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Incidence of recreational snowboarding-related spinal injuries over an 11-year period at a ski resort in Niigata, Japan

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ABSTRACT

Background There is limited knowledge regarding the incidence of recreational snowboarding-related spinal injuries.

Objective This study investigated the incidence and characteristics of recent recreational snowboarding-related spinal injuries and discussed possible preventive measures to reduce the risk of spinal injuries.

Methods This descriptive epidemiological study was conducted to investigate the incidence and characteristics of snowboarding-related spinal injuries at the Myoko ski resort in Niigata Prefecture, Japan, between 2006 and 2017. The incidence of spinal injuries was calculated as the total number of spinal injuries divided by the number of snowboarding visitors, which was estimated based on the ticket sales and estimates regarding the ratio of the number of skiers to the number of snowboarders reported by seven skiing facilities.

Results In total, 124 (72.5%) males and 47 (27.5%) females suffered spinal injuries. The incidence of spinal injuries was 5.1 (95% CI 4.4 to 5.9) per 100 000 snowboarder visitors. Jumps at terrain parks were the most common factor in 113 (66.1%) spinal injuries, regardless of skill level (29/49 beginners, 78/112 intermediates, 6/10 experts). Overall, 11 (including 9 Frankel A) of 14 (78.6%) cases with residual neurologic deficits were involved with jumps.

Conclusions In recreational snowboarding, jumping is one of the main causes for serious spinal injuries, regardless of skill level. The incidence of spinal injuries has not decreased over time. Individual efforts and educational interventions thus far have proven insufficient to reduce the incidence of spinal injury. Ski resorts and the ski industry should focus on designing fail-safe jump features to minimise the risk of serious spinal injury.

Key points

What are the new findings?

- This study provided a current update of the incidence of recreational snowboarding-related spinal injuries over the last decade based on data from 11 winter seasons in Japan.
- Jumps at terrain parks are one of the greatest risk factors for serious spinal injuries regardless of skill level.
- The incidence of spinal injuries has not decreased compared with past reports.

How might these findings impact on clinical practice in the near future?

- Ski resorts and the ski industry should focus on designing fail-safe terrain park jump features to minimise the risk of serious spinal injury.

INTRODUCTION

The danger of spinal injuries has been highlighted as a risk associated with the spread of recreational snowboarding.[1–8] Increasing media coverage of snowboarding events and competitions, such as the World Cup, Olympics and Winter X games, may have affected the way in which recreational snowboarders perform, prompting them to attempt to emulate professionals.[9] The spinal region is one of the most common injured body parts for critical injury among snowboarders[1–8] and traumatic paraplegia may result in permanent disability.[10 11] It has been reported that spinal injuries to the thoracolumbar region are most likely to be associated with jumping.[1–5] Although many terrain park (TP) features have been designed for jumps and aerial manoeuvres, snowboarders are significantly more likely to sustain spine injuries in TPs than on regular slopes.[6–8]

In Japan, the frequency of snowboarding-related spinal injuries due to jumping has increased since the latter half of 1990.[2] Yamakawa *et al*[2] reported that the total numbers of patients with snowboard-related spinal injuries have exceeded the total numbers of patients with ski-related spinal injuries since the 1995–1996 season and the total numbers of snowboarder visitors have exceeded the total numbers of skier visitors since the 1997–1998 season. However, there are few reports on spinal injuries in Japan. It is unknown whether the incidence of spinal injuries has decreased in the last decade. Consequently, there is a need for research that elucidates the occurrence of spinal injuries in snowboarders, which may have been

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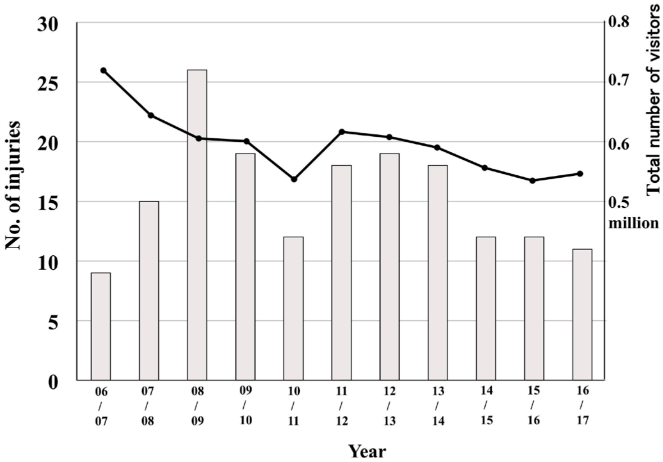

Figure 1 Total numbers of visitors (black circle and black line) and numbers of snowboarding-related spinal injuries (grey bar).

affected by recent changes in their behaviour or slope design.

The purpose of this study was to investigate the incidence and characteristics of snowboarding-related spinal injuries at the Myoko ski resort in Niigata Prefecture, Japan, between 2006 and 2017 and to discuss possible preventive measures to reduce the risk of spinal injury.

PATIENTS AND METHODS

The Myoko ski resort is a famous ski resort with seven ski facilities in Niigata Prefecture, Japan, and approximately 0.6 million visits per year. The closest primary emergency care hospital to the Myoko ski resort is Niigata Prefectural Myoko Hospital, and Niigata Prefectural Central Hospital is the only local referral centre for serious spinal injuries. Therefore, we supposed that the vast majority of patients with spinal injuries that occurred while snowboarding at the Myoko ski resort were treated in these two hospitals. This study included all patients with snowboarding-related spinal injuries who were treated in one of the two hospitals between December 2006 and April 2017.

The factors investigated in this study included sex, age, skill level, cause of accident, location of injury, pattern of spinal injury, and severity of neurologic injury. Self-reported skill levels were classified as beginner, intermediate or expert.

Causes of injuries were categorised in simple fall (on a regular ski slope, not in a TP), collision on slopes with objects or other snowboarders or skiers, jump in TPs or 'other'. At this resort, the arbitrary creation of jump features is prohibited on regular slopes and there are no half pipes at this ski resort. Jumping is therefore performed only in TPs. Most TP jump features were built by former professional snowboarders, skilled groomers and resort staff who were entrusted by the ski resort administrator. Injuries that occurred on non-aerial TP features, such as boxes and rails, were classified as 'other'. Cases of spinal injury in off-piste areas were excluded.

To determine the incidence of snowboarding-related spinal injuries, the total number of visitors to the Myoko ski resort was estimated based on the number of ticket sales announced by each of the seven skiing facilities that comprise the resort. Each facility also reported estimates regarding the ratio of the number of skiers compared with the number of snowboarders based on ski patrol observations. Estimation of the number of snowboarders was based on this ratio. The incidence of spinal injuries was calculated as the total number of spinal injuries divided by the number of snowboarding visitors.

The regions of spinal injury were divided into the cervical vertebrae (C1–C7), thoracic vertebrae (Th1–Th12), lumbar vertebrae (L1–L5) and sacral-coccyx. Furthermore, to clarify the characteristics of the location of injuries, the thoracolumbar junction level (Th10–L2) was divided and its characteristics were investigated.

Spinal injuries were classified into several types: compression fracture, burst fracture, facet subluxation, dislocation fracture, spinous process fracture, lumbar transverse process fracture and sacral-coccyx fracture. Patients with sprains or contusions of the spine were not included in this study. The location of injury, presence of spinal cord injury (SCI) and fracture pattern were investigated from medical records and images between December 2006 and April 2017.

In cases with multiple vertebral body fractures, we defined the location of vertebral fracture based on the largest vertebral body collapse observed with a lateral view using X-ray imaging. Neurologic severity was evaluated according to the Frankel grade[12] at the time of first visit and at discharge.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

Incidence

During 11 winter seasons, there were approximately 3 334 000 visits by snowboarders and 171 spinal injuries. Therefore, the incidence of spinal injury was 5.1 (95% CI 4.4 to 5.9) per 100 000 snowboarder visitors. The total numbers of visitors and snowboarding-related spinal injuries per year are shown in figure 1.

Sex, age, skill levels and causes of injuries

Over 11 winter seasons, 171 snowboarders suffered spinal injuries, including 124 (72.5%) males and 47 (27.5%) females. The average age of the snowboarders with spinal injuries was 27±7.1 (17–60). Overall, 49 (28.7%) snowboarders were beginners, 112 (65.5%) were intermediates and 10 (5.8%) were experts.

Jumps were the most common factor in 113 (66.1%) spinal injuries, followed by 44 (25.7%) falls, 10 (5.8%) collisions and 4 (2.4%) others (3 box falls, 1 rail fall). Spinal injuries that involved jumping occurred regardless

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Table 1 Characteristics of snowboarding-related spinal injuries between 2006 and 2017

Parameter	Snowboarders (n=171)
Male/female	124 (72.5%)/47 (27.5%)
Age (mean, range)	27±7.1 (17–60)
Skill level	
Beginner (Be)	49 (28.7%)
Intermediate (Int)	112 (65.5%)
Expert (Ex)	10 (5.8%)
Cause of accident	
Jump	113 (Be 29, Int 78, Ex 6) (66.1%)
Fall	44 (Be 15, Int 25, Ex 4) (25.7%)
Collision	10 (Be 4, Int 6) (5.8%)
Other	4 (Be 1, Int 3) (2.4%)

of skill level (29/49 beginners, 78/112 intermediates, 6/10 experts), as the χ^2 test revealed a non-significant association between skill level and the injury rate (table 1).

Locations of injuries

The locations of the spinal injuries were 11 cervical, 62 thoracic, 90 lumbar and 8 sacral-coccyx. The cervical injuries included one case of C2 hangman fracture, one C6 compression fracture, one C5 burst fracture, two cases of C4/5 facet subluxation, three cases of cervical spinous process fracture and three cases of cervical central cord injury. At the thoracic level, there were 46 compression fractures, 4 burst fractures and 12 dislocation fractures (1 case of T6/7, 2 cases of Th10/11, 4 cases of Th11/12 and 5 cases of Th12/L1). The lumbar injuries included 45 compression fractures, 17 burst fractures, 27 transverse process fractures, 1 case of L5 spinous process fracture and 8 coccyx fractures (table 2). There were 126 vertebral body injury cases (92 compression fractures, 22 burst fractures and 12 dislocation fractures). All dislocation fractures involved jumps in TPs.

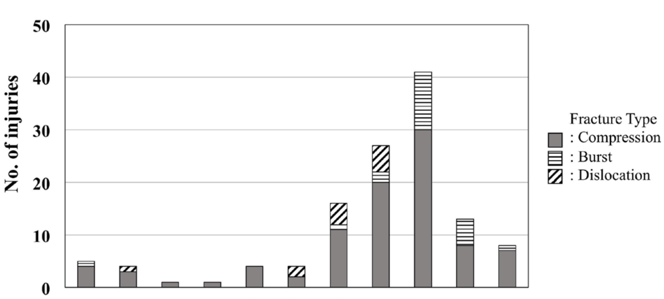

Figure 2 Characteristics of the location of vertebral spinal injuries from thoracic to lumbar region, focusing on the thoracolumbar junction (Th10–L2). in total, 101 (59.1%)of 171 spinal injuries occurred in this area.

Table 2 Details of snowboarding-related spinal injuries

Parameter	Snowboarders (n=171)
Location of Injuries	
Cervical (C1–C7)	11
Thoracic (T1–T12)	62
Lumbar (L1–L5)	90
Sacrum and coccyx	8
Fracture type	
Compression	92
Burst	22
Dislocation (anterior)	12
Hangman*	1
Cervical facet subluxation	2
Cervical central cord injury†	3
Spinous process	4
Transverse process	27
Coccyx	8

*Levine type II.
†Cervical cord injury without fracture or dislocation.

Focusing on the thoracolumbar junction (Th10–L2) area, there were 71 compression fractures, 19 burst fractures and 11 dislocation fractures. In total, 101 (59.1%) of 171 spinal injuries occurred within this narrow area (figure 2), and 76 (75.2%) cases involved jumps in TPs.

Severity of injuries

At the time of the first visit, 27 snowboarders had neurologic deficits associated with their spinal injuries. Among these patients with neurologic deficits, jumps were involved in 18 cases, falls in 7 cases, collision (with a tree) in 1 case and other (rail fall) in 1 case. The patterns of associated injuries included 1 case of C2 hangman fracture, 2 cases of C4/5 facet subluxation, 3 cases of cervical central cord injury (1 fall, 1 jump, 1 rail fall), 9 cases of burst fracture (1 case of C5, 5 cases of L1, 3 cases of L2) and 12 cases of fracture-dislocation.

At final follow-up, 12 males and 2 females with a mean age of 27±6.1 (20–42) had a neurologic deficit. There were nine cases with Frankel A (three beginners, three intermediates, three experts) and five cases with Frankel D (three beginners, two intermediates). Overall, 11 (9 Frankel A, 2 Frankel D) of 14 (78.6%) cases with residual neurologic deficit involved jumps in TPs.

DISCUSSION

Little is known about the incidence of snowboarding-related spinal injuries. According to Sacco *et al*,[13] between January 1990 and December 1995 in Vermont, USA the incidence of spinal injury was 1.3 per 100 000 visits for snowboarders and approximately 15% of ski resort users were snowboarders at the time of the study. Tarazi *et al*[1] reported that the incidence of spinal injury was 4.0 per 100 000 visits for snowboarders over two seasons

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(December 1994–April 1996 in Vancouver, Canada) and approximately 15% of ski resort users were snowboarders. On the other hand, Yamakawa *et al*[2] reported that the incidence of spinal injury was 5.7 per 100 000 visits for snowboarders over 12 seasons (December 1988–March 2000 in Gifu Prefecture, Japan) and more than 50% of ski resort users were snowboarders since the 1997–1998 season. In the present study, the incidence of snowboarding-related spinal injury was 5.1 (95% CI 4.4 to 5.9) per 100 000 snowboarder visitors over 11 seasons (December 2006–April 2017) and snowboarders accounted for approximately 40% to 60% of the Myoko ski resort visitors. Over the past three decades, the ratio of snowboarders has increased to around 50%, and the incidence of spinal injuries has increased up to approximately 5 per 100 000 visits. We suggest that the increased incidence of spinal injuries is partly related to the popularisation of TPs without appropriate safety measures.

Snowboarders like to perform tricks and aerial manoeuvres.[3–6 9] To attract more snowboarders, ski resorts construct TPs with man-made features, allowing more acrobatic jump manoeuvres. Since around 2000, various jump features have been introduced to the TPs at the Myoko ski resort in response to global snowboarding trends. These features include tabletops, step-downs, spines, hips and gaps and non-aerial items, such as boxes and rails. It has been reported that snowboarders in TPs are significantly more likely to sustain spine injuries in TPs than on regular slopes.[6–8] Although many aerial features in TPs have been designed for jumping and aerial manoeuvres, the rate of injuries associated with jumping is four times higher than in alpine skiing,[14] and it has been reported that 52% to 77% of snowboarding spinal injuries involved jumping.[1 2] In the present study, jumps in TPs were the most common factor in 113 (66.1%) spinal injuries, and 11 (78.6%) of 14 SCIs with residual neurologic deficit involved jumps in TPs. In total, 10 (59.1%) cases of spinal injury affected the thoracolumbar junction (Th10–L2). Our results are consistent with those of previous reports[1–8] and show that jumps in TPs remain one of the greatest risk factors for serious spinal injuries at the thoracolumbar junction, and that the incidence of spinal injuries has not decreased.

Conventional preventive measures with regard to recreational snowboard injuries can be divided into two types: those undertaken by individuals and those undertaken by ski resort administrators. Regarding individual preventive measures, Ishimaru *et al*[15] reported that hip pads reduce the overall risk of injury in recreational snowboarders, but hip pads are not considered being an effective protection against life-threatening injuries (including SCIs). There is also no evidence demonstrating the efficacy of body trunk protectors for protection against thoracolumbar spinal injuries.[16]

Some reports have emphasised the importance of educational intervention.[17 18] According to Cusimano *et al*,[18] educational intervention in the form of brochures and videos aimed at young skiers and snowboarders appeared to be effective in improving safety-related knowledge, attitudes and behaviours, although there was no significant difference in injury rates between the control and intervention groups. Few strategies for reducing the incidence of spinal injuries have been evaluated for efficacy.[5] The present study shows that serious spinal injuries occur in TPs regardless of skill level. In the case of recreational snowboarders, it seems impossible to reduce the incidence of spinal injuries through only individual efforts and risk perception.

It is also important to note the inherent risk in TP jump features. Snowboarders tend to fall backward from jumps.[3] This phenomenon may result from the concave curved takeoffs, a design feature that can induce backward rotation.[19] Falling backward is more likely to result in direct impact at the back of the trunk because of difficulty of cushioning backward falls using the upper limbs.[20] Thus, backward falls from jumps may lead to vertebral fractures of the flexion-distraction type (dislocation fracture with or without burst fracture).[21] The likelihood and severity of injury have been reported to be related directly to the impact on landing.[22 23] Historically, the design of skiing equipment such as skis, snowboards, bindings and helmets has been carried out by professional engineers at experienced companies. However, jump features in modern TPs are designed by skilled groomers and resort staff with little scientific basis.[22 24] Currently, most recreational TP jump features are built without the involvement of professional engineering design.[22–25]

'Fail-safe' and 'fool-proof' are important concepts for the prevention of accidents caused by human error. 'Fool-proof' refers to the ability to mitigate injury when users make errors. In this regard, all that can be done to prevent snowboarders from performing jumps is to remove all jump features from ski resorts. Goulet *et al*[26] reported that removing man-made jumps from TPs prevented severe injury. However, removal of all jump features is unacceptable for the resorts and resort users. 'Fail-safe' refers to the ability to maintain safety even when a failure mode occurs. For instance, a fail-safe jump would be one in which the snowboarder does not suffer from catastrophic injuries (including SCIs) even if he/she fails to jump. In this regard, McNeil *et al*[24] evaluated the safety of jump features quantitatively and created TP jump features using an engineering design approach to minimise the risk of serious spinal injury.

Hubbard *et al*[22] suggested that the probability of severe injuries on landing is correlated with jumper velocity perpendicular to the landing surface, and proposed that landing impact severity can be reduced by constructing landing slopes that are nearly parallel to the trajectory of the jumper. McNeil *et al*[23] also introduced the concept of shaping of the landing to minimise impact, using the equivalent fall height to parametrise impacts. McNeil *et al*[24] proposed that engineered jump designs limit the energy dissipated at impact by designing the shape of the landing surface

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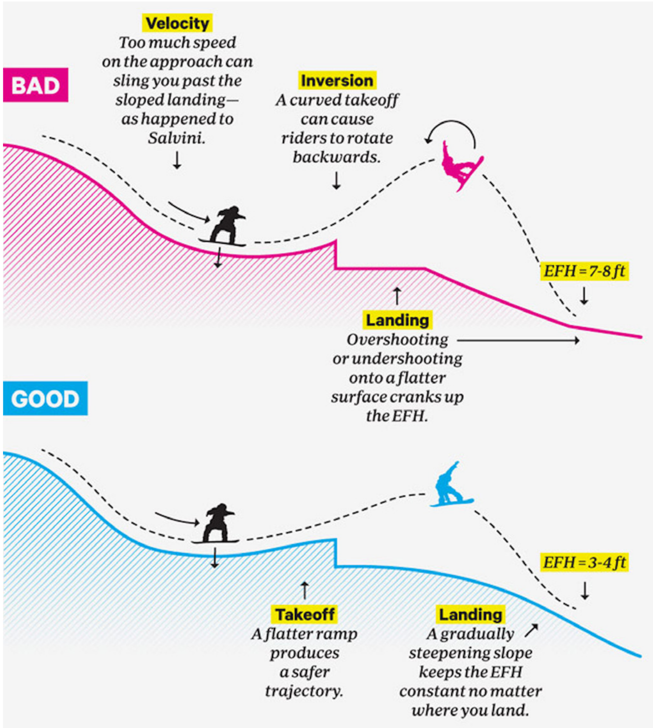

Figure 3 Examples of bad and good jump facility design (reprinted with permission of the publisher https://www.wired.com/2012/12/20-12-st-terrainpark/). EFH, equivalent fall height.

and reduce the inversion risk by limiting the curvature to the 'late' section near the end of the take-off ramp (figure 3). Based on this theoretical foundation,[22–24] Petrone *et al*[25] constructed TP jump features to test the feasibility of controlling landing impact. Audet *et al*[9] recommended that an engineering approach considering TP design and management might help prevent injuries and that future research should focus on how to design and maintain a safer environment. Further studies are needed to verify whether an engineering approach to TP jump feature's design can contribute to reducing the incidence of catastrophic spinal injury.

This study has several limitations. First, it was conducted at one ski resort in Japan. However, the features at the Myoko ski resort do not differ from those at other ski resorts (personal communication with the Myoko ski resort administrators). In addition, one of the ski grounds that comprise the Myoko ski resort has been making TPs under the guidance of an internationally renowned company since 2015. Therefore, we consider that our findings can be generalised to the latest trends in recreational snowboarding-related spinal injuries at ski resorts, where TPs are made without an engineering approach. Second, our study patients did not rate themselves as Sulheim *et al*[27] advocated that snowboarding skill was classified into four categories by the type of turns they routinely performed. Third, the incidence of spinal injuries we calculated in this study was crude incidence and was not adjusted for age, sex or other factors, unlike typical epidemiological studies. Fourth, the ratio of the number of skiers to the number of snowboarders were estimated based on ski patrol observations and may not have been strictly accurate. However, the Japan Association for Skiing Safety[28] reported that the mean ratio of the number of skiers to the number of snowboarders were 53% to 47%, respectively, during the period 2013–2017, which is close to our estimated ratio. Therefore, we regard our calculated total number of snowboarders as a reasonable denominator. Finally, we have missed patients with minor trauma who did not seek medical attention. However, it is unlikely that a patient with a spinal injury required medical care would not visit a medical institution, as almost all people in Japan are insured.

CONCLUSION

Snowboarding-related spinal injuries are a frequent occurrence at ski resorts. In this study, the incidence of snowboarding-related spinal injury was 5.1 (95% CI 4.4 to 5.9) per 100 000 snowboarder visitors over 11 seasons. Preventive measures should focus on reducing the likelihood and consequence of spinal injuries involving jumps in TPs. While individual effort and educational interventions may be valuable, ski resorts and the ski industry should also focus on constructing fail-safe TP jump features to minimise the risk of serious spinal injury.

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Competing interests None declared.

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REFERENCES

1 Tarazi F, Dvorak MF, Wing PC. Spinal injuries in skiers and snowboarders. *Am J Sports Med* 1999;27:177–80.
2 Yamakawa H, Murase S, Sakai H, *et al*. Spinal injuries in snowboarders: risk of jumping as an integral part of snowboarding. *J Trauma* 2001;50:1101–5.
3 Seino H, Kawaguchi S, Sekine M, *et al*. Traumatic paraplegia in snowboarders. *Spine* 2001;26:1294–7.
4 Wakahara K, Matsumoto K, Sumi H, *et al*. Traumatic spinal cord injuries from snowboarding. *Am J Sports Med* 2006;34:1670–4.
5 Kary JM. Acute spine injuries in skiers and snowboarders. *Curr Sports Med Rep* 2008;7:35–8.
6 Brooks MA, Evans MD, Rivara FP, *et al*. Evaluation of skiing and snowboarding injuries sustained in terrain parks versus traditional slopes. *Inj Prev* 2010;16:119–22.
7 Goulet C, Hagel B, Hamel D, *et al*. Risk factors associated with serious Ski patrol-reported injuries sustained by skiers and snowboarders in snow-parks and on other slopes. *Can J Public Health* 2007;98:402–6.
8 Russell K, Meeuwisse W, Nettel-Aguirre A, *et al*. Characteristics of injuries sustained by snowboarders in a terrain Park. *Clinical Journal of Sport Medicine* 2013;23:172–7.
9 Audet O, Hagel BE, Nettel-Aguirre A, *et al*. What are the risk factors for injuries and injury prevention strategies for skiers and snowboarders in terrain parks and half-pipes? A systematic review. *Br J Sports Med* 2019;53:19–24.
10 Levy AS, Smith RH. Neurologic injuries in skiers and snowboarders. *Semin Neurol* 2000;20:233–46.
11 Masuda T, Miyamoto K, Wakahara K, *et al*. Clinical outcomes of surgical treatments for traumatic spinal injuries due to Snowboarding. *Asian Spine J* 2015;9:90–8.
12 Frankel HL, Hancock DO, Hyslop G, *et al*. The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. I. *Paraplegia* 1969;7:179–92.
13 Sacco DE, Sartorelli DH, Vane DW. Evaluation of alpine skiing and snowboarding injury in a northeastern state. *J Trauma* 1998;44:654–9.
14 Sakamoto Y, Sakuraba K. Snowboarding and Ski boarding injuries in Niigata, Japan. *Am J Sports Med* 2008;36:943–8.
15 Ishimaru D, Ogawa H, Wakahara K, *et al*. Hip pads reduce the overall risk of injuries in recreational snowboarders. *Br J Sports Med* 2012;46:1055–8.
16 Torjussen J, Bahr R. Injuries among competitive snowboarders at the National elite level. *Am J Sports Med* 2005;33:370–7.
17 Macnab AJ, Cadman R. Demographics of alpine skiing and snowboarding injury: lessons for prevention programs. *Inj Prev* 1996;2:286–9.
18 Cusimano M, Luong WP, Faress A, *et al*. Evaluation of a Ski and snowboard injury prevention program. *Int J Inj Contr Saf Promot* 2013;20:13–18.
19 J. A. McNeil. The Inverting Effect of Curvature in Winter Terrain Park Jump Takeoffs. In: Johnson R, Shealy J, Greenwald R, *et al*, eds. *Skiing Trauma and Safety*. West Conshohocken: PA: ASTM International, 2012: 19. 136–50. https://www.astm.org/DIGITAL_LIBRARY/STP/PAGES/STP20120062.htm
20 Nakaguchi H, Fujimaki T, Ueki K, *et al*. Snowboard head injury: prospective study in Chino, Nagano, for two seasons from 1995 to 1997. *J Trauma* 1999;46:1066–9.
21 Hahler TR, Felmly WT, O'Brien M. Thoracic and lumbar fractures: Diagnosis and management. In: Bridwell KH, DeWald RL, eds. *The textbook of spinal surgery*. 2nd ed. Philadelphia: Lippincott-Raven, 1997: 1. 1763–837.
22 Hubbard M, Johnson RJ, Shealy J, *et al*. Safer Ski jump landing surface design limits normal impact velocity. *J. ASTM Int.* 2009;6:101630–9.
23 McNeil JA, McNeil JB. Dynamical analysis of winter terrain Park jumps. *Sports Eng* 2009;11:159–64.
24 McNeil JA, Hubbard M, Swedberg AD. Designing tomorrow's snow park jump. *Sports Eng* 2012;15:1–20.
25 Petrone N, Cognolato M, McNeil JA, *et al*. Designing, building, measuring, and testing a constant equivalent fall height terrain Park jump. *Sports Eng* 2017;20:283–92.
26 Goulet C, Tremblay B, Hamel D, *et al*. Removing man-made jumps from SNOW-PARKS reduces the risk of severe SKI-PATROL reported injuries sustained by skiers and snowboarders. *Inj Prev* 2012;18:A59.2–60.
27 Sulheim S, Ekeland A, Bahr R. Self-estimation of ability among skiers and snowboarders in alpine skiing resorts. *Knee Surg Sports Traumatol Arthrosc* 2007;15:665–70.
28 Japan Association for Skiing Safety (JASS). Skiing ground injury report 2016/2017 season (in Japanese), 2017. Available: http://www.nikokyo.or.jp/safety-snow/pdf/2016-2017.pdf [Accessed 10 Oct. 2019].

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