

WILDERNESS MEDICAL SOCIETY PRACTICE GUIDELINES

# Wilderness Medical Society Practice Guidelines for Prevention and Management of Avalanche and Nonavalanche Snow Burial Accidents



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To provide guidance to clinicians and avalanche professionals about best practices, the Wilderness Medical Society convened an expert panel to develop evidence-based guidelines for the prevention, rescue, and medical management of avalanche and nonavalanche snow burial victims. Recommendations are graded on the basis of quality of supporting evidence according to the classification scheme of the American College of Chest Physicians.

**Keywords:** airbags, air pocket, avalanche, hypothermia, rescue, resuscitation, snow burial, wilderness medicine

## Introduction

Snow and ice avalanches are widespread in mountainous regions of the world. Worldwide avalanche-related morbidity and mortality are difficult to estimate due to the lack of reporting systems in many countries. Europe and North America have relatively accurate systems for capturing data on avalanche fatalities. Approximately 150 fatalities occur annually in Europe and North America.<sup>1–4</sup> During the 31 winter seasons between 1983 and 2015, Europe and North America recorded 5123 avalanche fatalities,<sup>5</sup> about 165 deaths per year; most are from Europe, about 130 per year. In the same

period an average of 24 people died in avalanches each winter in the United States and 12 in Canada.<sup>5</sup> Avalanche fatalities in mountain regions of other locales—for example, the Andes and the Himalaya—are not systematically recorded. However, the number of fatalities per year may be many times higher than fatalities officially recorded in Europe and North America. Catastrophic avalanches that killed over 10 persons, for example, include the serac fall in Nepal in 2014 and the earthquake in Nepal in 2015. Nonfatal avalanche events are extremely difficult to quantify because many accidents are not reported and organized search and rescue teams are not activated.

Most documented North American and European avalanche fatalities occur in recreational user groups such as snowmobilers, skiers, snowboarders, mountaineers, and snowshoers. Occupational-related avalanche

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fatalities among ski patrollers, mountain rescuers, mountain guides, and transportation workers occur less frequently, although job requirements may place these personnel at higher and more prolonged risk.<sup>1</sup>

Avalanche avoidance should be the main method to mitigate risk of injury and death. If an avalanche incident occurs, rescue by one's companions—including appropriate resuscitation and advanced life support measures—are critically important to reduce avalanche morbidity and mortality.

## Methods

The Wilderness Medical Society convened an expert panel to develop evidence-based recommendations for 3 primary aspects of avalanche accidents: prevention, rescue, and resuscitation. Nonavalanche deep snow and tree-well burial were included as related conditions with pathophysiology and recommendations similar to avalanche burial.

The PubMed database was searched using keywords including avalanche, snow burial, snow asphyxiation, and nonavalanche-related snow immersion death. Secondary references were also included. The panel mainly considered peer-reviewed randomized controlled trials, observational studies, case series, and case reports for inclusion. Only a limited number of studies of avalanche accidents have been published in the peer-reviewed academic literature, so conference proceedings, avalanche center data, letters to the editor, review articles, and books were included for background information. When no studies existed to provide evidence, the recommendations of the panel were based on review articles, textbooks, patient-care experience, and firsthand knowledge of equipment and techniques.

The panel developed recommendations by consensus. The panel graded recommendations based on the strength of the recommendation and the quality of evidence using the classification scheme of the American College of Chest Physicians (see online supplementary Table 1).<sup>6</sup> When no evidence existed, the panel made recommendations based on expert consensus.

## Pathophysiology

Avalanche morbidity and mortality largely depend on duration of burial, patency of the airway, air-pocket volume, depth of burial, and traumatic injuries. The term *air pocket* is defined as a patent airway and any space in front of mouth and nose.<sup>3,4,7–11</sup> The chance of survival after complete burial (head and chest below the snow) for an uninjured victim is about 50%.<sup>1–4</sup> If only partially buried (head and chest out of the snow), chance of survival is nearly 100% if trauma is not a contributing factor.<sup>1,2,12</sup> Asphyxia is the most common cause of death

during avalanche burial. About 75% of avalanche deaths are due to asphyxia, 25% are due to trauma, and few are due to hypothermia.<sup>9,12–18</sup>

## ASPHYXIA

Asphyxiation during avalanche burial occurs by 3 primary mechanisms: physical blockage of the upper airway caused by inhaled snow, ice mask formation, and oxygen deprivation due to rebreathing expired air. In addition, the weight and compaction of snow may limit chest expansion and impair ventilation, especially with heavy, dense snow, which is more common in a maritime snow climate and during spring conditions.<sup>14</sup>

Complete obstruction of the upper airway by snow or debris results in hypoxia in <10 minutes and acute asphyxiation during the first 30 to 60 minutes of avalanche burial. If the airway is patent, ice mask formation occurs when water vapor in exhaled air condenses and freezes on the snow in front of the face, forming an impermeable barrier that prevents airflow. Because asphyxia is the major cause of death during avalanche burial, time to extrication is a foremost determinant of survival. According to Swiss data, completely buried avalanche victims had >90% chance of survival if they were extricated within about 15 minutes, but only a 30% chance of survival if they were extricated after approximately 30 minutes (Figure 1).<sup>3,7,12</sup>

Survival of a buried victim after more than 30 minutes requires a patent airway and the presence of an air pocket. The larger the volume of the air pocket, the longer the duration of possible survival after burial. Inspired air contains 21% oxygen ( $O_2$ ) and less than 0.03% carbon dioxide ( $CO_2$ ). Expired air contains about 16%  $O_2$  and 5%  $CO_2$ . Rebreathing expired air during avalanche burial results in a progressive decrease in the fraction of inspired oxygen ( $F_I O_2$ ) and a progressive increase in the fraction of inspired carbon dioxide ( $F_I CO_2$ ).<sup>8,19,20</sup> Hypoxia and hypercapnia eventually cause death by asphyxiation unless an adequate air pocket exists or the victim is extricated before asphyxia can occur. A larger air pocket volume provides greater surface area for air flow, allowing expired  $CO_2$  to diffuse from the air pocket into the snowpack and  $O_2$  to diffuse from the snowpack into the air pocket. Snow density and porosity surrounding the air pocket also is a factor in the diffusion of gases, but their impact on survival is still not fully understood.<sup>19</sup> If the air pocket is large enough, asphyxiation is delayed and an avalanche victim may survive for many hours.<sup>8,20</sup>

## TRAUMA

Trauma accounts for less than 25% of avalanche deaths in North America and Europe in avalanches that are

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