TERRAIN AND TRAUMATIC INJURY IN U.S. AVALANCHE ACCIDENTS

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ABSTRACT: Previous studies have investigated the incidence of traumatic injury in avalanche victims. But the relationship between these injuries and the terrain that produces them remains largely unknown. The goal of this study was to examine the prevalence of traumatic injury among historical avalanche victims and to evaluate the correlation with terrain features generally regarded to be traps. An analysis was conducted of 22 years of historical avalanche incidents in the United States that was compared to detailed terrain and injury data for avalanche incidents in Utah. The analysis showed that traumatic injury is common among avalanche victims, although it is less commonly listed as an official cause of death. Trees, cliffs and rock bands appear to produce the most frequent trauma in avalanche accidents. These results emphasize the importance of prudent route selection and first aid skills in addition to the use of current avalanche rescue technologies.

KEYWORDS: Avalanche terrain, trauma, rescue, education, risk management.

1. INTRODUCTION

Recent developments in avalanche rescue technology show great promise for reducing the mortality of avalanche victims. Devices such as the AvaLung™ and avalanche airbag systems have been successfully utilized in avalanche burials, and continuing advances in rescue beacon and reflector technologies have greatly simplified the process of locating buried avalanche victims.

But rescue technology does not ensure live recovery in all cases, and because avalanche victims are the predominant trigger in the vast majority of avalanche accidents (Tremper, 2001:11), prevention would seem to play a central role in keeping people alive in avalanche terrain.

Traditional prevention efforts have generally taken the form of avalanche education. One of the central pillars of these programs has been the recognition and avoidance of terrain traps – land features that compound the effects of being caught in an avalanche (Fredston and Fesler, 1999; McClung and Schaerer, 2006).

Unfortunately, there is little formal knowledge about the specific effects of terrain traps on avalanche victims and virtually no quantitative injury data to guide route selection decisions relative to these features. This study examines retrospective accident data in order to characterize the relationship between terrain traps and injury type and severity in avalanche accidents. The aim is to provide a quantitative perspective useful in selecting travel routes in avalanche terrain, and in presenting terrain concepts to avalanche students.

2. PRIOR WORK

A number of investigators have examined trauma as the cause of death in avalanche victims. In a review of ten studies involving 343 avalanche fatalities, McIntosh et al. (2007) found that trauma was attributed as the cause of death in between 0% and 43% of avalanche victims. Studies typically indicated a relatively low incidence of trauma as the cause of death (median 9%), and a high incidence of asphyxia (median 82%). In a study of 105 avalanche victims admitted to a university hospital in Austria, Hohlrieder et al. (2007) found that only two died of trauma. These findings support the common belief that asphyxiation is the leading cause of death among avalanche victims (McClung and Schaerer, 2006:244).

There have been several studies that examined avalanche trauma ancillary to death. These studies are important because they highlight the types of injuries that an avalanche victim might suffer that fall short of being immediately fatal. Such findings are also important to ski partners and rescue parties, since these individuals must manage a victim's injuries in the immediate aftermath of an avalanche accident.

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Grossman et al. (1989) found that of ten non-survivors transported to a medical facility, nine had sustained blunt or penetrating traumatic injuries. In a study of 28 avalanche-related deaths, Johnson, Johnson and Barton (2001) found that 61% of victims showed signs of closed head injury. In a study of 105 avalanche victims, Hohlrieder et al. (2007) found that 47% had sustained significant traumatic injuries. And in a radiological study of fourteen avalanche victims, Grosse et al. (2007) found musculosketal trauma in 61% of victims and extrasketal trauma in 39% of the victims.

These studies suggest that traumatic injuries in avalanche victims may be far more common than is suggested by a strict mortality analysis.

Although it is likely that terrain features are a significant factor in avalanche trauma, only qualitative discussions of terrain effects can be found in the medical literature. In describing the difference between compressive asphyxia and mechanical injuries in avalanche victims, Stalsberg et al. (1989) note that “the difference may be due to the presence of more trees.” Grossman qualitatively describes the effects of “rocks and trees” on the incidence of mechanical trauma, and Tough and Butt (1993) describe a case where avalanche trauma resulted from a victim being carried down a gully and over cliffs. A quantitative picture of how terrain features produce trauma in avalanche victims has been unclear.

3. METHODS

To explore the effects of terrain features on avalanche trauma, this study reviewed historical avalanche accident data and autopsy reports on avalanche victims. Accident data for the United States from 1986 to 2008 was derived primarily from accident records maintained by the Colorado Avalanche Information Center (Boulder CO), and a number of web-based avalanche accident data services. The type of terrain involved in each accident was reviewed and coded into one of eight trap types, with a ninth type coded for cases where no terrain trap was present. The severity of injuries sustained by individuals caught in these avalanches was coded according to the scheme shown in Table 1. It should noted be that in many cases, the cause of death of an avalanche victim was not stated in the available records, and it was not possible to determine if the individual had died of trauma, asphyxia or other cause. To minimize reporting and other biases, highway, residential and in-bounds ski area avalanches were excluded from the study. Accidents where victims were never recovered were also excluded from the study.

Code	*Description*
No injuries	Victim reported as uninjured
Minor	Injuries that would be field treatable by first aid: e.g. abrasions, small lacerations, minor athletic injuries.
Critical	Injuries that would normally require transport to a medical facility: e.g. fractures, internal injuries, head or spine trauma.
Fatal	Death due to asphyxia, trauma or other cause.

Table 1. Four codes were used to classify injury severity in U.S. avalanche victims.

A second data set was used to examine the relationship between terrain features and specific types of traumatic injury. This data set was derived from accident records of the Utah Avalanche Center (Salt Lake City UT) and the Utah Medical Examiner’s Office. Terrain data from these accident records was matched to case files and autopsy reports for avalanche fatalities occurring in Utah from 1992 to 2006. When available, internal autopsy results were also reviewed. External and internal injuries and cause of death were recorded using the Abbreviated Injury Scale (AMA et al. 1971) and the Injury Severity Score (van Camp, 2001). Both scales have been extensively validated for rating severity of trauma (MacKenzie, 1985).

Unless otherwise noted, comparisons between injury proportions were conducted using a chi square 2 x n contingency test, where $P < 0.05$ defined statistically significant differences between proportions.

4. RESULTS

A total of 434 cases were identified in the U.S. data set that had sufficient information to code the type of terrain trap and severity of injuries of avalanche victims. Of the 725 victims, 92% were male. Ages ranged from 5 to 67 years, with a median of 30 years (mean 31.8 years). Recovery of avalanche victims that were completely buried was accomplished by a variety of reported methods, including rescue beacons, probing, search dogs, and recovery after melting of the avalanche debris.

The frequencies of terrain traps in accidents over the study period are shown in Figure 1. Because many accidents involved multiple victims being carried into the same terrain trap, frequencies are shown for both avalanche incidents and avalanche victims. About 82% of victims were carried into terrain traps, and trees, cliffs, rock bands and gullies accounted for 90% of the these traps.

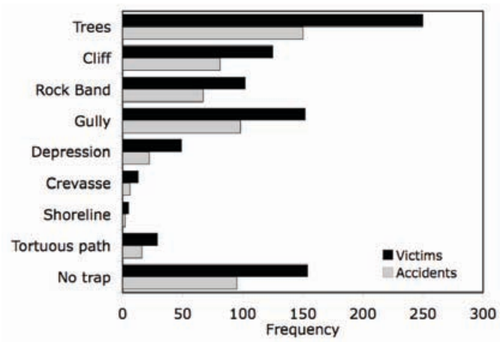

Figure 1. Frequency of terrain traps in avalanche accidents. Some accidents involved multiple terrain traps.

Eighty-one percent of accidents where a terrain trap was present involved a single type of trap. For each of the four most common traps (trees, cliff, rock band, gully) we assessed the severity of injury using the descriptors in Table 1. Because of reporting variations, the distinction between rock bands and cliffs was not consistent across all accidents. The severity distributions for these two traps were not statistically different (P = 0.061) and so these distributions were combined, as shown in Figure 2 (b).

For comparative purposes, Figure 2 shows the frequency of injury severity relative to the total number of victims carried into each trap (N). Figure 2 reflects only those accidents where a single trap type was involved.

A total of 51 cases were identified in the Utah data set where autopsy results could be matched against the terrain types shown in Figure 2. Six cases involved combinations of terrain traps and three cases involved individuals buried while sleeping in a tent. These nine cases were omitted from the analysis.

In the 42 remaining cases, victim ages ranged from 18 to 59 years, with a median of 30 years (mean 31.6 years). Ninety-four percent of the victims were male.

The median severity score for Utah victims involved in each terrain trap by anatomical category of the Abbreviated Injury Scale (AIS) is shown in Table 2. AIS scores above 3 are generally life threatening, and scores above 4 are generally fatal. Also shown are the number of cases for each terrain trap (N) and the proportion of victims where the medical examiner observed evidence of physical trauma (injury rate).

Distributions of Injury Severity Scores (ISS) for Utah accidents are shown in Figure 3. Each whisker plot shows the maximum, minimum, median and interquartile range of ISS scores. It is notable that over 40% of the accidents shown in Figure 3 involved trees, rocks or cliffs.

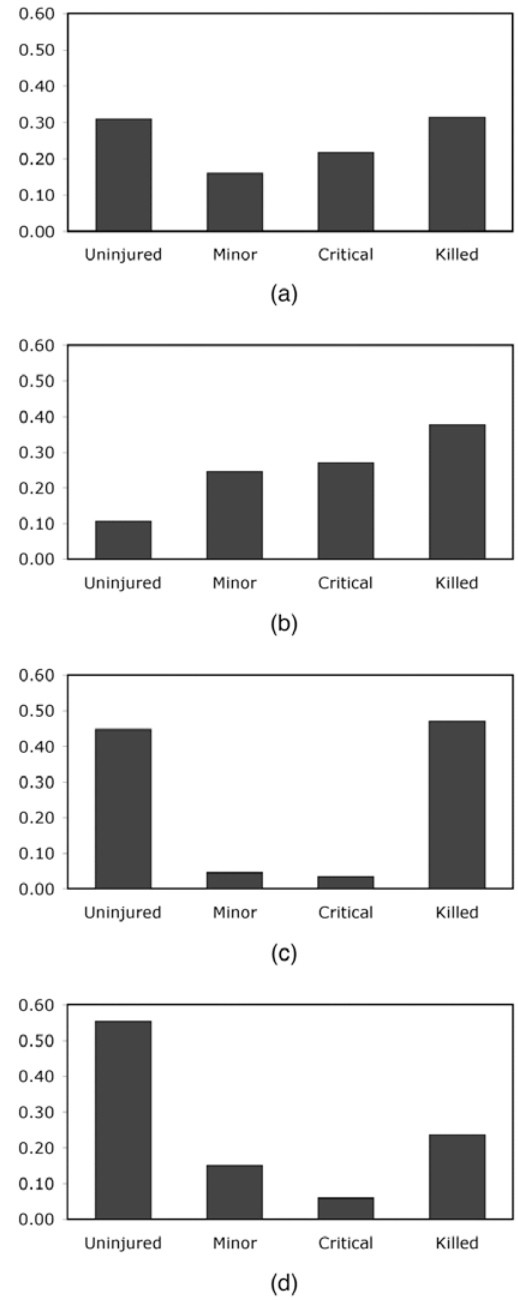

Figure 2. Severity of injuries by trap type, where "killed" contains an unknown proportion of victims who died of trauma. (a) Trees (N = 194), (b) rock bands or cliffs (N = 122), (c) gully (N = 87), (d) no trap (N = 186).

All Utah accidents for the study period were analyzed separately for injury severity using the descriptors shown in Table 1. Severity distributions for Utah were compared with severity distributions for the rest of the United States (excluding Utah). The number of cases in each comparison and the results of contingency table tests are shown in Table 3. No significant difference was found between the Utah severity data and the national data, although results for rocks and cliffs should be viewed with caution due to the small number of Utah cases available for comparison.

	Trees	*Rocks/ Cliff*	*Gully*	*No trap*
Head/neck	5	3	1	1
Chest	5	5	0	0
Abdomen	0	4.5	3	0
Extremities	2.5	3	0	0
General	1	2	1	1
N	10	7	13	12
Injury rate	0.9	1.0	.4	.4

Table 2. Median severity scores for AIS anatomical categories for each terrain trap type in Utah avalanche accidents.

The incidence of terrain traps was also evaluated across four behavioral risk management levels of avalanche accident parties. As described by McCammon (2004), these categories reflect qualitative differences in hazard recognition and mitigation steps taken by accident parties immediately prior to the avalanche. Four risk management levels were compared: no awareness of hazard, awareness of hazard without mitigation, incomplete or ineffective mitigation, and full mitigation precautions.

Figure 3. Injury severity scores for terrain traps in Utah.

Our data set contained 410 accidents with complete information regarding level of risk management and presence or absence of terrain traps. Comparison of the proportions of accidents involving no terrain traps and those involving terrain traps yielded no significant differences across levels of risk management (P = 0.814). In other words, more skilled parties did not appear to expose themselves to fewer terrain traps than less skilled parties.

	Trees	*Rocks/ Cliff*	*Gully*	*No trap*
Utah	26	7	18	19
Other U.S.	184	141	80	101
P	0.182	0.297	0.636	0.720

Table 3. Comparison of injury severity distributions between Utah and the rest of the United States.

Our data set contained 973 avalanche victims for which the level of risk management of the group and the severity of injury were known. Comparison of the incidence of minor or no injuries to the incidence of serious injury or death showed no significant difference across levels of risk management (P = 0.097). In other words, more skilled parties sustained about the same proportion of severe injuries as unskilled parties.

5. DISCUSSION

In the majority of avalanche accidents in this study, victims were swept through or into terrain traps. In 90% of these cases, the terrain traps were trees, cliffs, rocks or gullies.

Injury severity by type of terrain trap also showed reasonable results. In both the Utah and U.S. data sets, the absence of a terrain trap (open slope running out into a flat or gently sloping basin) produced few traumatic injuries, as did burial in a gully. In these cases, asphyxia was the predominant cause of death.

Trees appeared to be variable in their effects on avalanche trauma. In some cases, victims were swept through trees and sustained little or no trauma. In the Utah data set, the cause of death among these victims was invariably asphyxia. In other cases, victims sustained serious or fatal trauma. Avalanche victims in the Utah data set most commonly sustained trauma to the head, neck and chest.

Rock bands and cliffs appear to be fairly consistent in their trauma effects on avalanche victims. Injuries appear to be common and often serious or fatal in victims who are swept over cliffs or through rock bands. Utah victims most commonly sustained trauma to the head, neck, chest, abdomen and extremities. This trauma was often fatal. National data suggests that the proportion of accident victims who emerge uninjured from an accident involving this type of terrain trap is likely to be quite low.

These results may have important implications for individuals who rely on avalanche rescue technologies. These devices generally aim to reduce the effects of asphyxia by reducing the depth, duration or hypercapnic consequences of burial

(Brugger et al. 2007; Radwin and Grissom, 2002). Because they do not protect explicitly against trauma, such devices appear to be secondary to prudent route choices and the prevention of accidents that are likely to involve serious trauma.

These results also suggest that parties that travel in treed or rocky avalanche terrain must be prepared to aggressively treat traumatic injury in the field. Wilderness medical skills remain outside the curriculum of most avalanche training courses. However, a clear and explicit emphasis on their necessity seems appropriate in view of our findings.

Finally, our results suggest that skilled parties involved in accidents did not necessarily avoid terrain traps with a greater frequency than novices. In addition, higher risk management levels did not appear to decrease the overall severity of injury. These results argue for more explicit presentation of the relationship between terrain traps and injury in avalanche courses, so that those who travel in avalanche terrain can more fully anticipate the consequences of their route selection decisions.

6. LIMITATIONS

There are number of limitations of this study that suggest caution in broadly applying the results. First, as with any retrospective analysis, systematic errors may exist in accident observations, reporting and record keeping that will compromise any statistical results. For example, the reporting rate for avalanche accidents involving serious injury or death is generally very high whereas the reporting rate for accidents where all victims are recovered uninjured may be quite low.

Second, the classification schemes used in this study characterize complex phenomena with very simple categories. Different injury patterns may produce identical AIS and ISS scores, and important regional differences in avalanche trauma may not be apparent. Also, the AIS & ISS do not take into account complications that may arise when providing emergency medical care in a wilderness environment. Serious injuries that may have a favorable prognosis in an urban environment may be drastically impacted by delayed access to definitive medical care.

Third, this study only examined accidents where a single type of terrain trap was involved. Accidents involving more than one type of terrain trap are not uncommon, and the effects of multiple terrain traps on trauma type and severity remains unknown.

Finally, this study has omitted a terrain feature that appears commonly in accidents but is only infrequently considered a terrain trap. Anecdotal data suggest that avalanche victims who are swept long distances sustain greater trauma than those swept shorter distances. Further research is needed to understand the effects of this potentially important terrain trap.

7. CONCLUSIONS

While other research has shown that asphyxia is the main cause of death in avalanche victims, this study provides evidence that traumatic injury is relatively common among avalanche victims. Certain terrain traps can result in trauma at a higher frequency than others, and awareness of these terrain traps would appear to play a crucial role of prevention of serious injury in avalanche terrain.

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