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

Adam Stich1*, Jacob Blanco2*

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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.

<table>
<thead>
<tr>
<th>Study (study location)</th>
<th>Outcome Studied</th>
<th>Risk Factor Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grimsdottir and McClung (2006) (British Columbia)</td>
<td>Risk of triggering avalanche</td>
<td>Snowpack stability rated poor or very poor</td>
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<tr>
<td></td>
<td></td>
<td>Alpine environment</td>
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<tr>
<td></td>
<td></td>
<td>Early and mid-winter</td>
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<td></td>
<td></td>
<td>North, Northeast, and East facing slopes</td>
</tr>
<tr>
<td>Techel et al. (2015) (Switzerland)</td>
<td>Risk of avalanche accident</td>
<td>Avalanche forecast danger level (positive correlation with increasing danger rating)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfavourable snowpack (i.e., persistent weak layer)</td>
</tr>
<tr>
<td>McClung et al. (2014) (Switzerland and British Columbia)</td>
<td>Risk of avalanche accident</td>
<td>Slab depth; fatality increased with slab depth, however risk of triggering decreased. Risk of accident was highest between 0.6–1.0 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope angle 33–45°. Highest risk of triggering was between 38–40°</td>
</tr>
</tbody>
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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.5 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).5,6,9 Individuals aged 25–29 were found to

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1Department of Family Medicine, University of British Columbia
2Department of Family Medicine, University of British Columbia
*Both authors contributed equally to this work

Correspondence to
Adam Stich (astich@gmail.com)
Jake Blanco (j.blanco@alumni.ubc.ca)
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.9 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.38 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 unanomously 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.

<table>
<thead>
<tr>
<th>Study (study location)</th>
<th>Outcome Studied</th>
<th>Risk Factor Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furman et al. (2009) (USA)</td>
<td>Exposure to avalanche terrain</td>
<td>Forecast suggesting minimal hazard, untracked slope, familiar terrain, group had a leader, other parties present, skier committed to skiing a particular line</td>
</tr>
<tr>
<td>Gehring and Latosuo (2014) (Alaska)</td>
<td>Factors associated with higher risk tolerance, exposure to avalanche terrain</td>
<td>Risk tolerance decreased with increasing levels of avalanche training, weekends more common, regardless of avalanche danger, no correlation between avalanche terrain usage and avalanche danger</td>
</tr>
<tr>
<td>Techel et al. (2015) (Switzerland)</td>
<td>Exposure to avalanche terrain</td>
<td>No correlation between avalanche terrain usage and unfavourable snowpack (i.e., persistent weak layers)</td>
</tr>
<tr>
<td>Sole and Emery (2008) (Western Canada)</td>
<td>Avalanche mortality</td>
<td>Male sex, age 25–29, desire for intense experiences, exposure time, male-dominant groups, behaviour motivated by “fun seeking” as opposed to “memory creating”</td>
</tr>
<tr>
<td>McCammon (2000) (USA)</td>
<td>Avalanche accident risk</td>
<td>Lack of formal avalanche safety training (due to more risks taken and decreased risk mitigation by victims)</td>
</tr>
</tbody>
</table>

**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%). 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%).

Furthermore, the probability of survival significantly decreases after 35 minutes of burial. 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 extraction 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. 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.” Trauma can exacerbate hypothermia and asphyxia, and is an important cause of avalanche death in Western Canada. 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. Furthermore, avalanche resuscitation should include management of hypothermia using a combination of insulation and vapor barriers.

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. 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. A retrospective review of global avalanche data found a significant reduction in mortality associated with usage of the airbag equipment (22% to 11%). 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. The device appears promising, but there is currently a lack of data demonstrating its effectiveness in real-world use.

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