ISCoS The International Spinal Cord Society

ARTICLE

The trends in sports-related spinal cord injury in China

Jun Li[1,2,6], Jun Liu[1,2,6], Hong-Wei Liu[1,2], Song Wei[1], Yun-Xiao Jia[3] and Jian-Jun Li[1,2,4,5]✉

STUDY DESIGN: Retrospective epidemiological study.
OBJECTIVES: To determine the characteristics of sports-related spinal cord injury (SCI) in China and assess changes in the trend of these injuries that may impact policy making.
SETTING: China Rehabilitation Research Center (CRRC), Beijing.
METHODS: Of the 2448 SCI cases reviewed, 6.7% ($n = 164$) were caused by sport- and recreation-related accidents. They were admitted to the CRRC between January 1, 2013 and December 31, 2019. We collected data on age, sex, etiology, the neurological level of injury, the American Spinal Injury Association (ASIA) Impairment Scale (AIS) scores on admission, and the neurological recovery results at discharge.
RESULTS: Dancing (58.6%), followed by water sports (14.7%) and taekwondo (4.2%) were the leading etiologies. Of the SCIs caused by dancing, 27.1% of the individuals had incomplete injury, and of these, 57.7% showed improved neurological function. However, 72.9% had complete injury, and these individuals did not show any improvement in neurological function. Individuals with dance-related SCIs graded as A and D according to the AIS, showed no significant improvement in their motor function scores at the time of discharge. While the scores of those graded B and C increased significantly, there were no significant differences in the light touch and pin touch scores.
CONCLUSIONS: The etiology of sports-related SCI in China has changed dramatically, with dancing replacing water sports as the primary cause of SCIs. Individuals with dance-related SCIs have a poor prognosis. In China, prevention of dance-related SCIs has become a priority.

Spinal Cord (2023) 61:218–223; https://doi.org/10.1038/s41393-022-00872-0

INTRODUCTION

Spinal cord injury (SCI) is one of the most devastating conditions that can occur from sports activities [1]. There is currently no effective treatment for SCI [2], and it is thus associated with a substantial economic burden [3]. The proportion of sports-related spinal injuries among traumatic spinal injuries has increased [4]. In New Zealand, the proportion of sports-related SCI increased from 11.0% in 1993 [5] to 22.0% in 2020 [6], and in Canada, from 9.3% in 2004 [7] to 17.9% in 2012 [8]. Previous studies have reported that sports-related SCIs have accounted for 0.2% to 4.2% of traumatic SCIs in China [9]. In general, the incidence of sports-related SCI varies widely, with the highest incidence in Russia at 32.9% and the lowest in Nigeria at 1.7% [10]. The characteristics are distinct and strongly related to the geographical and cultural characteristics of the country. In Norway, the most common cause of SCI is skiing; [11] in New Zealand, it is rugby; [5] and in Ireland, it is equestrian sports [12]. Many countries have implemented preventive measures for sports-related SCI, but it has not attracted enough attention in China. However, with the continuous improvement in the living standards and increased health awareness among people in China, sports and recreational activities have become an important aspect of their lives. Therefore, this study aimed to investigate the characteristics of sports-related SCI in China and assess any changes in the trend of these injuries that may impact policy making.

METHODS

Study design and individuals

This was a hospital-based retrospective study of individuals with sports-related SCI admitted to the China Rehabilitation Center (CRRC) between January 1, 2013 and December 31, 2019. Only individuals with injuries of the vertebral column with spinal cord lesions resulting from sports-related accidents were included in the study. Individuals with spinal cord ischemia, spinal cord vascular malformations, acute myelitis, and other autoimmune lymphoproliferative disorders were excluded.

Two researchers from CRRC, Li and Jia, collected data on age, sex, etiology, treatment, neurological level of injury, and neurological deficits. Neurological deficits were classified according to the level and severity of injury, using the American Spinal Injury Association (ASIA) Impairment Scale (AIS) for SCI. The individuals were divided into six groups by age: 4–11, 12–29, 30–39, 40–49, 50–59, and ≥60 years [13]. The neurological level of injury was classified as cervical, thoracic, or lumbar/sacral.

Statistical analysis

The statistical package for the Social Sciences (SPSS) version 21.0 (IBM, Armonk, NY, USA) and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) were used to manage and analyze the data. The individual

[1]School of Rehabilitation Medicine, Capital Medical University, Beijing, People's Republic of China. [2]Department of Spinal and Neural Function Reconstruction, China Rehabilitation Research Center, Beijing, People's Republic of China. [3]College of Rehabilitation Medicine, Shandong University of Traditional Chinese Medicine, Jinan, Shandong, China. [4]Center of Neural Injury and Repair, Beijing Institute of Brain Disorders, Beijing, People's Republic of China. [5]China Rehabilitation Science Institute, Beijing, People's Republic of China. [6]These authors contributed equally: Jun Li, Jun Liu. ✉email: liujun17611547739@163.com

Received: 22 January 2022 Revised: 20 December 2022 Accepted: 22 December 2022
Published online: 30 December 2022

Table 1. Characteristics of sports-related spinal cord injury.

Variables	*n*	%
Age, years		
4–11	101	61.7
12–29	35	21.3
30–39	18	11.0
40–49	4	2.4
50–59	4	2.4
≥60	2	1.2
Sex		
Male	57	34.8
Female	107	65.2
Etiology		
Dancing	96	58.6
Water sports	24	14.7
Taekwondo, martial arts	7	4.2
Climbing	6	3.7
Equestrian sports	6	3.7
Acrobatics	5	3.0
Horizontal bar	5	3.0
Snow skiing	3	1.8
Air sports	3	1.8
Equestrian sports	2	1.2
Ball game	2	1.2
Motocross	2	1.2
Gymnastics	2	1.2
Parkour	1	0.7

n number, *SD* standard deviation.

characteristics were expressed as numbers or mean ± standard deviations. Frequency analysis was mainly used. For the difference in ASIA light touch and motor function scores between admitted and discharged individuals with SCI, we applied paired sample t-tests. A $P < 0.05$ was considered statistically significant.

RESULTS

Individual characteristics

Of the 2448 individuals evaluated [14], 164 (6.7%) had sports-related SCIs. The mean age was 15.23 (±13.83) years old. The median (25% and 75% percentiles) age were 6 and 22 years old. Most were female (male/female ratio: 0.47:1) and aged between 4 and 70 years. The individual characteristics are shown in Table 1. Dancing was the leading cause of sports-related SCIs, accounting for 58.6% of the injuries. This was followed by water sports (14.7%) and taekwondo (4.2%). The highest proportion of individuals with SCIs was in the 4–11-year-old age group at 61.7%, and when combined with the 12–29-year-old group, accounted for 83.0% of the total SCIs.

Dancing

Of the 96 individuals who had dance-related SCIs, 89 (92.7%) had thoracic SCI. All individuals were female, and 85.4% of them were aged between 4 and 7 years (Table 2). The mean age was 6.17(±1.45) years old. The median (25% and 75% percentiles) age were 5 and 7 years old. Among those whose SCI was caused by dancing, 42 individuals (43.8%) had injured segments in T9–11. Further, 90 (93.8%) and 6 (6.2%) individuals had SCIs due to performing "Bridge" and handstands during practice, respectively.

Table 2. Distribution of gender and age in individuals with dance-related spinal cord injury.

Variables	*n*	%
Sex		
Male	0	0
Female	96	100
Age, years		
4	10	10.4
5	24	25
6	26	27.1
7	22	22.9
8	8	8.3
9	3	3.1
10	2	2.1
11	1	1.0
Injury level		
T2-3	4	4.2
T4-5	11	11.5
T6-7	19	19.7
T8-9	15	15.6
T10-11	33	34.4
T12-L1	9	9.4
L2-3	5	5.2

n number.

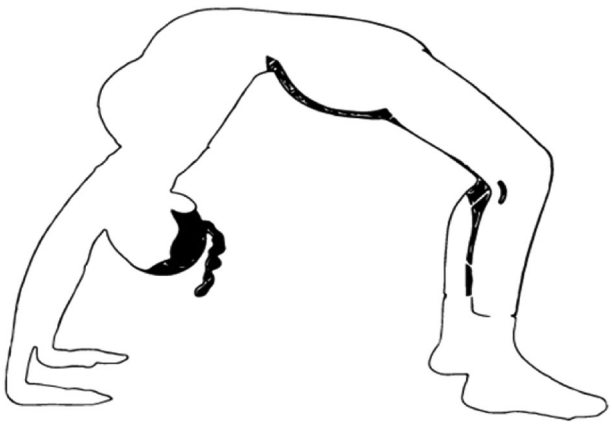

Fig. 1 Standard posture of "Bridge" in dancing. A common movement performed in children's dance."Bridge": Stand with your legs apart, keep your feet on the ground, and bend your upper body backward and downward until your hands touch the ground, and the body becomes an arch. It has the potential to cause hyperextension injuries of the thoracic spine and even the thoracolumbar junction.

The "Bridge" is a common movement in dance and is needed to improve body flexibility [14] (Fig. 1).

Of the 96 SCIs caused by dancing, 70 (72.9%) were graded as A (no improvement was observed); 11 (11.4%) as B; seven (7.3%) as C, and eight (8.4%) as D according to the AIS. Of the 11 individuals with a B graded injury, five (45.2%) recovered to a C grading, and four (36.5%) to a D grading at discharge. Of the seven individuals with a C graded injury, four (57.1%) recovered to a D grading. Of the eight individuals with a D graded injury, two (25%) recovered to an E grading.

Table 3. Differences in the motor function scores of individuals with dance-related spinal cord injuries on admission and discharge.

AIS score	Motor function score on admission (Mean ±SD)	Motor function score at discharge (Mean ±SD)	*t*	*P*-value
A	50.1 (±0.3)	50 (±0.24)	1	0.321
B	50.5 (±1.8)	73.5 (±16.4)	−4.684	0.001
C	54.3 (±6.3)	76.6 (±16.4)	−4.454	0.004
D	81.1 (±19.6)	85.4 (±19.1)	−2.472	0.43

SD standard deviation.

Table 4. Characteristics of different sports-related spinal cord injuries.

	Mean age (±SD)	Sex		Level of injury			No. of fracture	No. of surgery
		Male	female	Cervical	Thoracic	Lumbar/ sacral		
Dancing	6.17 (±1.45)	0	96	0	89	7	0	0
Water sports	30.0 (±13.27)	22	2	21	3	0	19	21
Taekwondo, martial arts	18.57 (±12.18)	6	1	4	3	0	4	4
Climbing	32.83 (±10.46)	3	3	1	4	1	6	6
Trampolining	20 (±4.69)	5	1	6	0	0	6	6
Horizontal bar	40.2 (±20.54)	5	0	5	0	0	5	5
Acrobatics	22.8 (±12.46)	5	0	5	0	0	5	5
Skiing	29 (±5.29)	2	1	0	1	2	3	3
Air sports	21.33 (±2.08)	2	1	1	1	1	3	3

SD standard deviation.

There was no significant difference in the light touch and pin touch scores at discharge of individuals with SCIs caused by dancing. Individuals with dance-related SCIs graded as A and D showed no significant improvements in their motor function scores when they were discharged from hospital, while the scores of those graded as B and C increased significantly (Table 3). Of the 96 individuals who had dance-related SCIs, none had fractures and no surgeries were performed (Table 4).

Water sports

In total, 24 SCIs were cause by water sport accidents. The median (25% and 75% percentiles) age were 22 and 33.5 years old. Of these, 13 (54.2%) were from hitting the bottom of the pool after diving; five (20.8%) from falling into the pool; two (8.3%) from being hit by waves on the beach; the other 4 patients were injured due to water skiing, jet ski accident, breaststroke training, and swimming with neck degeneration. Most of the individuals with water sports-related SCI were men, and 75% were younger than 32 years old. Further, most of the individuals had a cervical SCI, with 18 (75.0%) having injured segments in C4-6. Of the 24 individuals, only two (8.3%) individuals showed improvement in neurological function: one individual had a diving-related SCI and the AIS score was changed from grade B to C, and the other individual was knocked down by waves and the AIS score was changed from grade C to D.

Martial arts

Of the seven individuals with martial arts-related SCI, four individuals developed the injury from taekwondo, three by practicing the “Bridge” movement, and one by performing a somersault. A further three individuals developed SCIs from body slamming during wrestling, after their heads were pushed to the ground. The median (25% and 75% percentiles) age were 9.5 and 26 years old.

Climbing

Climbing-related SCIs were present in six of the individuals. The median (25% and 75% percentiles) age were 28 and 37 years old. Of these, five developed the injury after falling from a high altitude while mountain climbing, while the remaining individual was injured by falling stones while climbing.

Trampolining

Six individuals developed SCIs after falling head first while jumping during trampolining. The median (25% and 75% percentiles) age were 17 and 26 years old. All individuals had cervical SCIs, with the injured segment being C4-5.

Horizontal bar

Horizontal bar-related SCIs were present in five individuals and were due to head trauma from falling from the horizontal bar. The median (25% and 75% percentiles) age were 22 and 51 years old.

Acrobatics

Five individuals had acrobatics-related SCI, all of which were due to head trauma from hitting the ground during acrobatics and training. The median (25% and 75% percentiles) age were 17 and 19 years old. All individuals had cervical SCIs, with the injured segment being C4-5.

Skiing

Of the individuals with sports-related SCIs, three were injured by high-altitude and high-speed falls during skiing. The median (25% and 75% percentiles) age were 27 and 32 years old. At discharge, no improvement in neurological function was noted.

Air sports

Air sports-related SCIs were present in three individuals. The median (25% and 75% percentiles) age were 20.5 and 22.5 years

old. Of these, one was injured by a high-altitude crash while riding in a hot air balloon, one by skydiving, and 1 by paragliding.

Other sports

Two individuals developed SCIs following falling from a horse, with B and D graded injuries according to the AIS. Another two developed SCIs from motorcycle accidents, and both were A grade injuries. Of the two gymnastic-related SCIs, one was from performing "Bridge" (AIS grade A), and the other a somersault (AIS grade B). Two individuals developed SCIs from football (AIS grade C) and table tennis (AIS grade D). One individual had a parkour-related SCI, height not recorded in medical records, the downward movement of "flying dive roll" is performed (AIS grade A). Due to inexperience, the landing posture is wrong and the neck is injured.

DISCUSSION

In epidemiological studies of spinal cord injury in China, sports-related SCIs is rarely investigated. This study found that the characteristics of sports-related SCIs in China are very distinctive.

Ye et al. collected epidemiological data on sports-related SCI in Beijing from January 1, 1993 to December 31, 2006 [13]. Compared to the findings from the study by Yet et al., we found that the percentage of dance-related SCIs had rapidly increased from 5.3% in to 58.6% in this study. Meanwhile, the percentage of water sports-related SCIs decreased from approximately 64.9% to 14.7%. Consequently, dancing has replaced water sports as the main cause of sports-related SCIs, likely owing to the increased popularity of dancing in China in recent years.

We also found that there were obvious differences in the age distribution of SCIs. The percentage of individuals in the 4–11-year-old age group increased from 7.0% to 61.7%, while the corresponding percentage in the 12–29-year-old age group decreased from approximately 63.2% to 21.3% during the same period, and the mean age also significantly decreased from 24.49 (±11.9) years in the previous study to 15.23 (±13.83) years in this study. Further, the 4–29-year-old age group accounted for 70.2% of the individuals in the previous study, whereas they accounted for 83.0% in this study. The individuals with sports-related SCIs have become younger. The male to female ratio also decreased from 3.3:1 to 0.47:1, and most of the individuals are now female children. With respect to prognosis by injury grade, as graded according to the AIS, individuals with an A graded injury on admission did not show improvement at the time of discharge. Meanwhile, 81.8% and 57.1% of the individuals who upon admission, had a B and C graded injury, respectively, achieved neurological recovery. Among individuals with a D graded injury, only 25.0% regained near normal neurological function. There were no significant differences in the light touch scores of individuals with dance-related SCIs at discharge. Individuals with dance-related SCIs with AIS gradings of A and D had no significant improvement in their motor function scores at discharge in our study, so based on these results, we make some recommendations, for these AIS A and D patients, they can return home after proper and adequate treatment to continue rehabilitation in community hospitals, and rehabilitation centers can also conduct video Tele-rehabilitation guidance and patients can go back to school to continue their studies, which helps to allocate medical resources more rationally and reduce the financial burden on families, especially for families with poor economic conditions. Individuals with AIS gradings of B and C had significant score increases, neurological function is likely to improve after a proper extension of the hospital stay. However, these conclusions still need to be further explored in large-scale prospective studies.

The majority (93.8%) of the individuals with SCI in this study were caused by performing "Bridge" during dance practice. In 1977, Cheshire described a 6-year-old girl who was severely paralyzed below T11 after a backflip [15]. In 1990, Rivello et al. reported a 3-year-old girl who was paralyzed from "Bridge", MRI scans showed edema of the thoracic spinal cord [16]. In 2002, Yamaguchi et al. reported a 14-year-old girl who, after performing "Bridge" movements, suffered paralysis of both lower limbs, hypoesthesia below the L1 level, and bladder and bowel dysfunction [17]. The unique and inherent anatomical extensibility of the spine. The pathomechanism of the injury is unclear, with various hypotheses including hyperextension, flexion, stretch, and spinal cord ischemia [18–22]. The clear pathophysiological mechanism needs further basic research to explore. Among the individuals with dance-related SCIs, 92.7% had injuries in the thoracic segment. This leads to lower limb motor dysfunction and bowel and bladder dysfunction. When considering the individual's age, it will affect their entire life including studies, marriage, and childbirth. Consequently, government departments need to pay more attention to the management of dance training institutions, strengthen the standardized training of dance teachers, and strictly ban both dance schools that lack formal protocols and dance teachers without adequate qualifications. Compared to general diseases, dance-related SCIs are rare, and even doctors may lack knowledge on these injuries. The average parent is even more lacking in medical knowledge, and it is therefore easy to overlook the potential dangers of dance. Risk education should be provided for the parents of children participating in dance. It is important to adhere to the principle of scientific moderation, and to choose dance styles that suit the children's physical and mental characteristics. Full preparations for warming up should be made before practicing dance; the necessary precautions should be taken during the training of some dangerous movements; and "Bridge" or similar dangerous actions should only be allowed under the guidance of qualified dance teachers.

Of the individuals who developed water sports-related SCIs, 54.2% of the individuals developed the injury from diving. Violent neck injuries, caused by hitting their heads at bottom of the pool, often resulted in cervical fractures and cervical SCIs. Individuals with this SCI etiology had a poor neurological prognosis. This highlights the need for guests who visit to the pool should be educated about safety protocols, and for the public to be informed about the risk of water sports-related SCI, with emphasis on the possibility of a SCI even in shallow waters. Pools should include markers of water depth, particularly markers indicating that it is safe for diving [12]. There should also be personnel present to prevent dangerous behaviors. Another cause of water sports-related SCI was from accidentally falling into the pool. Thus, anti-slip flooring should be standardized. In this study, no water sports-related SCI was owing to alcohol consumption. However, alcohol consumption around swimming pools should be prohibited, as previous studies have shown it to be associated with water sports-related SCI [23, 24].

The type of sports- and recreation-related factors contributing to SCIs varied. Performing "Bridge" was also the main cause of taekwondo-related SCIs. Another cause was somersaulting. All cases of trampoline-related injury were severe and from landing head-first after jumping. Trampolines are dangerous, but they are often used for child entertainment. Parents and trampoline operators usually lack awareness of the dangers of trampolines. For horizontal bar-related SCIs, protective measures, such as the use of magnesium powder, should be reasonably implemented. Collectively, our results support the need for coaches, referees, and athletes to be educated on safety measures in relation to SCI, particularly on protection of the neck.

Skiing, which is highly dangerous owing to the high speed and altitude at which it is performed, is a relatively new sport in China. In other countries, SCIs caused by skiing mostly occur during jumping movements, and jumping failure may lead to serious spinal injuries [25]. Notably, previous studies showed that skilled skiers are more likely to develop SCIs than beginners [26]. Safety measures, including avoiding overcrowding, providing adequate protective

equipment, and hiring professional coaches, should be implemented. Additionally, a professional medical rescue team is crucial [27]. In China, the number of people skiing is projected to increase, mainly owing to the promotion of such activity ahead of the 2022 Beijing Winter Olympics. In this context, the proportion of ski-related traumatic SCIs is also expected to increase. Thus, related preventive measures should be developed and implemented.

Air sports-related SCIs often occur by high-energy, violent trauma that results in spinal cord and thoracic injuries. Previous research on paragliding and parachuting injuries showed that the best ways to prevent pelvic and SCIs in these sports, was by improving technical ability and using back protection devices [28].

For equestrian sports, previous studies have shown that the main cause of injury is falling off the horse's back, and that the level and location of the spinal injury depend on how the rider hits the ground. Thus, it is very important to have a thorough understanding of the horse and its behavior, and the rider should be taught safe-fall techniques [12]. Further, riders must always wear protective gear. However, although protective equipment reduces the risk of rib fractures and soft tissue injuries as well as serious head injuries, there is no evidence that it prevents spinal fractures or spinal cord injuries [29].

The incidence of sports-related SCI is projected to further increase considering the improvements in the lifestyle of people living in China, particularly in leisure. However, implementing evidence-based safety measures will profoundly help curb the projected increase in SCIs.

This study had some limitations. First, although the CRRC is the largest rehabilitation hospital in China, China is large, and thus data from the CRRC cannot be considered to include all individuals with sports-related SCI in China. Second, individuals' motor function scores were calculated using their medical records. There may have been certain errors. Third, the study sample was small. Fourth, the conclusions drawn on the prognosis of dance-related SCI were based on retrospective data. Fifth, compared with the highly subdivided rehabilitation institutions in the developed countries, China's pattern of acute and rehabilitation care in one institution is different. CRRC is rehabilitation specialist hospital and undertakes some functions of inpatient rehabilitation hospitals (IRFs), long-term acute care hospitals (LTACs), and skilled nursing facilities (SNFs), acute care was administered to the patients which accounts for the long stays in hospital. In future, rigorous, large-sample prospective studies should be used to further investigate these findings.

In conclusion, the etiology of sports-related SCI in China has markedly changed, with dancing now being the primary cause. Although most of the individuals with dance-related incomplete SCIs showed improvement in motor function, the overall prognosis of dance-related SCIs was poor because individuals with complete SCIs accounted for the majority and showed no improvement in motor function. These results highlight the need for policymakers in China to pay particular attention to dance-related SCI, particularly among young people. "Bridge" movements during dancing should be banned, and training institutions should be required to have only professional personnel.

DATA AVAILABILITY

The data sets generated during the current study are available from the corresponding author upon request.

REFERENCES

1. Macnab AJ, Smith T, Gagnon FA, Macnab M. Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. Inj Prev. 2002;8:324–7.
2. Wang HW, Liu XW, Zhao YW, Ou L, Zhou Y, Li CQ, et al. Incidence and pattern of traumatic spinal fractures and associated spinal cord injury resulting from motor vehicle collisions in China over 11 years: An observational study. Medicine. 2016;95:e5220.
3. Yang R, Guo L, Huang L, Wang P, Tang Y, Ye JC, et al. Epidemiological characteristics of traumatic spinal cord injury in Guangdong, China. Spine (Philos Pa 1976). 2017;42:E555–61.
4. Tator CH, Edmonds VE. Sports and recreation are a rising cause of spinal cord injury. Phys Sportsmed. 1986;14:156–67.
5. Dixon GS, Danesh JN, Caradoc-Davies TH. Epidemiology of spinal cord injury in New Zealand. Neuroepidemiology. 1993;12:88–95.
6. Mitchell J, Nunnerley J, Frampton C, Croot T, Patel A, Schouten R, et al. Epidemiology of traumatic spinal cord injury in New Zealand (2007-2016). N. Z Med J. 2020;133:47–57.
7. Pickett GE, Campos-Benitez M, Keller JL, Duggal N. Epidemiology of traumatic spinal cord injury in Canada. Spine (Philos Pa 1976). 2006;31:799–805.
8. Lenehan B, Street J, Kwon BK, Noonan V, Zhang HB, Fisher CG, et al. The epidemiology of traumatic spinal cord injury in British Columbia, Canada. Spine (Philos Pa 1976). 2012;37:321–9.
9. Yuan S, Shi Z, Cao F, Cao FJ, Li JH, Feng SQ, et al. Epidemiological features of spinal cord injury in China: A systematic review. Front Neurol. 2018;9:683.
10. Chan CW, Eng JJ, Tator CH, Krassioukov A. Epidemiology of sport-related spinal cord injuries: A systematic review. J Spinal Cord Med. 2016;39:255–64.
11. Hagen EM, Eide GE, Rekand T, Gilhus NE, Gronning M. A 50-year follow-up of the incidence of traumatic spinal cord injuries in Western Norway. Spinal Cord. 2010;48:313–8.
12. Boran S, Lenehan B, Street J, McCormack D, Poynton A. A 2011 A 10-year review of sports-related spinal injuries. Ir J Med Sci. 2011;180:859–63.
13. Ye C, Sun T, Li J, Zhang F. Pattern of sports- and recreation-related spinal cord injuries in Beijing. Spinal Cord. 2009;47:857–60.
14. Liu HW, Liu J, Shen MX, Yang XH, Du LJ, Yang ML, et al. The changing demographics of traumatic spinal cord injury in Beijing, China: a single-centre report of 2448 cases over 7 years. Spinal Cord. 2021;59:298–305.
15. Cheshire DJ. The paediatric syndrome of traumatic myelopathy without demonstrable vertebral injury. Paraplegia. 1977;15:74–85.
16. Riviello JJ, Marks HG, Faerber EN, Steg NL. Delayed cervical central cord syndrome after trivial trauma. Pediatr Emerg Care. 1990;6:113–7.
17. Yamaguchi S, Hida K, Akino M, Yano S, Saito H, Iwasaki Y. A case of pediatric thoracic SCIWORA following minor trauma. Childs Nerv Syst. 2002;18:241–3.
18. Tong A, Zhang J, Zhou H, Tang HH, Bai JZ, Wang FY, et al. Ischemic damage may play an important role in spinal cord injury during dancing. Spinal Cord. 2020;58:1310–6.
19. Pang D, Wilberger JJ. Spinal cord injury without radiographic abnormalities in children. J Neurosurg. 1982;57:114–29.
20. Moore BJ, Batterson AM, Luetmer MT, Reeves RK. Fibrocartilaginous embolic myelopathy: demographics, clinical presentation, and functional outcomes. Spinal Cord. 2018;56:1144–50.
21. Pang D. Spinal cord injury without radiographic abnormality in children, 2 decades later. Neurosurgery. 2004;55:1325–42. discussion 1342–1343
22. Kwon BK, Tetzlaff W, Grauer JN, Beiner J, Vaccaro AR. Pathophysiology and pharmacologic treatment of acute spinal cord injury. Spine J. 2004;4:451–64.
23. DeVivo MJ, Sekar P. Prevention of spinal cord injuries that occur in swimming pools. Spinal Cord. 1997;35:509–15.
24. Perrine MW, Mundt JC, Weiner RI. When alcohol and water don't mix: diving under the influence. J Stud Alcohol. 1994;55:517–24.
25. Wakahara K, Matsumoto K, Sumi H, Sumi Y, Shimizu K. Traumatic spinal cord injuries from snowboarding. Am J Sports Med. 2006;34:1670–4.
26. Katoh S, Shingu H, Ikata T, Iwatsubo E. Sports-related spinal cord injury in Japan (from the nationwide spinal cord injury registry between 1990 and 1992). Spinal Cord. 1996;34:416–21.
27. Banerjee R, Palumbo MA, Fadale PD. Catastrophic cervical spine injuries in the collision sport athlete, part 1: epidemiology, functional anatomy, and diagnosis. Am J Sports Med. 2004;32:1077–87.
28. Schulze W, Richter J, Schulze B, Esenwein SA, Büttner-Janz K. Injury prophylaxis in paragliding. Br J Sports Med. 2002;36:365–9.
29. Lin CY, Wright J, Bushnik T, Shem K. Traumatic spinal cord injuries in horseback riding: a 35-year review. Am J Sports Med. 2011;39:2441–6.

ACKNOWLEDGEMENTS

We would like to thank the China Rehabilitation Research Center for allowing us access to data. We would also like to thank Professor Liang-Jie Du for his assistance and advice.

AUTHOR CONTRIBUTIONS

J-JL: Planning the study and drafting of paper. J Li : Planning the study, interpretation of data, and drafting of paper. SW: Collecting data and drafting of paper. H-WL: Data analysis, interpretation of data, and drafting of paper. J Liu: Planning the

study, interpretation of data, and drafting of paper. Y-XJ: Collecting data and drafting of paper.

FUNDING

This work was supported by a grant from the National Key Research and Development Program (No. 2018YFF0301104), the Beijing Science and Technology Major Project (D161100002816004), the Capital Health Research and Development of Special Project (2018-1-6011), and the 2019 China Rehabilitation Research Center Scientific Research Project (2019zx-04).

COMPETING INTERESTS

The authors declare no competing interests.

ETHICS APPROVAL

This study was approved by the Ethics Committee of the China Rehabilitation Research Center (approval number CRRC-IEC-RF-SC-005-01). The requirement for individual informed consent was waived owing to the retrospective nature of the study.

ADDITIONAL INFORMATION

Correspondence and requests for materials should be addressed to Jian-Jun Li.