Class IIa, the safety equipment of choice). Avalanche beacons are marginally effective at reducing fatalities, ($p=0.054$) (Class IIb, acceptable and useful devices). Due to the lack of data, AvaLung, Avagear and the K2 Avalanche Ball are determined to be “Class III, indeterminate efficacy”, as additional confirmation is needed.

Keywords: Avalanche, classification, mortality, rescue device, safety equipment

Introduction

In the last few years the options for safety equipment for the ski tourer and off-piste skier have been expanded by a few interesting possibilities. Although there is already a retrospective evaluation for the efficiency of avalanche rescue transceivers⁽¹⁾, there have not been any evaluations for the efficiency of the newer types of equipment. In this overview, we will analytically compare and classify the available safety equipment based on previously published data. Only those pieces of safety equipment which are either available on the market or in the stage of final testing are included in this comparison. Search devices suitable only for organized rescue teams (e.g.; RECCO) were not included.

Pathogen factors of an avalanche burial

The survival chances for persons caught in avalanches are dependant on several factors. Apart from the fact that a person carried by an avalanche can suffer fatal injuries from mechanical snow pressure, collision with obstacles in the avalanche path, or falls over cliffs in the avalanche path, survival chances after the avalanche comes to a stop depends on whether the victim is able to breath, and in case of a critical burial (head and the upper part of the body in the snow), how fast the victim is dug out. If the airway of the buried person is not clear and if there is no air pocket round the victim, after 35 minutes the victim's fate is hopeless and any help will be too late⁽²⁾. However, with a clear air way and an air pocket, it is possible to survive longer. Survival of totally buried persons is also influenced by

hypothermia and other, up to now unknown co-factors⁽³⁾. Data show approximately 75% of avalanche fatalities are due to asphyxia, 15 to 20% due to deadly trauma and 5 to 10% due to hypothermia and other factors.

Effect of safety equipment

The most deadly risk during avalanche burial is the danger of acute asphyxia. The purpose of avalanche safety equipment is to prevent suffocation of the buried person. This purpose can be achieved by three different mechanisms, each with different working principles and efficiencies. The different approaches will be discussed in detail.

A. Reduction of the degree of burial

The most efficient means of preventing avalanche fatalities is to avoid complete burial. Of 1886 persons which were caught in avalanches in Switzerland between 1981 and 1998, 735 persons (39%) were fully buried, and 1151 (61%) were partly buried or stayed completely unburied on the surface. 433 persons (23%) did not survive the avalanche. For the completely buried persons, the mortality rate was 52%. For partly buried victims the mortality rate was only 4.2% ($p > 0.001$, Table 1)⁽³⁾. Measures which help to prevent complete burials reduce mortality. The ABS Avalanche Balloon System and the Avagear life vest provide floatation which keeps the victim on the surface while the avalanche is in motion. Swimming motions by the victim while the avalanche is in motion can be life saving if it is possible to stay on the surface⁽⁴⁾.

	Total number of burials	Location of burial (A)		Degree of burial (B)	
		open terrain	buildings, roads, railways	completely buried	not or partly buried
Survived	1453 77%	1053 73.4%	400 88.5%	350 47.6%	1103 95.8%
Dead	433 23%	381 26.6%	52 11.5%	385 52.4%	48 4.2%
Total	1886 100%	1434 100%	452 100%	735 100%	1151 100%

Table 1: Analysis of all persons caught by avalanches in Switzerland between 1981 and 1998 showing location of burial (A) and the degree of burial (B). The difference of the frequencies between (A) and (B) is highly significant ($p > 0.001$, Pearson's Chi-Square). Modified according to⁽³⁾.

B. Reduction of burial time

Chance of survival over time in a complete avalanche burial is not linear. (See Figure 1). In a complete burial situation, there are phases where the survival rate drops very rapidly - a high risk to die in the first 18 to 35 minutes of burial (asphyxia phase) - and phases with an almost stable survival rate - a greatly reduced risk to die between 35 and 90 minutes of burial (the latency phase)⁽⁵⁾. In principle, by reducing the burial time, mortality can be reduced. However, the efficiency of this strategy depends on which phase of the survival curve is affected. Safety equipment is especially efficient when the steep parts of the survival curve are affected. Transceivers and the K2 Avalanche Ball are examples of safety equipment that reduces burial time.

C. Prolonging survival time during complete burial

The survival chance of a fully buried victim also depends on the existence of free airway and an air pocket in front of the face when the avalanche comes to a standstill⁽²⁾. If the victim is able to keep the airway free and have an air pocket, survival time can be prolonged. This means more time available for the rescue of the victim, and this increases the survival chances. The rescue vest AvaLungTM⁽⁶⁻⁸⁾ is a device which creates an artificial air pocket.

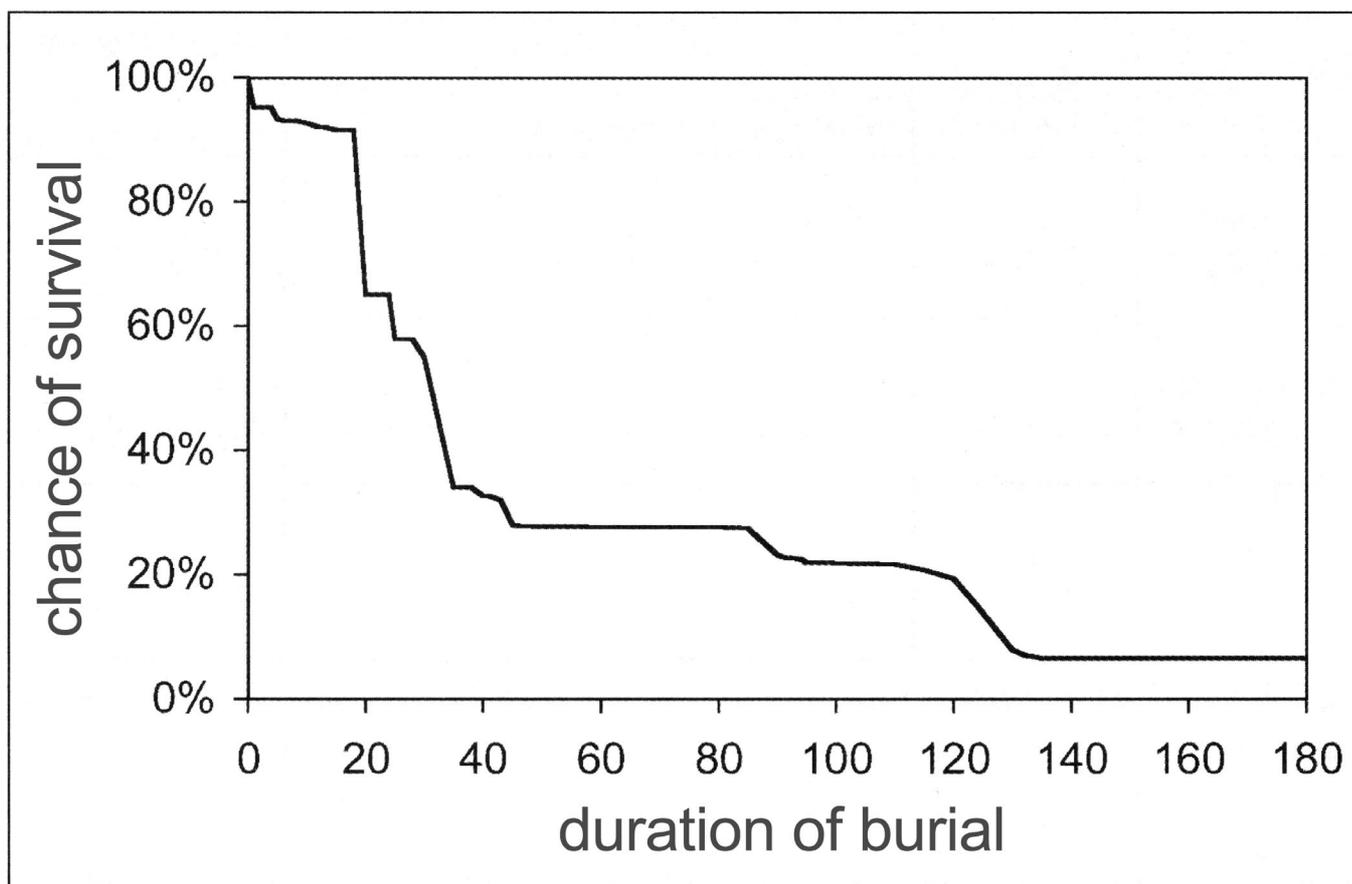


Figure 1: Chance of survival for persons who have been caught and completely buried in an avalanche in open terrain (Switzerland 1981-1998, n=735) as a function of burial time in minutes. Reducing the degree of burial raises the chance of survival, especially when the steep sections of the survival curve are included. Modified according to⁽³⁾.

Avalanche safety equipment

Depending on the function of the avalanche safety equipment, it can be categorised into one of three different classes. Type A minimizes the degree of burial, type B the burial duration and type C extends the time a fully buried avalanche victim can survive within the avalanche. The types B and C assume a full burial situation and therefore, in order to be efficient, must always be combined with a tool like a shovel which helps to uncover the victim. *Note from CAA – both probe and shovel required for effective location and recovery.*

Type A. Safety equipment which minimizes the extent of burial

The ABS Avalanche Balloon System⁽⁹⁾ is the only commercially available avalanche safety device designed to reduce the extent of burial. It consists of one or two balloons which are integrated into a special back pack. Pulling the emergency handle inflates the balloons with 150 litres of a nitrogen / air mixture within 2 to 3 seconds. Buoyancy due mainly to the effects of the inverse segregation^(10, 11) causes the person caught in the avalanche to be held on the snow surface.

All of the known accidents where persons have been caught by avalanches and used the ABS system (N=40) have been documented by the Swiss Institute for Snow and Avalanche Research⁽¹²⁾. Thirty nine persons (97.5%) using the ABS system survived the avalanche and one person (2.5%) did not (Table 2). In eight cases (20%), the balloon was not inflated because the release handle was not pulled or the inflation system did not function properly. Five persons (16%) were fully buried even though their balloon was inflated. Despite this failure rate, the ABS avalanche balloon reduces the likelihood of complete burial from 39% to 16.2% (Fisher's Exact Test, p=0.006) and lowers the mortality rate from

23% to 2.5% (Fisher's Exact Test, $p=0.001$). Since the study data was collected, the mechanical triggering mechanism has been replaced by a pyro-electric system and the single balloon system has been replaced with a double balloon design. Those modifications to the ABS have increased reliability. Even though the efficacy of the system is very high, in Europe the ABS system has not been accepted by the backcountry skiers and off-piste skiers in the expected way.

Table 2: Documented avalanche accidents with ABS Avalanche Airbag. Modified according to (12).

	Total number of burials	Degree of burial			Condition when recovered	
		not or partly buried	completely buried	unknown	alive	dead
Airbag inflated	32 80%	27 84.4%	5 15.6%	0 0%	31 96.9%	1 3.1%
Airbag not inflated	8 20%	4 50%	1 12.5%	3 37.5%	8 100%	48 4.2%
total	40 100%	31 77.5%	6 15%	3 7.5%	39 97.5%	1 2.5%

The Avagear rescue jacket is being developed in the United States and is in its trial phase⁽¹¹⁾. In contrast to the ABS balloons contained in a backpack, the Avagear balloons are contained in the collar or shoulders of a jacket or vest, and inflate around the neck and the shoulders of the victim. With this design the head of the victim should stay above the snow surface more often, and the balloon protects the victim's head and cervical spine during the flow of the avalanche. In addition, one hopes that with this system it is more likely to have an air pocket around the head and face of the victim if a full burial does occur. During the three tests which were made up to now, the victim's face remained free. Avagear seems to offer a further development of the avalanche airbag principle which makes sense.

Type B. Safety equipment which reduces the burial time

The avalanche rescue transceiver was developed in 1968 by John Lawton (USA) and is currently the most efficient device to reduce burial duration. A retrospective analysis of 328 fully buried avalanche victims has shown a highly significant decrease of the median burial duration from 120 min to 35 min ($p<0.001$)⁽¹⁾. The mortality rate was reduced from 75.9% to 66.2% ($p=0.054$). Reduction of the mortality rate is not as significant as the reduction of the burial duration. This is due to the fact that the reduction of the median burial time mainly affects the part of the survival curve which is relatively flat, and does not significantly affect the part of the survival curve between 18 and 35min after the avalanche occurred where the survival rate is rapidly decreasing. (See Figure 1). Since newer avalanche rescue transceivers use digital technology with a useful direction indicator, it is anticipated that the survival data for this new generation of transceivers will be better. However, there are no data available yet which prove that conclusion.

Based on one survey, the percentage of European ski and snowboard tourers who are equipped with avalanche rescue transceivers has increased from 29 % in the period 1970-1979 to 74% in the period 1990-1999 ($p=0.039$)⁽⁴⁾. Today the avalanche rescue transceiver is the most generally accepted type of avalanche safety equipment used by back country ski tourers and off-piste skiers.

The K2 Avalanche Ball is a further development of the avalanche cord, an old concept which is out of date. After pulling the trigger handle, the spring loaded Avalanche Ball pops out of a small pocket on a backpack, and opens itself. The low density ball stays attached to the person by a cord, and floats on the surface of the avalanche. When the avalanche stops, companions must visually locate the ball and then follow the cord leading to the buried person. The presumption is that prompt location of the victim

should lead to faster recovery, reducing the duration of burial. Up to now several successful tests have been conducted, but no “real life” uses of this device have been documented⁽¹¹⁾.

Type C. Safety equipment which prolongs the survival time for a fully buried avalanche victim

The AvaLung (TM) survival jacket was patented by MD Thomas Crowley and developed by Black Diamond Equipment Ltd. in Salt Lake City, Utah, USA⁽¹³⁾. The AvaLung is a sleeveless synthetic jacket which is worn when travelling in the backcountry. In an avalanche the victim needs to get the mouthpiece (which comes out of the collar) in his mouth and keep it there during the flow of the avalanche. A valve separates the inhaled air from the exhaled air. During inhalation, the air is extracted from the avalanche snow through a special textile filter on the front side of the victim; during exhalation, the air is directed and vented to the back side of the victim. Due to the separation of the exhaled air, the re-inhalation of CO₂ is prevented. The latest version of the AvaLung system is integrated into a light weight chest harness.

The goal of the AvaLung system is to prolong survival time in a full burial situation by at least one hour⁽⁶⁻⁸⁾. The AvaLung concept assumes a full burial situation, therefore a transceiver and a shovel must always be carried as well. To be successfully rescued, the victim depends on third party help. The efficiency of this safety equipment has been proven in 33 experimental tests where the human test subjects were buried at a 1m depth. There are 3 documented cases where the AvaLung was used in real avalanche situations. The question of whether or not the mouthpiece can be properly positioned and kept in the victim’s mouth through the turbulence of the avalanche can not be conclusively answered yet⁽¹⁴⁾. Compared to the ABS avalanche airbag system, the AvaLung has the advantage of lighter weight and lower price.

Valuation and classification of the safety equipment

The statistical proof of a significant decrease of mortality is the most important criteria for valuation of avalanche safety equipment. User friendliness and acceptance are additional criteria, which can indirectly influence the efficiency and mortality, but were not taken into account in this study. The analysis of the present data allows one to assign an evidence level (Table 3) to the safety equipment, following the international guidelines 2000 for cardiopulmonary reanimation⁽¹⁵⁾.

Table 3: Safety equipment and their mechanisms of action. The safety equipment is classified after its evidence level. The classification was made according to the international guidelines for cardiopulmonary reanimation 2000⁽¹⁵⁾.

Mechanism of action	Safety equipment	Classification
reducing the degree of burial	ABS Avalanche Airbag	IIa good to very good evidence level - acceptable and wise to use it
	Avagear	Indeterminate
reducing the duration of burial	Avalanche rescue transceiver	IIb medium to good evidence level - acceptable and wise to use it
	K2 Avalanche Ball	Indeterminate
prolonging the time of survival within the avalanche	AvaLung TM	Indeterminate

A. The ABS avalanche balloon system highly significantly reduces mortality. The class IIa can be assigned to it, which means a good to very good evidence level - acceptable and wise to use it - the safety equipment of choice. The further development of the balloon system leading to a jacket like

system which produces an air space around the face as well as a higher reliability rate in the triggering of the system could make the efficiency even higher.

B. The efficiency of the avalanche rescue transceiver is documented in several studies and they show a marginally significant reduction of mortality. The device is only efficient in connection with a shovel. The class IIb means medium to good evidence – acceptable and wise to use it. It has to be noted that the analysis of the efficiency is based on data of the years 1981-1994. It is possible that a new analysis based on current data shows a better significance.

C. AvaLung, Avagear and the K2 Avalanche Ball are all in the class III category “indeterminate”, which means that the evidence level can not be determined due to the lack of data.

Conclusions

There is sufficient data to determine the evidence level for two categories of avalanche safety equipment. As expected, there is no avalanche safety equipment which meets the class I criteria. Class I classification could only be proven through controlled studies, and it would not be reasonable to intentionally put live persons into harmful avalanches.

All this analysis was only possible thanks to the precisely collected data of Frank Tschirky and other employees of the Swiss Institute for Snow and Avalanche Research. Frank Tschirky died of a heart attack in spring 2001 on a trekking tour in Nepal - we lost one of the best avalanche experts.

Reliable analysis of avalanche safety equipment in the future will only be possible if the data is collected by an independent institute.

A common characteristic of all avalanche safety equipment is that devices can improve survival chances, but can never completely eliminate the risk of dying in an avalanche.

Risk compensation theory (a propensity to take higher risks because of perceived protection from avalanche safety equipment) suggests human factors could negate some of the technical improvements in avalanche safety equipment. In the back country we are only safe when we act in a defensive manner so that we avoid triggering avalanches. Technical devices will never replace this mountaineering skill. Recognition and respect for natural hazards in the mountains will always remain our most reliable partner.

Disclosure

This study has not been financially supported. The authors do not have patent or financial interests on the production or the sales of the described safety equipment.

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