Backcountry triggered avalanches: a summary of risk factors, causes of death, and wilderness medical management

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Abstract

Deaths due to avalanches have a significant mortality burden in Western Canada. The aim of this review is to summarize risk factors, causes of death, and important mitigation and management strategies in treating avalanche victims. Multiple risk factors for avalanches have been identified, which relate to both physical characteristics of the avalanche environment as well as human factors. Winter backcountry recreationists should be mindful of their motivations for exposing themselves to avalanche dangers and remain objective to the physical characteristics conferring avalanche accident risk. Asphyxia is responsible for the vast majority of deaths due to avalanche, while trauma remains an important cause in certain geographic areas. Avalanche training courses educate learners on avalanche rescue sequences, which utilize avalanche transceivers, probes, and strategic shoveling techniques. The primary goal of rescue is to reduce the median time of burial, thereby decreasing the incidence of asphyxia and ultimately, death. Following the extrication of an individual from an avalanche, rescuers may have to begin resuscitation efforts. Future developments in avalanche safety should focus on public education of avalanche risk factors, incorporation of basic life support into avalanche training courses, and further development of technologies that may increase survivability.

Introduction

Backcountry winter recreation has spiked in popularity over the past few decades.[1] In Canada, an average of 12 avalanche deaths occurred annually between 2008–2018, with the majority occurring in British Columbia (82.9%) and Alberta (13%). Snowmobilers contributed 48.8% of these fatalities, while backcountry skiing and out-of-bounds skiing cumulatively accounted for 25.2%.[2] While the avalanche mortality burden is relatively low compared to other causes of death, the disproportionate impact seen in British Columbia combined with the rising popularity of recreation in avalanche terrain highlights the necessity for greater avalanche awareness. This is particularly pertinent given avalanche awareness and safety training programs have been found to be effective in preventing avalanche accidents, as well as mitigating consequences in avalanche victims.[3] The goal of this review is to summarize risk factors for avalanche accidents, causes of death, and important mitigation and treatment strategies helpful in maximizing survivability. This review is not intended to be used as a field guide, nor should it replace formal wilderness medical training.

Avalanche Risk Factors

It is estimated that 90% of deaths from slab avalanches in Europe and North America are the result of human triggering.[4] McCammon found that avalanche awareness and safety programs have been associated with a decrease in avalanche mortality, suggesting that there are mitigation strategies that can be employed to prevent avalanche-related burial, critical injury, or death.[3]

We reviewed the literature to identify risk factors implicated in avalanche triggering or accidents and have separated these into physical features relating to weather, season, or terrain characteristics (Table 1), and human factors relating to avalanche triggering risk, exposure to avalanche terrain, and behavioural factors influencing the decision to expose oneself to avalanche hazard (Table 2).

Table 1 | Risk factors related to physical conditions.

Study (study location)	Outcome Studied	Risk Factor Identified
Grimsdottir and McClung (2006)[5] (British Columbia)	Risk of triggering avalanche	Snowpack stability rated poor or very poor Alpine environment Early and mid-winter North, Northeast, and East facing slopes
Techel et al. (2015)[6] (Switzerland)	Risk of avalanche accident	Avalanche forecast danger level (positive correlation with increasing danger rating) Unfavourable snowpack (*i.e.*, persistent weak layer)
McClung et al. (2014)[4] (Switzerland and British Columbia)	Risk of avalanche accident	Slab depth; fatality increased with slab depth, however risk of triggering decreased. Risk of accident was highest between 0.6–1.0 m Slope angle 33–45°. Highest risk of triggering was between 38–40°

Several studies have identified physical risk factors for triggering avalanches, all of which can be factored into decision-making regarding exposing oneself to avalanche hazard.[4–6] Unsurprisingly, information publicly available through avalanche forecasting, including snowpack instability and high avalanche danger ratings, were found to be associated with an increase in avalanche triggering and accident risk.[5,6] McClung *et al.* identified slab depths between 0.6–1.0 m and slope angles between 33–45° to be associated with the highest risk of triggering an avalanche of sufficient size to cause critical injury or death.[4] Additionally, Grimsdottir and McClung found that the risk of triggering avalanches was greater in the alpine environment (2200 m above sea level), in early and mid-winter, and on north, northeast, and east facing slopes.[5]

A number of studies have identified human factors associated with avalanche triggering risk, accident risk, and exposing oneself to avalanche terrain (Table 2).[3,6–9] Individuals aged 25–29 were found to

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be most risk tolerant and at higher risk for avalanche accident.[8,9] Males were found to be at higher risk for avalanche accident compared to females.[9] Interestingly, Gehring and Latosuo found no association between avalanche terrain usage and danger rating, and found usage was highest on weekends regardless of avalanche danger.[8] Similarly, Techel *et al.* found no association between avalanche terrain exposure and snowpack instability.[6] These results suggest that the decision to enter avalanche terrain may be influenced more by recreationist availability than avalanche triggering risk. A lack of formal avalanche safety training was associated with higher risk tolerance as well as avalanche accident risk.[3,8] With regards to decision-making in avalanche terrain, Furman *et al.* found that recreationists were more likely to expose themselves to avalanche terrain if the forecast suggested minimal hazard, a slope was untracked or was familiar to the user, the group had an identified leader, other parties were present in the terrain, or if a skier was committed to a particular line.[7] Furthermore, Sole and Emery found individuals who desired intense experiences or were motivated by "fun-seeking" had a higher risk of avalanche accident.[9]

Our analysis of avalanche risk factors suggests that while snowpack instability and avalanche danger ratings are accounted for in avalanche forecasts due to their association with increased avalanche risk, these do not necessarily correlate with lower avalanche terrain usage by recreationists. Users should be mindful of their motivations for exposing themselves to avalanche dangers and remain objective to the physical characteristics conferring avalanche accident risk. This is particularly important for high risk groups—namely, males aged 25–29. The findings of our review also suggest that avalanche safety training remains an effective strategy for decreasing avalanche accident incidence, both by preventing high-risk exposure and by training users to mitigate consequences of avalanches if they occur. Avalanche Canada reports that avalanche safety training course enrollment has been increasing with the boom in popularity of winter backcountry recreation; however, the proportion of enrollment for motorized users has been low compared to self-propelled users.[1] Thus, efforts to improve snowmobilers' participation in avalanche safety training may help to reduce their disproportionately high avalanche mortality risk.[10]

Causes of death

Among several studies analyzing cause of death in avalanche victims, asphyxia was unanimously found to be the most common cause of mortality.[11–13] Boyd *et al.* analyzed the causes of avalanche fatality in British Columbia and Alberta between 1984–2005 based on postmortem autopsy or full external examination, and found that the majority of deaths were caused by asphyxiation (75%) and trauma (24%).[11] Similarly, Hohlreider *et al.* reviewed autopsy reports of avalanche victims presenting to the University Hospital of Innsbruck in Austria between 1996–2005, and found that 91.7% of deaths were attributable to asphyxia, while only 5.5% were due to trauma.[12] McIntosh *et al.* examined medical records of avalanche fatalities from 1989–2006 from the Utah Avalanche Centre and the Medical Examiner's records in Utah, and found the leading cause of death to be asphyxia (91.7%), with only 5.4% of deaths being caused by trauma alone.[13]

Although these retrospective reviews consistently identified asphyxia as the most significant cause of death, geographical differences exist. In Western Canada, trauma is a significant cause of avalanche mortality.[11] This differs from studies conducted in Europe and the United States and may reflect differences in terrain or type of backcountry activity. Collision with trees is often implicated in traumatic avalanche accidents, which may account for this difference as there is more accessible forested terrain in parts of Western Canada, including British Columbia and Alberta.[11,14]

Table 2 | Human factors associated with avalanche risk.

Study (study location)	Outcome Studied	Risk Factor Identified
Furman et al. (2009)[7] (USA)	Exposure to avalanche terrain	Forecast suggesting minimal hazard
		Untracked slope
		Familiar terrain
		Group had a leader
		Other parties present
		Skier committed to skiing a particular line
Gehring and Latosuo (2014)[8] (Alaska)	Factors associated with higher risk tolerance	Risk tolerance decreased with increasing levels of avalanche training
		Age 25–29
	Exposure to avalanche terrain	Weekends more common, regardless of avalanche danger
		No correlation between avalanche terrain usage and avalanche danger
Techel et al. (2015)[6] (Switzerland)	Exposure to avalanche terrain	No correlation between avalanche terrain usage and unfavourable snowpack (*i.e.*, persistent weak layers)
Sole and Emery (2008)[9] (Western Canada)	Avalanche mortality	Male sex
	Avalanche accident risk	Age 25–29
		Desire for intense experiences
		Exposure time
		Male-dominant groups
		Behaviour motivated by "fun seeking" as opposed to "memory creating"
McCammon (2000)[3] (USA)	Avalanche accident risk	Lack of formal avalanche safety training (due to more risks taken and decreased risk mitigation by victims)

Approach to Management in the Field and Safety Equipment

Rescue Sequence

The Wilderness Medicine Society has published guidelines on the Prevention and Management of Avalanche and Snow Burial Accidents.[2] When an individual is buried in an avalanche, they first recommend establishing and ensuring scene safety prior to carrying out the rescue. A visual surface search can then be carried out to identify an incomplete burial. If the visual search is not successful, rescuers are then recommended to perform transceiver search, followed by a pinpoint/probe search and strategic shoveling to uncover the avalanche victim.[15] Contacting local emergency services should not delay the rescue response and can happen at any point during the rescue.

When avalanche rescue is initiated by companions at the scene, as opposed to professional rescue teams, the time to extrication is

shorter (16 versus 150 minutes) and the probability of survival is higher (75% versus 30%).[16] The use of avalanche transceivers is also associated with a shorter median burial time (20 versus 102 minutes without transceivers) and reduction in mortality (53.8% versus 68%).[17] Furthermore, the probability of survival significantly decreases after 35 minutes of burial.[18] Given that asphyxia is the most common cause of death, reducing burial time is paramount and backcountry users should be prepared and able to perform companion rescue efficiently.

Resuscitation

Following the extrication of an individual from an avalanche, a rescuer may have to begin resuscitation efforts if clinically indicated. With limited resources or assistance, this can be a daunting task in the avalanche terrain. In a rescue sequence, the Wilderness Medicine Society advises using the European Resuscitation Council (ERC) Guidelines.[20] Section 4 of the ERC guidelines comments on resuscitation in special environments including avalanches, recommending "high-quality cardiopulmonary resuscitation (CPR) with minimal interruption of chest compressions and treatment of reversible causes."[21] Trauma can exacerbate hypothermia and asphyxia, and is an important cause of avalanche death in Western Canada.[11] The Wilderness Medicine Guidelines recommend trauma care as an integral part of resuscitation, including appropriately managing suspected spine injuries using validated guidelines such as the Canadian C-Spine Rules or Nexus.[2] Furthermore, avalanche resuscitation should include management of hypothermia using a combination of insulation and vapor barriers.[20]

An in-depth discussion of resuscitation and management in the field is beyond the scope of this article. It is, however, important to note that Basic Life Support (BLS) or CPR training is not currently incorporated into avalanche safety courses such as Avalanche Safety Training One or Avalanche Safety Training Two, and therefore may represent an area for future improvement in avalanche safety training.

Developments in Safety Equipment

With increased backcountry usage, there has also been development in technologies that may reduce mortality related to avalanches.[22,23] The avalanche rescue airbag is a piece of equipment that allows the user to inflate to emergency balloons that are integrated into a special backpack. An avalanche rescue airbag can decrease the depth of burial during avalanche through decreasing effective density of the user. Although the avalanche rescue bag started as a niche product in the 1970s, it has undergone recent development and is now more widely accepted amongst backcountry users.[23] A retrospective review of global avalanche data found a significant reduction in mortality associated with usage of the airbag equipment (22% to 11%).[24] As market competition in avalanche airbag technology accelerates, the unit price of airbags will decrease. As the technology becomes more economical and affordable, it is expected that utilization by the backcountry community to continue to increase, having a significant impact on the future of avalanche safety.

Another piece of safety equipment to consider are Artificial Air Pocket Devices. These mouthpieces allow avalanche victims to divert CO2 away from their airway, thereby delaying asphyxiation.[25,26] The device appears promising, but there is currently a lack of data demonstrating its effectiveness in real-world use.[23]

Conclusion

Backcountry enthusiasts who are entering avalanche terrain should take appropriate steps to educate themselves on the risk factors associated with avalanche accidents and strategies to mitigate those risks. Formal avalanche education programs have been shown to reduce avalanche mortality and we recommend that all users undertake this training and ensure they are proficient in avalanche rescue sequences prior to entering the backcountry. Future areas for improvement in avalanche safety include incorporation of first aid and basic life support into avalanche training courses, and further development of technologies that may increase survivability.

Conflict of interest

The authors have declared no conflict of interest.

References

1. Avalanche Canada. 2017-2018 annual report [Internet]. 2018. Available from: https://issuu.com/avalancheca/docs/ac_2018_annual_reportissuu
2. Van Tilburg C, Grissom CK, Zafren K, McIntosh S, Radwin MI, Paal P, *et al.* Wilderness Medical Society practice guidelines for prevention and management of avalanche and nonavalanche snow burial accidents. *Wilderness Environ Med.* 2017 Mar 1;28(1):23–42.
3. McCammon I. The role of training in recreational avalanche accidents in the United States. In: *International Snow Science Workshop*. 2000. p. 2–6.
4. McClung DM. Risk analyses for dry snow slab avalanches released by skier triggering. *Nat Hazards.* 2014 Jun 8;72(2):1139–58.
5. Grímsdóttir H, Mcclung D. Avalanche risk during backcountry skiing – an analysis of risk factors. *Nat Hazards.* 2006 Sep 21;39(1):127–53.
6. Techel F, Zweifel B, Winkler K. Analysis of avalanche risk factors in backcountry terrain based on usage frequency and accident data in Switzerland. *Nat Hazards Earth Syst Sci.* 2015 Sep 9;15(9):1985–97.
7. Furman N, Shooter W, Schumann S. The roles of heuristics, avalanche forecast, and risk propensity in the decision making of backcountry skiers. *Leis Sci.* 2010 Sep 30;32(5):453–69.
8. Gehring B, Latosou E. Avalanche risk: assessment, preparedness, and awareness of backcountry users in Turnagain Pass, Alaska. In: *International Snow Science Workshop*. 2014. p. 932–8.
9. Sole A, Emery C. Human risk factors in avalanche incidents. In: *International Snow Science Workshop*. 2008. p. 498–505.
10. Spencer JM, Ashley WS. Avalanche fatalities in the western United States: a comparison of three databases. *Nat Hazards.* 2011 Jul 23;58(1):31–44.
11. Boyd J, Haegeli P, Abu-Laban RB, Shuster M, Butt JC. Patterns of death among avalanche fatalities: a 21-year review. *CMAJ.* 2009 Mar 3;180(5):507–12.
12. Hohlrieder M, Brugger H, Schubert HM, Pavlic M, Ellerton J, Mair P. Pattern and severity of injury in avalanche victims. *High Alt Med Biol.* 2007 Mar 29;8(1):56–61.
13. McIntosh SE, Grissom CK, Olivares CR, Kim HS, Tremper B. Cause of death in avalanche fatalities. *Wilderness Environ Med.* 2007 Dec 1;18(4):293–7.
14. Haegeli P, Falk M, Brugger H, Etter H-J, Boyd J. Comparison of avalanche survival patterns in Canada and Switzerland. *Can Med Assoc J.* 2011 Apr 19;183(7):789–95.
15. Edgerly B, Atkins D AR. Strategic shoveling: The next frontier in companion rescue. In: *Proceedings of the 2006 International Snow Science Workshop*. 2006. p. 1–6.
16. Slotta-bachmayr L. How burial time of avalanche victims is influenced by rescue method: an analysis of search reports from the Alps. *Nat Hazards.* 2005 Mar;34(3):341–52.
17. Hohlrieder M, Mair P, Wuertl W, Brugger H. The impact of avalanche transceivers on mortality from avalanche accidents. *High Alt Med Biol.* 2005 Mar 16;6(1):72–7.
18. Brugger H, Durrer B, Adler-Kastner L, Falk M, Tschirky F. Field management of avalanche victims. *Resuscitation.* 2001 Oct 1;51(1):7–15.
19. Kornhall DK, Martens-Nielsen J. The prehospital management of avalanche victims. *J R Army Med Corps.* 2016 Dec 1;162(6):406–12.
20. Zafren K, Giesbrecht GG, Danzl DF, Brugger H, Sagalyn EB, Walpoth B, *et al.* Wilderness Medical Society practice guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia. *Wilderness Environ Med.* 2014 Dec 1;25(4):425–45.
21. Truhlář A, Deakin C, Soar J, Khalifa G, Alfonzo A, Bierens J, *et al.* European resuscitation council guidelines for resuscitation 2015: section 4. Cardiac arrest in special circumstances. *Resuscitation.* 2015 Oct;95:148–201.
22. Brugger H, Etter HJ, Zweifel B, Mair P, Hohlrieder M, Ellerton J, *et al.* The impact of avalanche rescue devices on survival. *Resuscitation.* 2007 Dec 1;75(3):476–83.
23. Brugger H, Falk M. Analysis of avalanche safety equipment for backcountry skiers. *Avalanche News.* 2004;34–8.
24. Haegeli P, Falk M, Procter E, Zweifel B, Jarry F, Logan S, *et al.* The effectiveness of avalanche airbags. *Resuscitation.* 2014 Sep 1;85(9):1197–203.
25. Grissom CK, Radwin MI, Harmston CH, Hirshberg EL, Crowley TJ. Respiration during snow burial using an artificial air pocket. *JAMA.* 2000 May 3;283(17):2266–71.
26. Brugger H, Sumann G, Meister R, Adler-Kastner L, Mair P, Gunga HC, *et al.* Hypoxia and hypercapnia during respiration into an artificial air pocket in snow: implications for avalanche survival. *Resuscitation.* 2003 Jul 1;58(1):81–8.