Fatal injuries in children during recreational skiing: two case reports and multidisciplinary context

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SUMMARY
Winter sports such as skiing, snowboarding, and sledding rank among the most popular recreational activities in developed countries, yet they also represent a significant source of traumatic injuries, including fatal cases. The combination of high speeds, altered stability, hard surfaces, the movement of other participants, and the presence of mechanized equipment on slopes creates a high-risk environment for injuries. Despite technological advancements in protective gear, the incidence of severe injuries remains alarmingly high, with head and spinal injuries predominating in terms of severity. The article analyzes two case reports of fatal injuries in minor individuals (aged 8 and 9) during recreational skiing. Although the injury mechanisms differed, both cases share a common factor – non-adherence to the principles of safe conduct on ski slopes. The study emphasizes the importance of continuous education, the individual responsibility of each slope participant, the selection of appropriate safety equipment, and adherence to safe conduct rules. A multidisciplinary analysis of these tragic events underscores the need for intensive prevention, interdisciplinary cooperation, and awareness-raising activities aimed at minimizing risks not only in children's but also in adult skiing.

Keywords: fatal injuries – children – skiing – traumatology – prevention – interdisciplinary cooperation

Smrteľné úrazy detí pri rekreačnom lyžovaní: popis dvoch prípadov a medziodborové súvislosti

SÚHRN
Zimné športy ako lyžovanie, snowboarding a sánkovanie patria medzi populárne voľnočasové aktivity, no zároveň môžu predstavovať významný zdroj závažných až smrteľných poranení. Kombinácia vysokých rýchlostí, zmenenej stability, neznalosti náročnosti terénu, pohybu iných účastníkov a prítomnosti mechanizácie na svahu vytvára prostredie s potenciálne vysokým rizikom úrazu. Napriek technologickému pokroku v ochrannom vybavení lyžiarov ostáva výskyt závažných poranení alarmujúco vysoký, pričom z hľadiska závažnosti dominujú úrazy hlavy a chrbtice. Štúdie zároveň potvrdzujú, že vysoký podiel úrazov je asociovaný s užívaním alkoholu, liekov a psychoaktívnych látok; skutočný rozsah je však pravdepodobne podhodnotený, keďže laboratórne testovanie sa realizuje prevažne len pri závažných úrazoch. Časté je aj súbežné užívanie psychoaktívnych látok, tiež ich reziduálne účinky z predchádzajúceho dňa, čo môže prostredníctvom kombinovaných mechanizmov účinku ďalej zvyšovať riziko úrazov. Predložená práca analyzuje dve kazuistiky fatálnych úrazov maloletých osôb (8 a 9 rokov) pri rekreačnom lyžovaní. Hoci mechanizmy úrazov boli odlišné, oba prípady zdieľajú spoločný menovateľ - nedodržanie zásad bezpečného pohybu na zjazdovkách. Kazuistika 1 opisuje cervikokraniálne poranenie u dieťaťa po kolízii s iným lyžiarom, spôsobené obojstranným nerešpektovaním pravidiel bezpečného správania na svahu. Kazuistika 2 opisuje izolované tupé poranenie brucha dieťaťa po kolízii s iným lyžiarom spôsobené stratou kontroly nad jazdou. Práca zdôrazňuje význam kontinuálnej edukácie, individuálnej zodpovednosti každého účastníka zjazdovky, výber vhodného bezpečnostného vybavenia a nutnosť dodržiavania pravidiel bezpečného správania. Multidisciplinárna analýza týchto tragických udalostí podčiarkuje potrebu intenzívnej prevencie, medziodborovej spolupráce a osvetovej činnosti zameranej na minimalizáciu rizík nielen detského, ale aj dospelého lyžovania, pričom systémové začlenenie bezpečnostných pravidiel do výučby zimných športov môže predstavovať kľúčový pilier prevencie najťažších poranení.

Kľúčové slová: fatálne úrazy – deti – lyžovanie – traumatológia – prevencia – interdisciplinárna spolupráca

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Over the past two decades, participation in winter sports has increased significantly, with alpine skiing and snowboarding ranking among the most popular activities worldwide (1, 2). These sports have beneficial effects on psychosocial health, the cardiovascular system, and the musculoskeletal apparatus (3). Despite their benefits, winter sports are also associated with an increased risk of injury, estimated at 0,5–1,35 injuries per 1,000 skier or snowboarder days (4,5). Fatal injuries, however, are relatively rare in these activities, with an incidence of approximately 0,77 deaths per 1 million exposure days (6), and among children, this figure represents only a small fraction of that number.

The risk of injury in winter sports activities is determined by a combination of intrinsic factors, such as physiological and psychological variables (e.g., muscle strength, anxiety, or the influence of alcohol, medications, and psychoactive substances), and extrinsic factors, including snow conditions, weather, slope gradient, and technical equipment parameters (7). Helmet use represents a significant preventive factor, contributing to a substantial reduction in the incidence of severe head injuries among younger skiers (8). In Slovakia, helmet use is legally mandated for skiers under 15 years of age, according to § 8a, point 6 of Act No. 544/2002 Coll. In neighboring countries, similar regulations apply: in Austria, helmets are required from age 15, while in Poland, the requirement extends to 16 years.

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Italy, effective from November 1, 2025, will be among the few countries to mandate the use of CE-certified helmets (CE EN 1077 – European certification for alpine skiing and snowboarding helmets) across all age groups. However, there are countries such as the Czech Republic, Switzerland, and France, where helmet use is not legally required but is recommended. Individual ski resorts or insurance providers may impose it in cases of insurance coverage (9, 10). Studies demonstrate that parental behavior and cultural norms regarding helmet use play a key role in shaping safety habits among younger generations (11).

Despite the relative rarity of fatalities on ski slopes compared to activities such as mountaineering or mountain climbing, the associated hazards should not be underestimated, particularly in the context of the growing popularity of recreational alpine skiing (12,13).

The primary causes of fatal accidents are collisions with fixed objects or other skiers, with high speed and risky behavior (especially among males) further increasing the risk of severe injuries (14, 5).

The present article presents two case reports of fatal skiing injuries in children, highlighting the importance of a comprehensive multidisciplinary approach encompassing clinical, forensic, and preventive dimensions.

CASE REPORT 1

Circumstances

Season 2023/2024, snow depth 50 cm, temperature 1,6 °C, partly cloudy. An 8-year-old skier became a passive participant in a collision in the afternoon. after another skier proceeded at excessive speed over a steep break in the slope where the injured child was seated, making him not visible to the approaching skier. The seated skier was struck in the head area. At the time of impact, the patient was wearing a helmet with a rigid chin guard. Immediate bystander first aid was provided due to unconsciousness, and the mountain rescue service was called. The patient was airlifted to the Clinic of Anesthesiology and Intensive Care Medicine. From admission, he remained unconscious with a Glasgow Coma Scale score of 3, requiring mechanical ventilation and hemodynamic support, without spontaneous respiration and exhibiting cardiac rhythm disturbances. After stabilization, a CT scan was performed, following which the patient's condition rapidly deteriorated, ultimately resulting in death.

Autopsy findings

The autopsy revealed injuries to the skull and cervical spine, specifically an atlanto-occipital dislocation with ventral condylar avulsion, resulting in complete disruption of the ligamentous connection between the skull and cervical spine, as well as a circular fracture of the cranial base surrounding the foramen magnum. These fractures were accompanied by intracerebral and intraventricular hemorrhage and traumatic brain edema (brain weight: 1370 g). The immediate cause of death was brain death due to mechanical disruption of the skull–cervical spine connection with intracerebral hemorrhage, also referred to as "internal decapitation" (16).

CASE REPORT 2

Circumstances

Season 2023/2024**,** snow depth 60–80 cm, temperature 0,6 °C, sunny, calm conditions. A 9-year-old skier lost control while skiing in the morning and collided with a stationary skier resting at the edge of the slope. Considering the magnitude of the impact

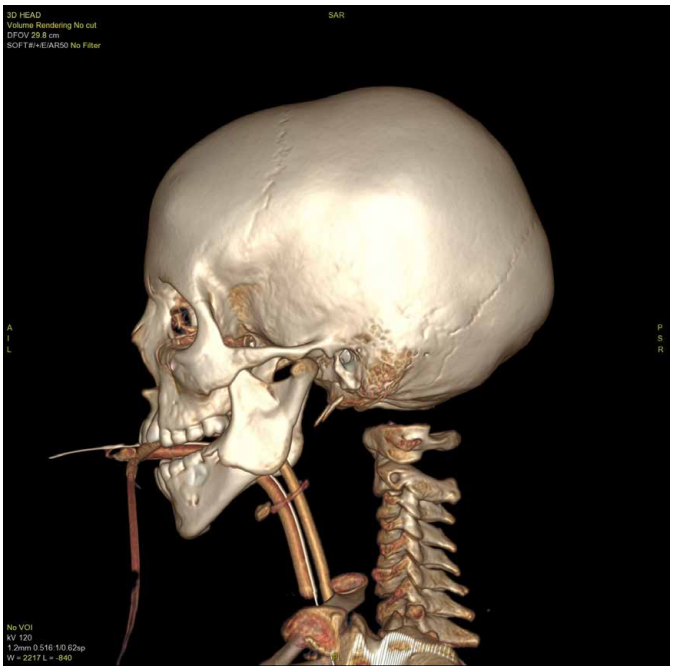

Fig. 1. Ventral atlanto-occipital dislocation (CT imaging – 3D volume-rendered reconstruction [VRT] in bone window, lateral view of skull and cervical spine).

the mountain rescue service was immediately contacted, with coordination for rapid transport to a hospital. Fifteen minutes after the incident, upon handover of the patient to the rapid response medical team, the patient experienced collapse and loss of consciousness. Upon arrival at the hospital, there were no vital signs present, and death was pronounced.

Autopsy findings

The autopsy revealed massive intra-abdominal hemorrhage, with approximately 1,300 ml of blood in the abdominal cavity, contusions of the spleen and kidney, laceration of the right hepatic lobe, and injury to an adjacent branch of the hepatic vein. The immediate cause of death was hemorrhagic shock due to blunt abdominal trauma. Quantification of flow through the injured hepatic vein branch indicated a bleeding rate of approximately 78 ml/min, which correlated with the time of collapse and the volume of blood loss observed at autopsy.

DISCUSSION

Winter sports such as skiing, snowboarding, and sledding (including toboggans, bobsleds, wintersleds and others) are popular recreational activities, yet they also represent a significant source of injuries, including fatal events. The combination of high speeds, altered stability, contact with hard surfaces, obstacles, other participants, and, albeit rarely, the presence of snow grooming vehicles such as snowcats or snowmobiles on the slopes, creates an environment with a high potential for severe injury (17). Technical errors in cable transport systems can also constitute a distinct cause of accidents. One of the most well-known tragedies of this type was the 2000 cable car fire in Kaprun, Austria, which resulted from the use of an incorrect heater and caused 155 fatalities (18). Slovakia has also experienced fatalities related to technical failures in cable transport: in 1992, a cabin collapse in Tatranské Matliary due to equipment malfunction led to the deaths of four high school

students (19). When comparing alpine skiing on prepared slopes to off-piste or freeride skiing, the latter is clearly associated with higher risk (20). Additional hazards in freeride skiing include more challenging terrain, insufficient training, inadequate equipment, and avalanche exposure, which can result in different mechanisms of injury and causes of death, including asphyxia and hypothermia, following blunt trauma (21). One of the most well-known off-piste skiing victims was the phenomenal Formula 1 driver Michael Schumacher, who suffered a severe head injury in the French Alps in 2013. Heli-skiing also carries an inherent risk of aviation-related accidents. Despite advances in protective equipment, injury rates remain high. Among skiers, knee ligament injuries account for approximately one-third of all injuries, along with spiral fractures of the lower leg and "skier's thumb" (ulnar collateral ligament rupture). Among snowboarders, wrist injuries are most common (21.6% of all injuries, of which 78% are fractures), followed by shoulder injuries. These differences reflect distinct mechanisms of falls and equipment attachment between skis and snowboards. The most severe health consequences involve cranio-cerebral and spinal injuries. Traumatic brain injury (TBI) is recognized as the leading cause of morbidity and mortality, accounting for up to 88% of all fatal ski slope injuries in several studies. Head injuries represent approximately 15–33% of all skiing and snowboarding injuries by incidence, but predominate in terms of severity. A typical mechanism of head injury is a backward fall (e.g., loss of balance or during jumps), resulting in occipital impact, which is most frequently associated with intracranial hemorrhage. Up to 22% of all head injuries lead to clinically manifest concussion, often necessitating neurosurgical intervention. The second critical injury type is spinal trauma, representing 1–17% of all injuries in these sports. Spinal injuries commonly affect the thoracolumbar junction and typically result from falls from height or poorly executed jumps. The typical mechanism involves axial loading in combination with flexion. Studies report that compression and burst fractures are most frequently diagnosed, although rotational and distraction-type injuries also occur. In younger age groups, overload-related damage to intervertebral discs and vertebral endplates (e.g., Schmorl's nodes) is also observed (22). Atlanto-occipital dislocation occurs approximately three times more frequently in children. This higher incidence is likely due to the more horizontal orientation of the articular surfaces, greater ligamentous flexibility, and relatively larger head size, which elevates the effective pivot point at the cervical spine – in other words, the child's head "sits" higher on the neck, increasing leverage on the skull and the first cervical vertebra connection and thus the risk of injury in this region (23). In the pediatric population, the incidence of life-threatening injuries is lower but not negligible. In a French study, the mean Injury Severity Score (ISS) among children admitted to intensive care units following winter sports injuries was 16, indicating a high degree of injury severity. Fifty-one percent of these children sustained head injuries, and up to thirty percent had intra-abdominal injuries. Thirty percent required surgical intervention within the first 24 hours of admission, and thirty percent required mechanical ventilation (24). Although helmet use is now widespread among skiers and snowboarders, its real-world effectiveness in preventing severe head injuries is somewhat limited. Helmets can mitigate impact in low- to moderate-energy collisions, but they often fail to prevent severe TBI in high-speed impacts or collisions (25). Promoting positive protective equipment habits among children can be facilitated by parental helmet use, which strongly influences children's behavior (26). Contrary to the belief that protective equipment encourages riskier behavior, several studies have not confirmed this assumption (27,28). Risk-prone behavior is more closely associated with personality traits such as sensation-seeking, identifying these individuals as a higher-risk group (29). Other protective equipment, such as wrist guards, significantly reduces the incidence of distal radius fractures, particularly among beginners; however, their protective capacity is limited in high-energy impacts or poorly executed falls (22).

Severe injuries in winter sports often do not occur solely as a result of equipment or technical failure, but rather due to inappropriate behavior-excessive speed, disregard for signage, failure to adapt to conditions, lack of awareness of other participants, and underestimation of one's own abilities. In addition to children, adolescents and young adults constitute a particularly high-risk group, characterized by lower risk perception and, especially in groups, a tendency toward competitive behavior.

Studies confirm that a high proportion of winter sports injuries is associated with the use of alcohol, medications, and psychoactive substances, with both novice and experienced participants engaging in such behavior (30-33). A study from the Dolomites reported positive blood alcohol levels in up to 43% of 200 skiers and snowboarders who sustained severe injuries (30). The true extent of these cases is likely underestimated, as most available data are derived from questionnaires (32) and voluntary breathalyzer tests (33), whereas laboratory confirmation of intoxication is typically conducted only in more severe injuries during the collection of biological samples in hospital settings (30,31). Concurrent use of alcohol, medications, and psychoactive substances is a common phenomenon, amplifying injury risk through various and combined mechanisms - ranging from sedative effects and hypotensive reactions to impaired cognitive and motor function (31,33). The most frequently identified psychoactive substance in winter sports was cannabis, detected in approximately 5% of victims of fatal high-altitude injuries in a ten-year retrospective study in the French Alps (34). An important consideration is the use of these substances on the previous day, which may lead to residual effects or a "hangover" during skiing or snowboarding, thereby increasing the risk of falls or collisions (31-33). Research also shows that resort visitors, particularly when fatigued or engaging in recreational substance use, often underestimate these risks and perceive them as less severe compared to their effects while operating a motor vehicle (33).

In this context, it appears essential that education on slope behavior must be integrated into systematic injury prevention. While most preventive measures focus on physical protection (helmets, spinal protectors, braces, and equipment), a standardized approach to teaching safe behavior may have an even greater impact. Participation in skiing or snowboarding schools reduces the risk of injury, but long-term prevention would also require dissemination of slope behavior codes (e.g., the rules of the International Ski Federation [FIS] (35)), emphasis on respecting personal limits and environmental conditions, practical training in crisis response (falls, collisions), and education on the risks of overestimating the protective capacity of equipment, as well as the use of alcohol, medications, and psychoactive substances.

CONCLUSION

Severe and fatal injuries in winter sports continue to pose a persistent challenge to the prevention of harm and preservation of human health, despite advances in protective equipment. While equipment may reduce the risk of less severe inju-

ries, its effectiveness remains limited in the case of fatal trauma, particularly to the brain and spine. Consequently, a key pillar of prevention must be properly conducted education focused on behavior, risk assessment, and adherence to slope safety rules. The systematic integration of these elements into recreational and sports training may represent the most effective strategy to reduce the incidence and consequences of the most severe injuries.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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