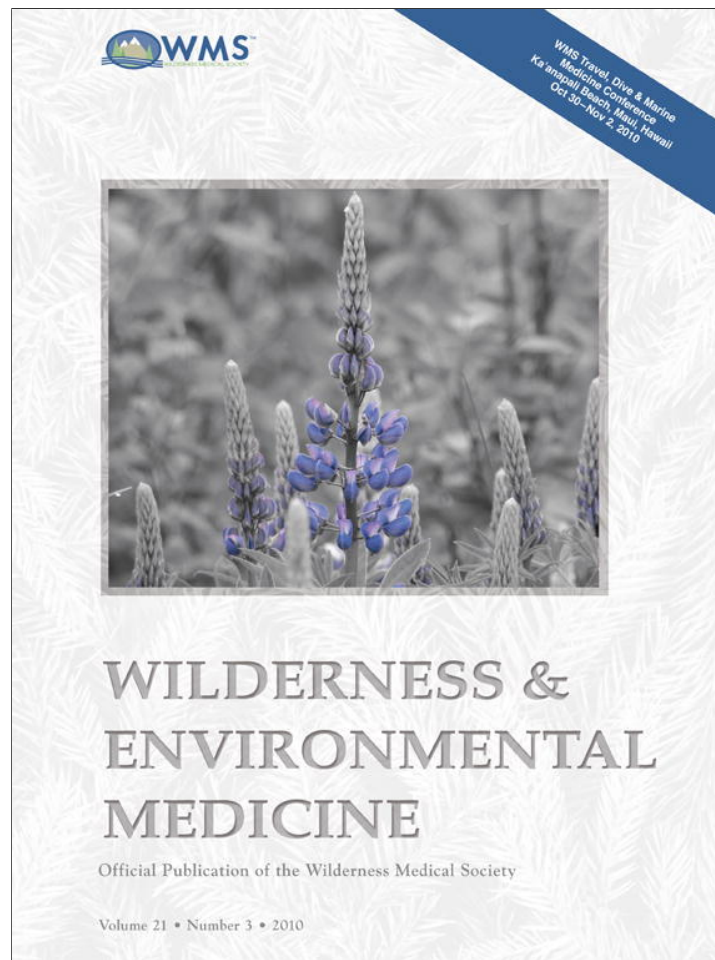


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REVIEW ARTICLE

Non–Avalanche-Related Snow Immersion Deaths: Tree Well and Deep Snow Immersion Asphyxiation

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Non-avalanche-related snow immersion death (NARSID), or snow immersion asphyxiation, is a significant winter mountain hazard for skiers and snowboarders. This phenomenon occurs predominately in western North America, where large tree wells and deep snowpacks develop. Although statistics are difficult to procure, snow immersion asphyxiation has resulted in more than 70 documented deaths in the past 2 decades. The primary purpose of this review is to examine the existing literature on NARSID to help prevent such dangerous accidents through educating wilderness medicine professionals and fostering public awareness. The exact duration of burial to time of death and the cause of death are not precisely known but can be postulated from accident reports, experimental snow burial studies, and avalanche literature. In most cases, death probably occurs within 15 to 30 minutes from the time of burial. However, survival after prolonged burial in a tree well and deep snow is possible. The cause of death is asphyxiation, probably due to one of the mechanisms that produce asphyxia in avalanche burial victims: positional asphyxia, airway obstruction, or carbon dioxide displacement asphyxia. Prevention of snow immersion asphyxiation begins with skiers and snowboarders staying within the limits of their skills, using the proper tools for deep powder, staying in control at all times, and employing a buddy system. A skier or snowboarder who falls near or into a tree well should tuck, roll, and try to land upright, grab the tree trunk or a branch, and yell or blow a whistle to alert partners. If buried upside down, the person should stay calm and create an air pocket, which is probably of paramount importance. Skiers and snowboarders should use avalanche safety equipment to lessen the risk of snow submersion asphyxiation.

Key words: NARSID, non–avalanche-related snow immersion death, snow immersion asphyxiation, tree well, skiers, snowboarders

Introduction

While avalanche accidents and prevention are highly publicized in the lay and medical literature, non–avalanche-related snow immersion death (NARSID) and near deaths from deep snow and tree well burial are widely under-reported. They are often reported locally to law enforcement and appear in news periodicals, but data are not captured by a larger database in the manner that avalanche statistics are recorded by public avalanche safety organizations. Although NARSID is the term used in previous literature, tree well and deep snow immersion asphyxiation is more descriptive, because it describes both geographic features that cause accidents as well as

the manner of death. Thus it is probably a more appropriate term.

Snow immersion asphyxiation occurs when a winter mountain traveler, a skier or snowboarder, falls upside down in a tree well or in deep snow unrelated to a tree well. Such accidents usually occur in midwinter, during or immediately following a storm, when deep powder abounds. Such conditions are found primarily in the mountains of the western United States and Canada, particularly the Cascades, Sierra Nevada, and ranges of British Columbia, where large conifers and deep, moisture-laden snow create conditions in which submersion in deep snow or tree wells can occur. Similar conditions are less common in the Rocky Mountains, where ski resorts have fewer large evergreens, the snow and climate are drier, and the snowpack is generally shallower.

Tree wells form at the base of large conifers on un-groomed ski slopes, both within ski areas boundaries (“in area”) or out of bounds (the “backcountry.”) Large low-lying branches limit the amount of snow that falls around a tree. The snowpack may be deep on open slopes, but the areas under tree branches typically have much less accumulation. These holes, or wells, can be 10 or more feet deep, depending on the seasonal snowpack. Tree wells can be made larger or smaller by slow season-long migration, or creep, of the snowpack downhill, by wind blowing snow either away from or into tree wells, by increased melting of the snow in the well from heat from the tree trunk, or by decreased melting due to shading. Tree branches often hide the wells. After a storm, the snow in and around the tree well is often soft and deep. In addition, when a skier or snowboarder falls into a tree well, additional snow is knocked off low-lying branches to cover him or her.

The mechanism of death of deep snow and tree well burial is asphyxiation. Trauma and hypothermia are not reported as comorbidities. The specific mechanism of asphyxiation is not known. However, it is probably similar to avalanche asphyxiation death, which results from one of several mechanisms: airway obstruction by snow or by an ice mask, airway obstruction by positioning of the head and neck relative to the torso (called “positional asphyxia”), or asphyxia from rebreathing expired carbon dioxide. Carbon dioxide displacement asphyxia can be accelerated by ice mask formation or by lack of an adequate air pocket.

An ice mask develops when moist expired air condenses then freezes on the victim’s face, either blocking the airway or reducing the size of the air pocket. An air pocket is a space in front of the victim’s face in which expired air mixes with air in the snowpack. With no air pocket, expired air rich in carbon dioxide displaces oxygenated air. A buried individual rebreathes carbon dioxide-rich air repeatedly and eventually asphyxiates. With a large air pocket, expired carbon dioxide dilutes snowpack oxygen more slowly and victims survive longer.

The time from submersion to death is uncertain but probably is related to pathophysiologic mechanisms discussed above. Several accident reports and interviews with victims and bystanders document rapid asphyxiation, within 15 to 30 minutes. Some cases described below suggest death may occur more rapidly, in as quickly as 5 to 10 minutes.

Methods

The author gathered information on snow immersion asphyxiation from the medical literature, from lay liter-

ature including news and magazine reports, from medical conference proceedings, by personal communication with snow sports professionals, by reviewing medical charts, and, in one circumstance, by interviewing a person who survived snow immersion asphyxia. PubMed was used to search the medical literature; all papers in which the terms NARSID and Non-Avalanche-Related Snow Immersion Death were included in the review.

Results/Discussion

Snow immersion asphyxiation has been described infrequently and sporadically in the medical literature and was absent from the lay winter sports literature until recently. In 1994 Kizer et al described 3 snowboarders who died from asphyxiation following a large storm in the Lake Tahoe region ski resorts in the Sierra Nevada Range.¹ All 3 victims were located several hours after they were noticed missing; rescuers found them by observing their snowboards in the snow. More recently, snow immersion asphyxiation has become more prominent in mountain recreational literature.²⁻⁴

Since Kizer first wrote about snowboarders, it was thought that this group was at increased risk. Interestingly, many authors postulated that skiers were at an advantage because they could kick off skis, and would have an easier time righting themselves.⁵⁻⁷ Such is probably not the case, based on more recent studies described below.

Two reports by Cadman in 1999 were the first to collect and analyze data that provided insight about prevention. He described 8 cases from 1993 to 1998 from British Columbia ski resort data, and noted several important issues.^{8,9}

Of 32 deaths in British Columbia ski areas from 1993 to 1998, 8 were snow immersion asphyxiation-related. Of the 8 people who died, 7 were skiers and 5 were in ski areas, documenting that snow immersion asphyxiation is a hazard for both skiers and snowboarders and is not limited to the backcountry. None had evidence of fatal trauma; all died of suffocation. Two bodies were located with avalanche rescue dogs.

In addition to analyzing the 8 cases, Cadman performed a small study in which he buried 6 skiers and 4 snowboarders upside down in a simulated tree well, essentially a hole in the snowpack. He developed several important findings. Of the 10, none could extricate themselves. When skiers kicked off their skis, they sank deeper. Snowboarders could not remove their snowboards. The parkas of skiers and snowboarders acted as funnels to collect snow, which piled up along the victims torsos and dragged them down; the effect was more pronounced when skis were removed.

Later, Hackett collected data from 1985 to 1995 and summarized nearly 2 dozen cases in unpublished data presented at a medical meeting. He found 2 similar issues¹⁰: the risk of snow immersion asphyxiation is up to 10 times greater than that of avalanche death within the boundaries of ski resorts, which confirmed that this is a significant issue within ski areas; and death occurred after short burial time. Six of the deceased were buried less than 30 minutes and 3 less than 15 minutes.

A recent paper by Baugher summarized the most complete data collected to date, as well as described an experiment similar to the one conducted by Cadman.¹¹ Baugher reviewed 65 cases, a database he collected from various sources: 51 were from the 1990–91 through 2005–06 ski and snowboard seasons.

Baugher found that snow immersion asphyxiation is a prominent cause of death within ski areas, as well as in the backcountry, with similar statistics to avalanche fatalities. From the 1990–91 through 2005–06 seasons, there were 3 in-bounds and 45 out-of-bounds avalanche deaths to skiers and snowboarders, compared to 6 and 46 for snow immersion asphyxiation. During this period, snow immersion asphyxiation accounted for 5% of all skier deaths and 15% of all snowboarder deaths in ski resorts. Ski resort deaths in the U.S. have averaged 38 per year over the last 10 years. Other causes of death were high-speed impact with a stationary object, collision with another skier, avalanches, and nontraumatic causes.

Baugher found that 65% of deaths were due to tree wells and 35% were due to open slope deep snow burial, confirming that snow immersion asphyxiation is not limited to tree wells.

In addition to summarizing the data, Baugher conducted a study similar to Cadman's where he buried 5 skiers and 5 snowboarders in tree wells. Baugher's findings confirmed those of Cadman. Struggling compromised the air pocket and caused most buried subjects to sink deeper. All subjects struggled, but only 3 were able to improve their situation and self-extricate. The common features of successful self-extrication were being able to bend 90 degrees at the waist and shallow burial. Thus burial depth and the ability to flex at the trunk appear to be important for self-extrication. Additionally, the ability to remove skis and snowboards did not significantly improve chances of self-extrication. Only 1 of the 3 subjects who self-extricated was able to remove skis. A second skier was able to remove skis but was not able to self-extricate.

When looking at recent deaths, evidence from accident reports can provide further understanding of snow immersion asphyxiation. For example, the 2006–07 winter season was a particularly abundant snow year for the Pacific Northwest: several big storms deposited deep

snow in the mountains in a short period of time. That season 5 snow immersion asphyxiation deaths occurred nationwide and at least 1 skier almost died.^{12–19} Two of the deceased were skiers and 3 were snowboarders. One of the dead was a mountain guide and ski instructor, and the near-death victim was an off-duty ski patroller. Four of the dead were found in tree wells, and 1 was in deep snow at the base of a rock wall. Four of the deaths and the near-death occurred in Washington State. In 2 cases, bodies were located with avalanche rescue equipment. One body was found with an avalanche transceiver and another was located after 7 hours using avalanche probes. These accidents confirm that snow immersion asphyxiation occurs to both skiers and snowboarders, in open slopes as well as tree wells, to both novice and mountain professionals, and predominantly in the Pacific Northwest in the U.S. and Canada.

Time to death is difficult to ascertain but probably occurs rapidly. One near miss exemplifies how a buried skier or snowboarder can quickly asphyxiate and gives an indication that it occurs within minutes of being buried. In a recent article, an off-duty ski patroller fell into a tree well when skiing the backcountry at Crystal Mountain, Washington.⁴ She was unable to move and instantly fell unconscious. She was rescued immediately by her partner, who pulled her out in what the partner estimated to be 5 to 10 minutes, at which time she was not breathing. He started cardiopulmonary resuscitation (CPR) and she was revived. She spent 3 days in the hospital then fully recovered⁴ (personal communication with patient, May 2007).

Another accident in December 2007 occurred at Mount Hood Meadows in Oregon. The snowboarder fell in deep snow and reportedly asphyxiated in minutes. His friends were on scene when it occurred and pulled him out of the snow after digging for 15 minutes. CPR was attempted immediately by bystanders and a mountain physician but was unsuccessful^{20,21} (personal communication with on-scene physician, February 2008).

Prevention

Reviewing accident reports, the literature, the Baugher data, and both Baugher and Cadman's burial experiments provides a much clearer understanding of snow immersion asphyxiation. In simulation studies, 90% of buried subjects could not extricate themselves. In many actual cases asphyxiation occurred in less than 30 minutes. Prevention strategies and early extrication are of paramount importance. Since exact mode of death and time of burial before death are not specifically known, prevention recommendations focus primarily on avoiding

deep snow and tree wells. Secondary tactics for extricating oneself are speculative.

Prevention begins with knowing that tree wells and deep snow banks exist and that they are dangerous; public awareness campaigns in ski resorts and articles in popular literature are of paramount importance. The subject has recently reached popular magazines, as well as ski resorts, particularly in the Pacific Northwest, in which resort websites have snow immersion asphyxiation awareness and safety pages. Baugher, for example, designed <http://www.treewelldeepsnowsafety.com>, a website geared to safety.²² Many Pacific Northwest ski areas have links to this site and post snow immersion asphyxiation warning signs on days when deep powder is the dominant snow condition.

Steering clear of tree wells, especially in gladed and treed areas, is important and requires a conscious effort by skiers and snowboarders. Skiing and snowboarding in control, staying within skill limits, and using the proper tools for the conditions help prevent accidents. For example, many skiers and snowboarders attempt to descend slopes of deep powder but lack the proper skills or have improper equipment. In powder snow, long, wide skis and snowboards with significant nose scoop and bindings set back from center can enhance flotation and control.

Snow riders should always use the buddy system in deep powder, in glades and woods, and in any other potentially hazardous areas. The buddy system has been a standard recommendation for all backcountry travel in any terrain or weather condition but not for in-area skiing and snowboarding. The buddy system means staying in voice and visual contact at all times, riding slopes one at a time, and using a spotter for the person descending. In 1 snow immersion asphyxiation death in 2002, a snowboarder voluntarily separated from her 2 friends, became lost, and was found 3 weeks later. The delay in locating her body was partly because of the large search area.^{2,3} Had that victim been using the buddy system, 1 partner may have immediately seen the victim fall into the tree well or at least known the specific run she was descending.

If skiers or snowboarders find themselves falling toward a tree well or in deep snow, it has been suggested that they should immediately employ 1 of several maneuvers to stay righted: tuck, roll, and attempt to land upright; attempt to ride to the side of the tree well; or try to maneuver through the low-lying tree branches to the other side. A skier or snowboarder who does topple into a tree well should try to grab a branch or the trunk. Baugher notes that it may be useful to ski without ski pole straps when in deep powder to improve the chances of grabbing the tree.

Anyone involved in an accident should scream or blow a whistle to their partner. Some manufactures incorporate a whistle into the plastic buckle for the sternum strap of a ski and snowboard backpack. Some snow riders keep a whistle attached to the zipper of their ski parka. Both allow snow riders to easily and quickly access the whistle.

A skier or snowboarder who is caught upside down should quickly make an air pocket with one hand while trying to reach the tree trunk or branch with the other. Avalanche data have clearly documented that an air pocket is critical to survival for those buried and that self-extrication is difficult. Struggling should probably be avoided. Baugher found that struggling compromised the air pocket and caused several subjects to sink deeper, although Cadman recommended initiating a gentle rocking motion to possibly help pack down the snow and aid in self extrication. Whether or not to struggle may be situational, and may depend on the depth of burial, consistency of snow, proximity of a tree branch, and other factors.

In 2 cases above, bodies were recovered with avalanche rescue equipment, 1 with a transceiver and a second with a probe. A letter by this author a few years ago suggested that avalanche rescue equipment would be useful for snow immersion asphyxiation prevention for quick location.²³ An artificial air pocket device such as the Avalung (Black Diamond Limited, Salt Lake City, UT) that diverts expired air to the buried individual's back would probably be useful for delaying carbon dioxide asphyxia and prolonging survival. However, no documented snow immersion asphyxiation near death has been reported using an artificial air pocket device.

A hand-held radio, such as the FRS/GMRA (Family Radio Service/General Mobile Radio Service) walkie-talkies commonly used by in-bounds skiers, may be useful. One was used in a live recovery. One case reported on an Internet forum in 2002 involved a man who fell into a tree well at Washington's Steven Pass.²⁴ He was upside down and unable to right himself. However, he was able to reach a hand-held radio in his pocket, and called his partner who had gone to the bottom of the ski area. From the lift, the man's partner spotted the treed area, notified ski patrol, and they were able to locate him, guided by voice and radio. The snowboard was buried 6 inches, with nothing visible from the surface. The man survived an estimated 30-minute burial time. Even more useful may be hand-held radios that have voice-activated transmission, allowing transmission to be activated without the use of hands if located close to the face, such as on a jacket lapel or hood.

Rescue or recovery by trained search dogs may also be useful; Cadman described the discovery of 2 bodies by search dogs. Many ski areas employ search dogs and have the dogs on standby for accidents. However, access to an accident site often takes more time than the 15- to

30-minute window for rescue. Usually dogs are employed for body recoveries.

Reference has been made in popular and medical literature that releasable bindings for snowboarders may aid in removal of the board and help prevent deaths.⁵⁻⁷ Releasable bindings are problematic for a number of reasons. First, the only 2 developed by Meyer and Miller are no longer available, most likely because the lack of widespread adoption by snowboarders resulted in poor sales. Second, removing the board is unlikely to aid in extrication, as highlighted by Cadman and Bauhger. Third, if releasable snowboard bindings were tight enough to ride on a typical slope, they would be too tight to remove without manually releasing them, making them equivalent to non-releasable bindings that have to be manually unbuckled or unclipped. Fourth, these bindings are probably more dangerous for general snowboarding because if only 1 foot were to release in a fall, the weight of a snowboard attached to the other foot would cause a huge torsion force on the contralateral leg, and likely cause knee injury.

Several versions of snowboard bindings such as those in the past by K2 Snowboard and more recently, Voile, had cords tied to the buckles of highback snowboard bindings or release levers of step in bindings. This would facilitate removing the board, such as when caught in an avalanche. However, due to the reasons discussed above, it is unlikely that removing the board would significantly help someone upside down, asphyxiating in deep snow. But, depending on the situation, it is the option one may wish to employ in attempts for self extrication.

Conclusion

Snow immersion asphyxiation, a prominent mountain hazard primarily in the northwest mountains of the United States and Canada, is more common than death by avalanches within the boundaries of developed ski resorts. Little awareness has been promoted until recently. The key for prevention is avoidance of tree wells and deep snow. If a skier or snowboarder falls upside down and cannot self-extricate, the only means for survival is rapid rescue by a partner who is immediately available. An air pocket is vital for prolonging survival. An expired air diverting device could delay carbon dioxide asphyxia. Avalanche beacons and radios have been shown to help aid in safety and location of a buried partner. Ultimately, avoidance of hazardous terrain and partner rescue are paramount for prevention and survival of snow immersion asphyxiation.

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