CAUSES OF DEATH AMONG AVALANCHE FATALITIES IN COLORADO: A 20-YEAR REVIEW

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ABSTRACT: Methods: We reviewed all avalanche fatalities between 1995 and 2015 in the state of Colorado, USA, using the database maintained by the Colorado Avalanche Information Center. For each fatality, we obtained the coroner's official determination of cause of death, and autopsy records if one was performed. We used these records to determine cause of death. Injury severity scores (ISS) were calculated for those victims who underwent autopsy.

Results: Mortality information was available for 110 fatalities occurring during the 20-year study period. Of these, 64 underwent autopsy. Almost all others had external forensic examination to determine cause of death. Asphyxia was the cause of death in 65% of fatalities (72/110). Trauma was the cause of death in 29% of the fatalities (32/110). Of these, the primary cause was multiple system trauma in 38% (12/32), head trauma 31% (10/32), and spinal injuries 19% (6/32). Of the victims who died of asphyxia and had autopsy, only 10% (4/42) also had significant trauma, defined as ISS greater than 15. There were six fatalities from other causes, including hypothermia, drowning, and primary cardiac arrest.

Interpretation: Reducing the occurrence and duration of critical burial, and therefore asphyxia, could have the largest reduction in fatalities. Mitigating the severity of head trauma may have a significant effect on reducing the number of traumatic fatalities in avalanche victims. Finally, greater emphasis on first aid skills is vital for those traveling in avalanche terrain and for rescuers called to help those in need.

KEYWORDS: trauma, avalanche fatalities, asphyxia, Colorado

1. INTRODUCTION

Over the past 20 years, from 1995-2015, avalanches have been the cause of 124 deaths in the state of Colorado. Previous studies have found rates of fatal traumatic injury as low as 5.6% in Europe (Hohlreider et al. 2007), and as high as 24% (Boyd 2009). Current avalanche education and prevention strategies focus primarily on avoidance, on strategies to mitigate the risks of asphyxia including safety devices such as airbags designed to reduce burial, transceivers to quickly locate a buried subject, and shoveling techniques to then dig them out.

Our primary goal was to determine cause of death in all avalanche fatalities in Colorado during the study period, and to examine the frequency and severity of traumatic injuries. A secondary goal was to investigate whether the incidence of fatal trauma in avalanches correlated with avalanche characteristics or user groups.

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2. METHODS

2.1 Population

We reviewed all snow avalanche deaths in the Colorado Avalanche Information Center (CAIC) database for the calendar years 2005-2015. We excluded incidents in which avalanche was not a primary contributor to the fatality, and avalanches which were limited to slides off a roof or building.

2.2 Data collection and abstraction

Avalanche data was abstracted from CAIC records by a single investigator (S.L.) who was blinded to the cause of death. Fields included elevation, date, group size, demographic information about victims, mode of travel, and avalanche characteristics.

We contacted individual county coroners to obtain records including the official cause of death and the autopsy report if one was performed. In total, we requested records for 124 fatalities from 26 separate county coroners in the state of Colorado.

A single investigator (A.S.) abstracted mortality data after training by a hospital employed trauma

registry coordinator. For all cases, cause of death was assigned based on the coroner's official determination of the principal cause of death. Other data abstracted included organ systems involved and type of injury sustained, if any. If an autopsy was performed, the investigator calculated an Injury Severity Score (ISS).

The Injury Severity Score (Baker et al. 1974) is an anatomical scoring system for injured patients based on the Abbreviated Injury Scale (AIS). An AIS is assigned to each of six body regions, and the three highest scoring regions are individually squared and then added together to produce the ISS score. The values range from 0 to 75, with severe trauma being defined as a score greater than 15.

2.3 Statistical analysis

We examined the incidence of traumatic fatalities for correlation with avalanche characteristics and some demographic data of the victims. We used chi-squared tests to assess possible correlation of trauma with avalanche type or with victim's primary travel mode. We used Mann-Whitney U tests to assess possible correlation of trauma with avalanche start elevation or with victim age (Conover 1980).

3. RESULTS

We indentified 124 avalanche fatalities during the specified 20-year study period. We excluded 3 deaths that resulted from avalanches off the roof of a structure or building, resulting in a total of 121 eligible incidents. Mortality data was available for 110 of these; 64 had complete forensic autopsies performed.

The primary cause of death was determined to be asphyxia in 65% (72/110) of cases. Trauma was determined to have been the cause of death in 29% (32/110) of the fatalities. Of these traumatic fatalities, the primary cause was multiple system trauma in 38% (12/32), head trauma in 31% (10/32), and spinal injuries in 19% (6/32) of victims. There were six fatalities from other causes, including hypothermia, drowning, and primary cardiac arrest (Table 1).

Table. 1: Primary cause of avalanche fatalities

Cause of death	*#/110*	*Percent*
Asphyxia	72	65
Trauma	32	29
Hypothermia	4	4
Drowning	1	1
Primary cardiac	1	1

We calculated ISS scores for all 64 victims who had forensic autopsies performed; of the 64 autopsies reviewed, 17 were determined to have trauma as the primary cause of death, and 42 as asphyxia. The ISS calculated on the 17 trauma fatalities indicated severe injuries for all victims, and ranged from 16 to 75 with a median of 35, and mean of 38. In the subjects whose cause of death was non-traumatic, 30 had ISS of zero or one, and only four had ISS greater than 15 (Fig. 1). The incidence of severe trauma in asphyxia victims was 4/42 (10%) of those who underwent autopsy.

Injury types for scores below 10 are generally only superficial abrasions and lacerations or isolated closed extremity fractures. Scores of 15-30 can be more complex fractures and internal injuries that may or may not be immediately life threatening. Greater than 30 are injuries likely to cause death rapidly, for example in our study this included severe craniofacial injuries, vascular injuries of the aorta or other major vessels, and multi system trauma. Multiple injuries in the same body region may score lower as only the most severe injury for anatomical region is used to calculate the ISS score.

Incidence of trauma did not vary widely with respect to mode of travel (Table 2) or avalanche type (Table 3). The percentage of trauma did not differ with the victim's primary activity ($\chi^2(7, N=107)=4.25$, $p=0.75$) or age ($U=1145$, $p= 0.50$). Likewise, the percentage of trauma did not differ with the avalanche type ($\chi^2(3, N=107)=3.24$, $p=0.36$) or starting zone elevation.

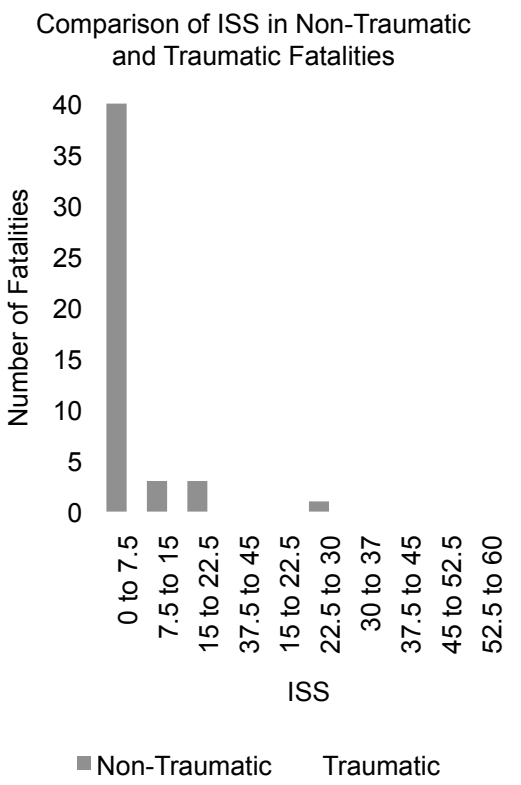

Fig. 1. Comparisons of ISS in non-traumatic and traumatic fatalities.

Table 2. Number of fatalities by primary activity and percent of traumatic fatalities.

Primary Activity	*Total Fatalities*	*% Trauma*
Snowmobiler	29	21
Backcountry Tourer	48	27
Sidecountry Rider	21	29
Inbounds Rider	4	50
Climber/Hiker	17	24

Table 3. Number of fatalities by avalanche type and percent of traumatic fatalities.

Avalanche Type	*Total Fatalities*	*% Trauma*
Loose	2	0
Soft Slab	66	29
Hard Slab	48	23
Wet Slab	3	67

4. LIMITATIONS

We were able to obtain records for 110 of 121 (91%) of eligible avalanche incidents. It is possible, though not likely, that information in the missing 11 records would substantially alter our results or our conclusions.

Although nearly 60% of the subjects in our study had definitive forensic autopsies performed, the remainder had cause of death attributed by external examination only. It is possible that this could result in misclassification in some cases.

We were unable to draw any conclusions about traumatic injuries sustained in avalanches in general, if the incident did not result in a fatality. These non-fatal cases were not part of this investigation, and are often not publicly reported unless a formal rescue is required (Edgerly 2010).

5. DISCUSSION

Asphyxia was responsible for the majority of deaths in our study. This is consistent across all similar previously published studies. Reducing the occurrence and duration of critical burial, and therefore asphyxia, has the potential to result in the largest reduction in fatalities. This is especially true in light of the low (10%) incidence of major traumatic injuries in asphyxia victims who had autopsy performed. If these victims had avoided critical burial or been uncovered rapidly, it is possible that some would have had a good chance of survival.

Nearly a third of victims in our study died of traumatic injuries. The incidence of trauma as the cause of avalanche deaths in Colorado is markedly higher than previous studies found in Europe and Utah (Neureuther 1975, Hohlrieder et al. 2007, McIntosh et al. 2007), and slightly higher than reported in Canada (Boyd et al. 2009). These differences have been attributed to geography, topography, and activities (McIntosh et al. 2007, Boyd et al. 2009). In the US, McCammon and colleagues found trauma to be relatively common as many avalanche victims were swept through or into trees, cliffs, rocks and gullies (McCammon et al. 2008).

International avalanche resuscitation guidelines were revised in 2013 (Brugger et al.) to give more importance to trauma care. Incidentally, Brugger (2009) has advocated for more importance to trauma management in the on-site care of avalanche victims, and the importance of this is supported by the high rate of trauma found in our series. It is notable that most safety equipment currently in use focuses on mitigating the potential for asphyxia as a consequence of critical burials. In our series, the use of preventive equipment such as air bag packs, Avalungs™ and

transceivers would likely not have prevented these traumatic fatalities. Given the high rate of trauma found in our avalanche victims it is important that travelers in avalanche terrain have appropriate first aid training. Likewise, rescuers should also be prepared to manage serious traumatic injuries.

Head injury was the primary injury in nearly a third of the traumatic fatalities in Colorado. This rate is notably less than the 42% reported in Canada (Boyd et al. 2009) but greater that the 21% reported by Johnson and colleagues (2001) for a series of avalanche deaths in Utah. Collectively, the experience in western North America contrasts sharply with an Austrian study (Hohlreider et al. 2007) that found no lethal head injuries in a review of Austrian avalanche fatalities. While helmets have been recommended (Johnson et al. 2001, McIntosh et al. 2007, Boyd et al. 2009) for those in avalanche terrain it is not definitively known whether use of currently available helmets offers significant protection in the event one is caught in an avalanche.

In comparing avalanche type, mode of travel, age, and elevation we did not find statistically significant differences in the proportion of traumatic fatalities. This suggests that all backcountry travelers, regardless of demographic, are at risk for fatal trauma if caught in an avalanche. This would suggest that we need further research into the effectiveness of equipment and other mitigation strategies intended to prevent injuries.

Over the decades a number of other studies have looked at the cause of death in avalanches; however, limitations in study design, small sample sizes, incomplete information, and unusual conditions limited the meaningful conclusions (Radwin 2008, Brugger et al. 2009). Brugger highlighted the importance of autopsy, or at least full external forensic examination as the minimum from which to draw postmortem conclusions.

6. CONCLUSIONS

Based on autopsies and external forensic examinations asphyxia was the primary cause of death to most avalanche victims; however, lethal trauma killed nearly one-third of victims, which is a notably higher rate than reported elsewhere in North America and Europe. While prevention is the best action to ensure survival in avalanche terrain, strategies that aid rapid rescue and that provide prompt emergency medical care will result in the best opportunity to save additional lives.

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