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Safety helmets for skiers and snowboarders – efficacy, safety and fitting principles. Review of literature

Kask narciarski – jego skuteczność, bezpieczeństwo stosowania i zasady doboru.

Przegląd piśmiennictwa

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Additional key words:

helmets
head trauma
skiing
snowboarding

Dodatkowe słowa kluczowe:

kask
urazy głowy
narciarstwo
snowboard

Head trauma is leading cause of mortality after injuries related with skiing and snowboarding. Wearing a helmet is considered to be a primary method to prevent traumatic brain injuries (TBI) among alpine sports participants. This article, based on literature review, determines the efficacy of helmets and safety of their use. It also presents practical principles of proper helmet fitting. A well proven reduction in the risk of TBI connected with helmet use is reported in the literature, ranging from 22 to 60%. Helmet use does not increase the risk of neck and C-spine injury. There is no good evidence to support the claim that use of helmets increases the risk compensation behaviors among participants. Proper fit includes adequate size, non-attenuated peripheral vision and hearing, well adjusted retention system (chinstrap). This factors may influence both efficacy and safety of helmet use. Helmets are recommended for all skiers and snowboarders.

Obrażenia głowy są najczęstszą przyczyną zgonu na skutek urazu odniesionego podczas jazdy na nartach lub snowboardzie. Noszenie kasków jest uznawane za podstawową metodę prewencji urazów czaszkowo mózgowych podczas uprawiania sportów zimowych. Na podstawie przeglądu piśmiennictwa przedstawiono dowody na temat skuteczności kasków, bezpieczeństwa ich stosowania oraz omówiono zasady doboru kasku. Według literatury używanie kasku zmniejsza ryzyko urazu głowy o 22-60%. Noszenie kasku nie zwiększa ryzyka urazu kręgosłupa szyjnego. Nie ma wystarczających dowodów, aby uznać, że noszenie kasku w istotny sposób zwiększa skłonność do zachowań ryzykownych podczas uprawiania sportu. Właściwy rozmiar, nieograniczenie pola widzenia i słyszalności oraz właściwa regulacja paska zabezpieczającego mogą wpływać na skuteczność i bezpieczeństwo stosowania kasku. Zaleca się używanie kasków wszystkim osobom uprawiającym narciarstwo i snowboarding.

Introduction

Traumatic Brain Injuries (TBI) are leading cause of death among all injuries connected with alpine skiing and snowboarding [1-3]. Safety helmets are considered to be a basic method of prevention against head trauma related with alpine sports [2,4,5]. Percentage of helmet wearers increases systematically [6-9], nevertheless some controversies on helmets efficacy are still actual. Moreover, the issue of helmets impact on the risk of neck and cervical spine injury, especially in children is discussed. It is also unclear if wearing a helmet increases risk compensation behaviors among alpine sport participants.

Alpine sports injuries - epidemiology

Estimated overall rate of injury related with alpine sports is 2-3/ 1000 participants/ 1 day of activity [1,2]. This risk decreased from 5-8/ 1000 participants/day since 1970s. This change is connected with modern sport

equipment (especially ski bindings) [1,2]. According to National Ski Areas Association (NSAA), 40.5 people in United States dies every year while skiing and snowboarding, therefore fatality rate is about 1.06/ 1 million days of activity/ participant [6]. Surprisingly, while overall injury rate decreased significantly, the risk of TBI didn't change in the same way. According to some researches [1,2,10-12] the incidence of head injuries among skiers and snowboarders remains unchanged, or even increased. Authors claim that this is an effect of increasing popularity of alpine sports, especially snowboarding [2,11].

While some authors suggest that risk of injury is similar among skiers and snowboarders [13], other researches show that rate of injuries and deaths is significantly higher in snowboarders [2,5,11].

Alpine sports related trauma mostly affect extremities. In skiers, lower extremity injuries are more common (78% of all injuries in this group) [13,14], especially involving

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cruciate ligaments (45% of all injuries in this group) [13]. Upper extremity injuries are more common among snowboarders (24% of all injuries vs. 7% in skiers) [13,15]. 16% of skiers and 8% of snowboarders suffer from multiple injuries [13]. Abdominal trauma (particularly splenic) are far more common in snowboarders. Spine injuries account for 1-15% of injuries in all participants [10], with prevalence of snowboarders. Spinal cord injuries occur with a rate of 2-4% of all traumas [2].

According to the literature, TBI is a leading cause of death in both skiers and snowboarders [1-3]. TBI are responsible for 42.4-88% of all fatalities [3]. Levy et al. estimated that TBIs accounted for 28% of all injuries in skiers and 33.5% in snowboarders [10]. Although 69.4% were concussions, 14.3% of those patients had various types of more severe brain injuries [10]. Macnab and Cadman [16] reported the epidemiology of head trauma related with alpine sports. They used ski patrol reports, and found that injuries of the head and face constituted 22% and 17% of all injuries, respectively. In 22% of those patients, trauma was severe enough to cause loss of consciousness. Casualties with TBI account for 29% of all that required hospitalization after accident on slope [3]. Couple studies suggest that head injuries in snowboarders are usually more severe than in skiers [11,17-19], this regularity can be observed in children also [19]. Hagel et al. [18] reported that snowboarders are 50% more likely to sustain head and neck injury than skiers. Fukuda et al. [11] analyzed 1076 patients admitted to hospital due to head trauma related with alpine skiing (41.1% of patients) and snowboarding (58.9%). They reported that subdural hematoma (SDH) was more common in snowboarders, while skiers were more likely to have cranial fractures. A predominant cause of SDH in snowboarders was fall during jumping, while cranial fractures were connected rather with collisions. In described group one skier and four snowboarders died as a result of their head injuries [11].

Nakaguchi et al. examined the mechanisms that caused head trauma among snowboarders treated at the department of neurosurgery in two hospitals [20]. They reported that 68% of those injuries was caused by backward fall on moderate or gentle slope in so called "opposite edge phenomenon", leading to direct occipital impact. This phenomenon was further investigated by Scher et al. [21]. They emphasized the role of safety helmet in prevention of head trauma in this mechanism. Furthermore, with use of anthropometric test device they proved that helmet reduced modestly the neck loads in such fall scenario.

According to the literature, men are more likely than women to sustain TBIs related with alpine sports. Men are also more likely to suffer from serious head trauma [2,3,11]. The trauma risk is also higher for children, teens and adults younger than 53 years [2,3,5,7,16]. According to some reports, snowboarders in terrain parks, especially participating in jumping activities and other types of aerial maneuvers are more likely to sustain TBI [11,22,23], but not all authors

confirmed this relationship [15]. Langran and Selevraj in prospective study on epidemiology of alpine sports-related injuries [7] identified age ≤ 16 years, snowboarding, inexperience (particularly skiing or snowboarding for the very first time), and less than six days of experience on the slope in current season to be the most important risk factors of injury.

The cause of most serious head trauma among skiers, requiring admission to level I reference hospital is usually a collision with a steady object (commonly a tree). Risk of death in such accident was estimated for 7.2% in one study [5].

Helmet norms

Three norms, most commonly used for safety helmets assessment are described below.

Central European norm CEN 1077:2007 [25]. For testing purposes, the examined helmet is positioned on a headform of appropriate size. Linear acceleration of the head form is tested in crash tests. Protection from penetration is tested with a metal cone, on which helmeted headform falls from a specified height. Retention system ("chinstrap") testing is also included. Currently, CE 1077 norm classifies helmets in two classes: A and B. Both types are dedicated for alpine skiers, snowboarders and similar groups. Class A helmet covers greater area of the headform, including whole temporal region and ears. No parts of the coverage may be detachable. Smaller openings for ventilation and/or hearing are acceptable. Class A helmet has to resist fall on the metal cone from 750 mm height in penetration test.

Class B helmets may cover smaller area of the head (not including ears) or parts of the coverage may be detachable. In penetration test the helmet is dropped from 375 mm height. Differences between those two classes of helmets are summarized in the norm. "Class A helmets offer comparatively more protection. Class B helmets may offer greater ventilation and better hearing, but protect a smaller area of the head and give a lesser degree of protection against penetration." This information (among others) has to be supplied by the manufacturer with every helmet in the language of the country of sale.

North American Society for Testing and Materials (ASTM) F 2040 Norm [25]. Just as already mentioned European norm, also this one includes crash tests and retention system test. In crash tests, the helmet is dropped from greater altitude than in CE 1077, therefore impact energy is slightly higher (98 vs. 96 Joules). No separated penetration test is conducted. Helmets are tested in low (from -22 to -28°C), high (32-38°C) temperatures and wet conditions. The ASTM F 2040 norm is similar to the ASTM norm for cycling helmets.

Snell RS-98. This norm, created by Snell Memorial Foundation [26], is the most rigorous of three norms mentioned in this article. Tests include crash tests (four drops on three kinds of anvils), penetration test, dynamic retention system test. Moreover, the clearance for peripheral vision is checked. The chin bar test is also conducted

(applies for full face helmets only). Testing is performed in cold and wet conditions. Only a few manufacturers participate in Snell's certification program.

Shealy et al. [28] developed a study to determine how fast do the alpine sports participants travel on slopes. The average speed was 43.0 km/h, with a standard deviation of 11.2 km/h. It was significantly higher for skiers (44.5 km/h) than for snowboarders (38.9 km/h). Authors emphasized that all this speeds are well above those used for helmets testing (for example 22.6 km/h in ASTM protocol).

Russel et al. [29] noticed that rigorous research is required to determine which types of helmets provide best protection. At present, no such studies are available in the literature (PubMed database).

Helmet use among skiers and snowboarders

In 1951 Haider was the first one to mention the issue of protective helmets in his study about fatal skiing accidents in Austria [3,30]. Over last three decades, percentage of helmet wearers increases systematically in Europe, Northern America and Australia [6-9]. Ruedl et al. [31] reported that in 2010, 63% of skiers and snowboarders on Austrian slopes declared wearing a helmet. Helmet use was far more common among locals compared with foreigners (75% vs. 52%). The percentage of helmet-wearers was highest in participants younger than 20 years (78%), and lowest in older than 60 years (53%). Helmets were far more common in more experienced participants compared with beginners (67% vs. 47%).

According to Burtscher et al. [32] in regions of Austria, where helmet is compulsory since 2009 for children under 16 years old, the percentage of wearers increased from 76% to 92% in this group. NSAA reported [6] that percentage of helmet-wearers in US increased from 25% in 2002/2003 season to 73% in 2013/2014.

One of the factors that might increase the use of helmets among winter sports participants are fatal accidents of well-known people, who were often non-helmeted [3].

Participants that refuse to wear helmets claim that headgear may attenuate peripheral vision and hearing, increase reaction time for peripheral stimuli, increase the risk of cervical spine injury and increase risk compensation behaviors [2,7,8,33,34]. 11% of non-wearers give financial issue as a reason of nonuse [7].

The effect of helmets on the risk of head and neck injuries

There are many evidences that wearing a helmet decreases the risk of head injury [2-5,11-13,29,32,35].

Ackery et al. [2] reviewed 24 articles about head and spinal cord injuries among skiers and snowboarders. They reported that wearing a helmet reduces the risk of TBI by 22-60%. Authors stated that there are no evidence that helmets increase the incidence of neck injury, but this subject needs further research. On the basis of their review, authors recommend that all skiers and snowboarders should wear a protective

helmet. They also emphasize that proper size of helmet is essential, particularly in children.

Russel et al. conducted a meta-analysis on the effect of helmets on the risk of head and neck injuries [29]. 12 studies were finally included (10 case control, 1 case- control/case crossover, 1 cohort study). Authors reported that TBI occurred far less common among helmet wearers, when compared with non-wearers (OR 0.65, 95% CI 0.55-0.79). The result was similar for studies that used controls without an injury (OR 0.61, 95% CI 0.36- 0.92), those that used controls with injuries other than head and neck (OR 0.63, 95% CI 0.52- 0.80), and for studies that included children under the age of 13 years (OR 0.41, 95% CI 0.27-0.59). Wearing a helmet was not associated with an increased risk of neck injury (OR 0.89, 95% CI 0.72- 1.09).

Haider et al. reviewed literature on the efficacy of helmets in reduction of head injuries in skiers and snowboarders [3]. Based on evidences from the literature they created a level I recommendation, according to which all recreational skiers and snowboarders should wear safety helmets to reduce the incidence and severity of head injury during these sports. They also recommend (II level) taking interventions and policies to promote helmet use. Authors claim that helmets do not appear to increase the risk of neck and cervical spine injury (level II observation).

Cusimano and Kwok conducted a systematic review [4] on helmet efficacy and reported a reduction in the risk of head injury with helmet use ranging from 15% to 60%. According to one of included studies, helmet use was associated with statistically significant lower rate of head trauma with loss of consciousness. Five of included studies suggest that none or few of fatally head injured patients wore a helmet. Also Cusimano and Kwok concluded that there is no good evidence that helmet use increase risk of cervical spine injury.

Macnab et al. [12] studied the impact of helmets on the incidence of head/face and neck injuries in children under the age of 13 years, that were admitted to the medical center in a world class ski resort. Non-wearing a helmet was associated with increased risk of head/face/ neck injury when compared to helmeted participants (RR 2.24, 95% CI 1.23-4.12). The risk for non-wearers was slightly higher for snowboarders than skiers. Furthermore, authors reported that using a helmet in children younger than 13 years does not increase the incidence of cervical spine injury (RR 2.0, CI 95% 0.80-5.65, p=0.15 for non-wearers).

Helmet use and risk compensation behaviors

According to some theories [36], behaviors are modified due to changes in perceived injury risk. If the perceived risk has been reduced by any intervention (for example: helmet use) the individual may indulge in riskier behaviors. Using this theory, some helmet non-wearers claim that by giving "false sense of security" using a helmet may

increase injury risk [3,34]. Available literature provides contradictory information on this subject. Ruzic and Tudor [33] conducted a survey to determine the differences between helmet wearers and non-wearers in risk taking behaviors. They reported that for male participants under the age of 35 years, helmet use was one of the factors predisposing to risk-taking on the slope. This regularity was not observed in women. Hagel et al. [37] conducted a study to examine the effect of helmet use on non-head-neck injury severity and crash circumstances in skiers and snowboarders. They found no evidence that helmet use increases the risk of severe injury or high-energy crash circumstances. Authors concluded that helmet use is not associated with riskier activities among alpine sports participants. Also Haider [3] and Scott [38] found no evidence to support the claim that helmets increase risk of injury.

Effect of helmets on the reaction to peripheral stimuli

Majority of studies that aim to determine the influence of helmet use on reaction to stimuli is conducted in laboratory conditions. Therefore it is not sure how do they correlate with real on-slope conditions. Tudor et al. [39] conducted a study to determine whether a ski helmet reduces skiers' hearing, particularly sounds that can warn skiers of potentially dangerous situations. They performed audiometric testing, and reported that helmet use may attenuate hearing, particularly in frequencies between 2 and 8 KHz (this spectrum was identified as "danger sounds" on the slope). Authors concluded that helmet users might misinterpret the sounds of potentially dangerous situations. Ackery et al. [2] emphasized the importance of proper size of the helmet, especially in children, because poor fit means reduced protection, vision and hearing. Kwiatkowski et al. [40] conducted a study to determine the impact of ski helmet on the balance in children aged 9-11 years. Authors used a helmet that completely covered the ears (class A according to CE 1077:2007) in proper size. Participants were asked to walk between two lines on 10 meters distance in imposed time. They were looking at a point at the end of the route. Each child accomplished the test with and without a helmet. Every loss of balance or step beyond the line was counted as a "mistake". The number of mistakes with and without helmet was then compared. Helmet use did not increase significantly the number of mistakes.

Ruedl et al. [8] investigated whether ski helmet use affects reaction time to peripheral stimuli. They measured reaction time to peripheral stimuli during a tracking task during four conditions: ski cap, ski helmet, ski cap + goggles, helmet + goggles. No significant difference in reaction time between ski cap (477.3 ± 16.6) and helmet (478.5 ± 19.1 , $p=0.911$) was reported. However, reaction time was significantly longer for cap + goggles (514.1 ± 20.8 , $p=0.005$) and for helmet + goggles use (497.6 ± 17.3 , $p=0.017$) when compared to cap-only use. Authors concluded, that helmet does not increase reaction time to peripheral stimuli and claimed that this information should

be implemented in campaigns promoting helmet use.

Mandatory helmet use

Currently, helmet use in Poland is mandatory for all alpine skiers and snowboarders under the age of 16 years. (The Law on Mountain and Ski Resorts Safety and Rescue, Aug 18th 2011) [41]. Similar regulations were introduced for example in Italy and some regions of Austria [32].

Burtscher et al. [32] conducted a questionnaire survey in 2011 to assess compliance to compulsory helmet use among young skiers and snowboarders in Austria. They reported that 99% of participants aged 10-15 years (mandatory helmet use) declared helmet wearing. This rate was lower (91%) among skiers aged 16 years (for whom helmets are not mandatory). Authors concluded that compliance with helmet laws is very high, nevertheless further multifaceted interventions should be taken to increase helmet use among participants for whom wearing a helmet is not mandatory. Surprisingly, Ruedl et al. [42] studying the same subject reported that among participants older than 15 years, percentage of helmet wearers was lower in provinces with helmet mandatory compared with provinces without mandatory (63.1% vs. 68.1%, $p<0.001$).

How to fit and use helmet properly?

- Use only the helmets that were designed and certified for alpine sports.
- Proper size – the helmet should fit snugly, the position of the helmet has to be stable. There should be no red/pressure spots on the head after use [2]. It is unsafe to buy too large helmet for a child to allow "room to grow" [2, 39].
- The helmet should sit low on wearer's forehead. If wearer can't see the edge of the brim at the extreme upper range of his vision, the helmet is probably out of place, or is too small [27].
- Helmet should always give all the necessary peripheral vision [27], and should not attenuate hearing [39].
- Positional stability. Position the helmet on the head. Try to remove it without undoing the chinstrap. If the helmet comes off or shifts over the eyes, readjust and try again. If no adjustment seems to work, this helmet is not for this particular person, try another helmet [27].
- Acceptable design – may be very important especially among children and adolescents [39].
- Follow the manufacturer's instructions on size fitting, conservation and storage of the helmet.
- Snell Foundation recommends that a helmet impacted in an accident should be returned to the manufacturer for complete inspection. If it is not possible to return the helmet, it should always be destroyed and replaced. The helmet should be also replaced after five years or less if manufacturer so recommends [27].

Summary

- Head injury is the leading cause of mortality among skiers and snowboarders, both in adults and children.

• Wearing a protective helmet decreases the risk of head trauma and death among alpine sports participants.

• Helmet use does not increase the risk of neck and cervical spine injury.

• There is no good evidence to support the claim that wearing a helmet increases risk taking behaviors.

• All recreational skiers and snowboarders should wear safety helmets.

• Proper helmet fitting (particularly its size) may influence the level of protection and safety of use.

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