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Preživetje v primeru snežnih plazov – načini zdravljenja, tehnike samoreševanja in varnostna oprema za smučarje po neoznačenih progah

Considerations on Avalanche Survival, Therapeutic Principles, Self-rescue Techniques and Safety Equipment for Backcountry and Off-piste Skiers

IZVLEČEK

Srednja vrednost letne stopnje umrljivosti zaradi snežnih plazov, ki so bili beleženi v 17 državah ICAR od leta 1981 do leta 1998, je bila 146. Švicarski podatki navajajo stopnjo umrljivosti 52,4 % pri popolnoma zasutih osebah, v primerjavi s 4,2 % pri delno zasutih ali nezasutih osebah (n = 1886). Verjetnost preživetja pri popolnoma zasutih osebah na odprtih predelih (n = 638) upade z 91 % 18 minut po plazu na 34 % 35 minut po plazu (akutna zadušitev ponesrečenca, če ni zračnega žepa), potem pa ostaja precej stalna do drugega padca po 90 minutah (latentna faza za ponesrečence z zračnim žepom). Prelomna točka krivulje verjetnosti preživetja pri 35 minutah (slika 1) kaže na to, da ponesrečenci, ki so popolnoma zasuti pod snežnim plazom, ne morejo preživeti dlje kot 35 minut brez zračnega žepa. Prospektivna, randomizirana študija pri prostovoljcih (28 testov), ki so dihali v umeten zračni žep (s prostornino 1 l ali 2 l) v snegu, je pokazala da je obkrajna nasičenost s kisikom SpO_2 upadla iz srednje vrednosti 99 % na 88 % ($p < 0{,}001$) v 4 minutah. Tlak ogljikovega dioksida na koncu izdiha se je povečal iz srednje vrednosti 38 na 51 mmHg ($p < 0{,}001$), s posledično respiratorno acidozo. Sklepamo, da je stopnja hipoksije po zasutju v plazu odvisna od prostornine zračnega žepa, gostote snega in neznanih osebnih značilnosti posameznika, vendar je daljše preživetje možno že z majhnim zračnim mehurčkom. Kombinacija hipoksije, hiperkapnije in hipotermije pri osebah, zasutih pod plazom z zračnim žepom in s prostimi dihalnimi potmi, se imenuje »sindrom trojnega H«. Uvajajo se standardizirane smernice za reševanje ponesrečencev izpod plazov na terenu. Strategija reševanja je odvisna predvsem od dolžine zasutosti pod snegom, temperature jedra ponesrečenca in prisotnosti zračnega žepa. Če je bil ponesrečenec zasut ≤ 35 minut, je njegovo preživetje odvisno od preprečevanja zadušitve s hitrim izkopom in takojšnjim sproščanjem dihalnih poti ter s kardiopulmonalnim oživljanjem za nezavestne ponesrečence s spontanim dihanjem. Če je bil ponesrečenec zasut pod plazom dlje kot 35 minut, postane najbolj pomemben boj proti hipotermiji. Obvezen je torej previden izkop, snemanje EKG in spremljanje temperature jedra ter toplotna izolacija. Ponesrečence, ki se ne odzivajo, je treba intubirati. Če smo izključili očitno smrtne poškodbe, je treba vse ponesrečence izpod plazu, ki so imeli zračni žep in proste dihalne poti, a so v hipotermiji in brez pulza, zdraviti optimistično (temperatura jedra < 32 °C, [89.6 °F]). Skušamo jih ogreti v specialistični enoti z opremo za kardiopulmonalni obvod.

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ABSTRACT

The median annual mortality from snow avalanches registered in the 17 ICAR countries from 1981 to 1998 was 146. Swiss data document a mortality rate of 52.4% in completely-buried, versus 4.2% in partially-, or non-buried, persons (n = 1886). The survival probability of completely-buried victims in open areas (n = 638) plummets from 91% at 18 min after burial to 34% at 35 min (acute asphyxiation of victims without an air pocket), then remains fairly constant until a second drop after 90 min (the »latent phase« for victims with an air pocket). The inflection point of the survival probability curve at 35 min (figure 1) indicates that victims completely buried under an avalanche cannot survive beyond 35 min without an air pocket. A prospective, randomised study in volunteers (28 tests) breathing into an artificial air pocket (1 l or 2 l volume) in snow showed that peripheral oxygen saturation SpO_2 decreased from median 99% to 88% ($p < 0.001$) within 4 min. End-tidal carbon dioxide rose from median 38 to 51 mmHg ($p < 0.001$), with consequent respiratory acidosis. We conclude that the degree of hypoxia following avalanche burial is dependent on air pocket volume, snow density and unknown individual personal characteristics, yet long-term survival is possible with only a small air pocket. The combination of hypoxia, hypercapnia and hypothermia in persons buried by avalanches presenting an air pocket and free airways is designated as »triple H syndrome«. Standardised guidelines are introduced for the field management of avalanche victims. Strategy is primarily governed by the length of snow burial, the victim's core temperature and the presence of an air pocket. With a burial time ≤ 35 min, survival depends on preventing asphyxia by rapid extrication and immediate airway management, and cardiopulmonary resuscitation for unconscious victims without spontaneous respiration. With a burial time > 35 min, combating hypothermia becomes of paramount importance. Thus, gentle extrication, ECG and core temperature monitoring and body insulation are mandatory; unresponsive victims should be intubated. If obviously fatal injuries can be excluded, all pulseless hypothermic avalanche victims (core temperature < 32 °C [89.6 °F]) with an air pocket and free airways should be managed optimistically by attempted re-warming in a specialist unit with cardiopulmonary bypass facilities.

INTRODUCTION

The number of persons killed annually by snow avalanches world-wide is not known precisely. However, in the 17 countries represented by the International Commission for Alpine Rescue (ICAR) in Europe and North America, deaths from avalanche incidents have been accurately recorded over the past two decades; the median annual mortality registered between 1981 and 1998 was 146 (range 82–226) *(1, 2)*.

SURVIVAL PROBABILITY

»Complete burial« is defined as coverage of the victim's head and chest by snow, if not the complete body, otherwise the term »partial burial« applies *(3)*. Altogether 1886 avalanche victims were registered in Switzerland from 1981 to 1998. An analysis shows an overall mortality rate of 23.0%; 735 of these persons (39.0%) were completely buried, whereby 52.4% were dead on extrication, as compared with only 4.2% in 1151 partially-, or non-buried, victims *(4)*. Thus, any measure that decreases the chance of complete burial significantly lowers mortality.

The avalanche survival probability for completely-buried victims in open areas on the basis of Swiss data for 1981–1998 (n = 735) in relation to duration of burial, has been calculated by a computer-assisted, non-parametric method in Figure 1. The data show a precipitous drop in calculated 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 (the »latent phase« for victims

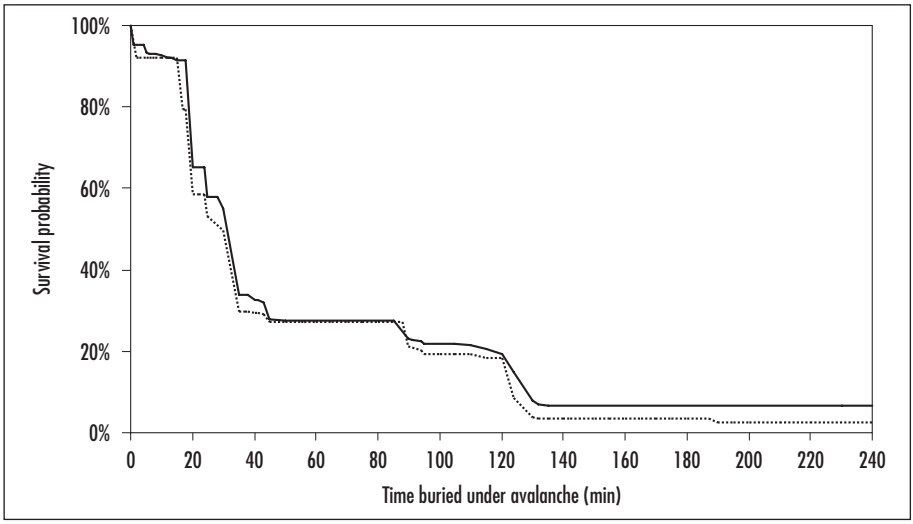

Figure 1. Survival probability for completely-buried avalanche victims in open areas in Switzerland from 1981–1998 (n = 735) in relation to time. The dotted curve represents the survival function for completely-buried avalanche victims in open areas (n = 422) based on the Swiss data for 1981–1991, calculated by Falk et al., Nature 1994. Reprinted from Brugger et al. (2001) Resuscitation 51: 7–15 with permission from Elsevier Science (4).

with an air pocket), followed by a second drop to only 7% at 130 min (death of victims with a »closed« air pocket from hypoxia, hypercapnia and hypothermia). This analysis confirms the previously-proposed survival probability curve *(5)*.

AIR POCKET PHYSIOLOGY

The inflection point of the survival probability curve at 35 min (figure 1) indicates that victims completely buried under an avalanche cannot survive beyond 35 min without an air pocket *(5)*. According to standard definition, an air pocket is any space surrounding mouth and nose, no matter how small, with the proviso of free air passages. The definition »no air pocket« is only permissible if the extricated victim's mouth and nose are found to be hermetically sealed off by snow or debris *(6)*. Air pockets are usually only a few centimetres wide in the case of buried skiers *(3)*. Although these can easily be overlooked in the stress of the rescue procedure, well-trained rescuers are usually able to identify even small air pockets, which are often iced up on the inner surface. Several rescue protocols of avalanche accidents document the survival of skiers, without indication of permanent hypoxic damage, after prolonged complete snow burial despite their presenting only a small closed air pocket on extrication *(3)*.

A prospective, randomised study in volunteers (28 tests) breathing into an artificial air pocket (1 l or 2 l volume) in snow showed that peripheral oxygen saturation SpO_2 decreased from median 99% to 88% ($p<0.001$) within 4 min *(7)*. End-tidal carbon dioxide rose from median 38 to 51 mmHg ($p<0.001$), with consequent respiratory acidosis. The decrease in SpO_2 was significantly greater in tests with the smaller air pocket ($p = 0.013$) and positively correlated to snow density ($r = 0.50$, $p = 0.021$). We conclude that the degree of hypoxia following avalanche burial is dependent on air pocket volume, snow density and unknown individual personal characteristics, yet long-term survival is possible with only a small air pocket. The combination of hypoxia, hypercapnia and hypothermia in persons buried by avalanches presenting an air pocket and free airways is designated as »triple H syndrome«.

Altogether, deaths by avalanches are attributable to acute obstructive asphyxia in approximately 65–70% of cases, to triple H syndrome in about 15% and to mechanical trauma in about 15–20%.

THERAPEUTIC PRINCIPLES

The ICAR MEDCOM Guidelines

An avalanche accident is a medical emergency *(8)*. In all decisions the goal of rapid rescue of the victim(s) must be balanced against the risks to the rescue team *(9)*. The possibility of a second avalanche, snow conditions, and topographic and meteorological factors must be evaluated. »Thinking ahead« should be the guiding principle of the rescue procedure. Rescuers should bring emergency doctors and/or paramedics and dog handlers with dogs (»docs and dogs«) as soon as possible to the site of the avalanche. The more persons that are buried, the more doctors and/or paramedics are needed.

With a short burial time (up to 35 minutes), rapid extrication has absolute priority. If a buried person is in critical condition before 35 minutes, acute asphyxia or mechanical trauma is the most likely causes. In case of respiratory arrest, start artificial respiration as soon as possible during recovery. After a complete burial (head and trunk buried), hospitalise the patient for 24 hours to observe for pulmonary complications such as aspiration and pulmonary oedema.

After a prolonged burial time (more than 35 minutes) hypothermia is to be expected, and therefore extrication should be not as speedy as possible but as gentle as possible. An air pocket and free airway are essential for survival and therefore on uncovering the face it is absolutely necessary to look for these. To date, a core temperature of 13 °C can be assumed as the lower therapeutic limit for re-warming, but core temperature in this range has to be measured esophageally since an epitympanic measurement can give falsely low values *(10, 11)*. Many clinicians reject a lower temperature limit on principle so as not to impact future therapeutic outcomes *(12, 13)*. Nowadays a non-lethal injury is no longer a contra-indication for re-warming with cardiopulmonary bypass *(14)*. If several buried persons must be attended to simultaneously, the maintenance of vital functions of survivors must have priority over resuscitation of buried victims without vital functions.

Equipment

Complete winter equipment includes: a thermometer for core temperature measurement, hot packs (table 1) and hot, sweet tea. Consider an airway warming device to administer warm, moistened O_2. If the outside temperature is low, make sure batteries are fully charged. If time permits, install a depot with a tent for medical care beyond the avalanche. Have medicines and instruments (metallic laryngoscope) kept warm; e. g., put a hot pack in the emergency physician's bag, or carry medicines on the body.

Localisation and extrication of the patient

Get the emergency physician and/or paramedic to the scene after finding the victim's position, not just upon rescuing. Watch for an air pocket (any cavity in front of the mouth and nose, no matter how small, provided the airway is clear). Avoid destruction of an existing air pocket during extrication! Do not dig vertically from above, but diagonally from the side in the direction of the buried victim. Absolutely avoid unnecessary movements of the victim's trunk and of main joints (shoulder, hip and knee). If movements cannot be avoided, carry them out as slowly as possible.

Monitoring

We recommend ECG monitoring during the entire time of rescue. Observe for provoked arrhythmia and ventricular fibrillation during extrication and removal. For core temperature monitoring, the auditory canal must be dry when using an epitympanic thermometer. Consider esophageal measurement in the lower third of the oesophagus (preferable in hypothermia stages III–IV). Pulse oximetry can be disregarded since it results in wrong values due to peripheral vasoconstriction.

Staging of hypothermia

Swiss staging (figure 1) has the advantage that it can be established by non-medical rescuers, since it is not based on measurement of the core temperature *(15)*.

Assessment of the patient and on-site treatment

The individual steps for assessment are shown in figure 1 *(4)*. All cases require core temperature and ECG monitoring, oxygen inhalation, and insulation in supine position. Consider airway warming. Administer 0.9% NaCl and/or 5% glucose only if an intravenous line can be established within a few minutes. The administration of ACLS drugs, including epinephrine and vasopressin, is not yet recommended in hypothermia stages III–IV, since cardioactive drugs may have arrhythmogenic effects and can also accumulate to toxic levels. In stages I–II, ACLS drugs may be administered, but with longer intervals between doses than in normothermic patients. Trauma treatment is provided as indicated.

Patient alert or drowsy

Change wet clothing without unnecessary movements (cutting is preferred). Hot sweet drinks are suitable as long as the swallow reflex is preserved. Transport to the nearest hospital with an intensive-care unit.

Patient unconscious

Whether a hypothermia stage III patient has to be intubated at the site of the accident is still a matter of discussion *(16)*. For intubation of a patient with protective reflexes, an intravenous line is needed for administration of medications. The risk of further heat loss during the time of treatment and transport has to be evaluated in relation to the advantages of intubation. The risk of provoked ventricular fibrillation with intubation is negligible. Transport to a hospital with intensive care unit and hypothermia experience, or preferably a unit with cardiopulmonary bypass.

Patient not breathing

Exclude obvious fatal injuries. Start cardiopulmonary resuscitation and intubate the patient. Check burial time and/or core temperature.

Asystole: Only the emergency physician should triage victims with asystole in order to differentiate hypothermia stage IV from asphyxia *(6)*. Bring patients with hypothermia stage IV to a hospital with cardiopulmonary bypass for re-warming. The criteria for re-warming include: burial time, core temperature, air pocket and airway. The emergency physician or the rescuer must provide the information about the air pocket and airway. Core temperature must be measured immediately after the rescue, since later measures are not reliable. The following situations are possible:

1. **Burial time ≤ 35 minutes and/or core temperature ≥ 32 °C**: continue resuscitation, following standard ACLS protocol. Successful: transport to the nearest hospital with intensive-care unit. In case of failure the emergency physician can establish death by »acute asphyxia«.
2. **Burial time > 35 minutes and/or core temperature < 32 °C**:
   a) **Air pocket present and airway free (or uncertain)**: suspect hypothermia stage IV. Resuscitation must be continued without break until re-warming. Therefore, start cardiopulmonary resuscitation only from the moment when an uninterrupted resuscitation is possible. Use normal guidelines for cardiopulmonary resuscitation. Transport to a hospital with cardiopulmonary bypass, continuing cardiopulmonary resuscitation. If a unit with cardiopulmonary bypass cannot be reached directly by road or air: transport to the nearest hospital, continuing resuscitation, for determination of serum potassium (criterion of irreversibility) *(17)*. With values exceeding 12 mmol/l, resuscitation can be stopped, while with values of 12 mmol/l or less a further transport should follow (under constant resuscitation) for re-warming to a hospital with cardiopulmonary bypass.
   b) **No air pocket present and/or airway blocked**: the emergency physician can terminate the resuscitation and death »by asphyxia with subsequent cooling« established.

Ventricular fibrillation at core temperature < 28 °C: electric defibrillation is generally unsuccessful, but can be tried up to 3 attempts with 200–300–360 J *(16)*. Transport to a hospital with cardiopulmonary bypass under constant CPR.

Table 1. *Algorithm for on-site management of avalanche victims. Staging of hypothermia according to Swiss Society of Mountain Medicine guidelines. Transport to the nearest hospital for serum potassium measurement if hospitalisation in a specialist unit with cardiopulmonary bypass facilities is not logistically possible (see text). Reprinted by permission of Elsevier from: Brugger H., Durrer B., Adler-Kastner L., Falk M., and Tschirky F. (2001) Field management of avalanche victims. Resuscitation 51: 7–15. C – Self-rescue techniques and safety equipment (4).*

Prevention of heat loss in all hypothermia stages: insulation, hot packs

2 to 3 chemical hot bags, 1 roll of aluminium foil, 2 wool blankets, 1 cap are needed.

a) **2 to 3 chemical hot packs** near the heart on thorax and upper part of abdomen, not directly on the skin.
b) Before removing the patient prepare the stretcher with **2 wool blankets and aluminium foil**.
c) On removing the patient **avoid big movements**.
d) Wrap up the patient closely packed in the blankets and in the aluminium foil.
e) **Cap** (30–50% of body heat is lost through the head).

SELF-RESCUE TECHNIQUES AND SAFETY EQUIPMENT FOR BACKCOUNTRY AND OFF-PISTE SKIERS

Death waits for 18 minutes

It is crucial that group members dig out the buried victim within a quarter of an hour, and every second counts. Quick location and quick shovelling are needed to rescue the buried victim. In ideal conditions, determining the position with an avalanche beacon takes 3–5 minutes and extricating the victim from under one meter of snow with a shovel takes 10–15 minutes (using ski tips it takes one hour). The more shovels are available, the sooner the victim can be dug out. Group members must remember their responsibilities to other members of the group as well as to themselves.

What to do in an avalanche

It is unknown whether self-rescue techniques improve survival chances after an avalanche. Immediate help by uninjured companion and the presence of an air pocket are essential in the case of a complete burial. In a survey 60 backcountry and off-piste skiers as well as mountaineers, who survived an avalanche accident, were questioned about self-rescue techniques during the descent of the avalanche using a standardised questionnaire *(18)*. During the descent of the avalanche, only 18% of the skiers freed themselves from the skis and 8% from both skis and ski poles. Among the 46% who tried swimming motions, it is unknown whether this reduced their chances of being completely buried. However, 50% of those who completely buried were able, at the time the avalanche stopped, to put a hand in front of the face, which allowed for free breathing. Therefore, anyone who is completely buried by an avalanche should make every effort to create an air pocket before the avalanche comes to a halt. This is the most effective means of self-rescue:

- After an avalanche has been released, do not attempt to release your bindings, but try to ski out of the avalanche path.
- Try to remain on the surface using »swimming« movements.
- Try to protect your face with your hands before the avalanche stops.
- Try to maintain an air pocket in front of your mouth and nose and to clear snow away from your mouth. Remain still and do not give up hope.

How uninjured group members should react in an avalanche emergency

- The goal: use all possible means to dig out the victim within 15 minutes. Watch the skier in the avalanche and mark the last-seen point.
- Call for help by radio or cell phone if available.
- All uninjured skiers should immediately search the primary search area for at least 20 minutes.
- A member of the group must go and report the accident (if unable to call by phone or radio).
- Locate the victim using an avalanche beacon and at the same time use your eyes and ears to search on the surface.
- If you locate the victim, evaluate the depth and the precise position of the buried victim using an avalanche probe, then leave it in place.

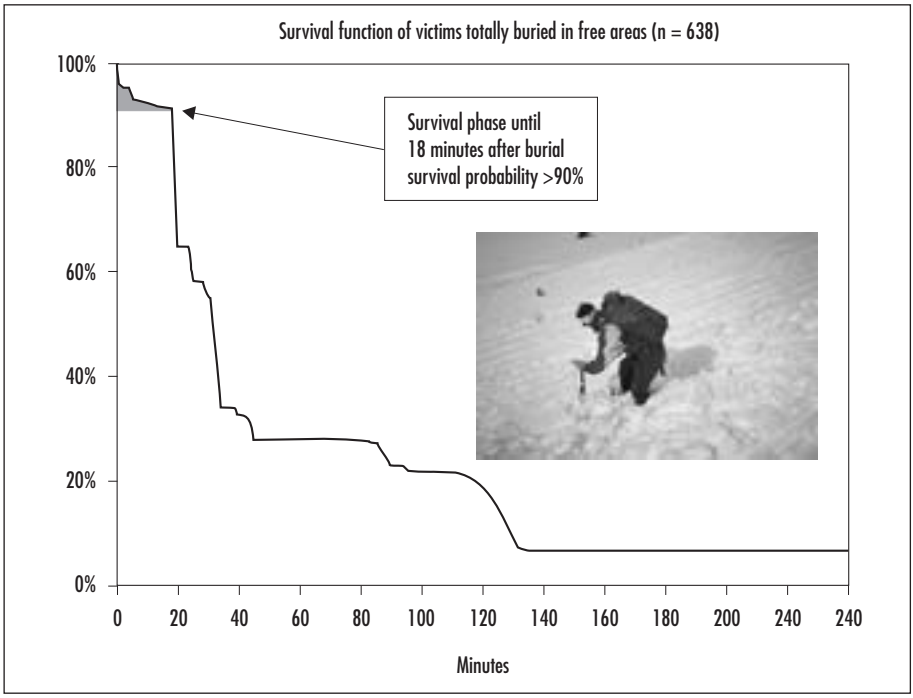

Figure 2. *Survival probability of completely buried victims with respect to the burial time. Up to 18 minutes after being buried in an avalanche, almost all buried victims survive if they are not seriously injured. Between 18 and 35 minutes, the »fatal kink« of the survival curve is reached. During this period, all the buried victims without an air pocket die quickly through suffocation. After 35 minutes only the buried victims with an air pocket survive (9).*

- Immediately start digging with all available shovels, not directly from above, but indirectly, from the sides.

Safety equipment

The following methods can be used to reduce the mortality of avalanche accidents *(19)*.

Decreasing the extent of burial using the buoyant effect (Avalanche Airbag)

The mortality rate of completely buried victims is extremely high – 52.4% – compared with only 4.2% with partially buried, or non-buried victims *(4)*. Usually a partially buried victim can be found quickly by searching the site of the avalanche. Any measure that decreases the chance of complete burial significantly lowers mortality. Safety equipment which reduces the risk of complete burial is more effective than equipment that is based on the possibility of complete burial.

Decreasing the length of burial (Avalanche rescue beacon)

If a victim is completely buried in an avalanche so that he or she cannot be found from the surface, uninjured companions can reduce the burial time and consequently reduce mortality, by locating the victim with an avalanche beacon or a probe. The burial time depends not only on the time to locate the victim, but also on the extrication time. All search devices are effective only in conjunction with a shovel.

Prolonging survival time during complete burial (AvaLung™)

If a completely buried person is able to open the airway and to create an air pocket in front of the mouth and nose, this can prolong survival in an avalanche. This increases the time available for extrication and improves the chance of survival. The AvaLung™ safety

vest contains a breathing system which creates an artificial air pocket *(20)*.

- All safety equipment may induce a false sense of security. Any increase in safety is negated if the user is willing to take greater risks (risk compensation).
- Behavior based on awareness of risks and avoidance of risky situations is the only sure protection against death in an avalanche**!**

Avalanche Airbag

This device, available since 1991, consists of two plastic balloons integrated into a rucksack. In an avalanche, pulling a string causes the balloons to fill with 120–150 litres of a mixture of nitrogen and air in a few seconds.

In an avalanche, the skier can avoid being completely buried by reducing the total density of the skier-balloon unit with respect to the snow density, and by using the physical effect of »inverse segregation« (larger grains remain on the surface), so that the skier is only partially buried or remains on the surface of the snow.

During the period from 1991–2003, 53 cases were documented in which people with airbags were caught by avalanches. Of these, 52 survived. One person was buried with fatal results in spite of the fact that the airbag deployed. In order to be buoyant, it is necessary that a skier be carried a short distance by the flow of an avalanche. If a person is trapped in avalanche debris and is buried by a second avalanche, buoyancy is no longer possible.

The Avalanche Airbag lowers the risk of complete burial from 45.8% to 15.1% and reduces the mortality rate from 29.2% to 1.9% *(21)*.

Based on these statistics the airbag is considered as acceptable, safe and useful – the safety equipment of choice:

- Even when using an airbag, never forget an avalanche beacon and a shovel.
- Never take excessive risks, even with an airbag!

Avalanche rescue beacon

The first avalanche transceiver (»Skadi«) was developed in 1968 by Lawton in the USA. Looking back, one can say that the beacon has improved the survival chances of buried avalanche victims, but not so effectively as many had expected.

Using an avalanche beacon to locate a buried victim reduces the average extrication time for completely buried skitourers (in remote areas) from 170 to 20 minutes, decreasing the mortality rate from 78.9% to 50.4% ($p < 0.001$). By contrast in completely buried off-piste skiers (in the surroundings of protected ski areas) the mortality decreases only from 67.7% to 58.5% (not significant) *(22)*.

In 22.4% of all searches, location of the buried victim using an avalanche beacon is done not by companions, but by organized rescue teams; in which case the mortality rate is 85.7%. An avalanche beacon serves its purpose if it can be used expertly by uninjured companions immediately after the victim is buried. This can only be done with proper training in the use of the beacon.

Many backcountry skiers or snowboarders are unable to use an avalanche beacon. This device works only if used by someone trained in its use; its effectiveness depends on the ability of the user. Practice in using an avalanche beacon is absolutely essential!

It remains to be seen how the new generation of digital avalanche transceivers, which allow a directional search, will affect mortality.

- Do you have an avalanche rescue beacon?
- Have you practiced using it?
- An avalanche beacon can only help you if you know how to use it!
- An avalanche beacon without a shovel is as good as no avalanche beacon at all!

Avalung™

The AvaLung™ was developed in 1996 by Thomas Crowley and Black Diamond Equipment Ltd. in Salt Lake City, UT, USA *(20)*. The device is built into a vest or harness, worn over the torso when travelling in areas that are not controlled for avalanches. If an avalanche is triggered the user must put the mouthpiece in the mouth and breathe through it while buried. A one-way valve allows inhalation from the surrounding snow and exhalation to the rear of the vest. This provides an artificial air pocket and avoids a build-up of carbon dioxide in the inspired air.

From 33 successful tests so far, one can conclude that a completely buried person can

survive with the device for up to an hour. So far, a few burials with AvaLung™ have been documented in which the victims survived. However, the International Commission for Mountain Emergency Medicine does not yet recommend using this »rescue vest« *(23)*.

Due to the lack of evidence, AvaLung™ is classified as »Indeterminate«, whereby additional confirmation is needed.

It remains doubtful, primarily, how many of those wearing the AvaLung™ will be able to position the mouthpiece correctly in an emergency. The most serious disadvantage of this system is the fact that use of the AvaLung™ implies acceptance of a complete burial with all its risks. Timely rescue, even with a prolonged period of survival cannot be guaranteed.

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Prispelo 26. 7. 2004