Review

Epidemiology of sport-related spinal cord injuries: A systematic review

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Context: Despite the recognition of sports as a significant contributor in the etiology of spinal cord injury (SCI), no studies have systematically explored the epidemiology of SCI caused by sports.

Objective: This paper aims to give a systematic overview of the epidemiology of sport-related spinal cord injury around the world.

Methods: A systematic review was conducted to identify published literature reporting the epidemiology of SCI caused by sports. The literature search was conducted in MEDLINE/PubMed, CINAHL, EMBASE, PsycINFO and Sportdiscus with date limits 1980 through to July 2015. Data from 54 studies covering 25 countries was extracted and collated.

Results: Important findings include identification of 6 countries in which sports accounts for over 13% of SCI (highest to lowest: Russia, Fiji, New Zealand, Iceland, France and Canada); individual sports with high risk for SCI (diving, skiing, rugby, and horseback riding); and the most common level of injury for various sports (almost entirely cervical for hockey, skiing, diving and American football, while over half of horseback riding and snowboarding injuries are thoracic or lumbosacral).

Conclusion: This paper identifies countries and sports with higher rates of sport-related SCIs where implementation of prevention programs and reporting systems to track SCI epidemiology may be helpful, and highlights gaps in our current knowledge for further investigation. The comparison of SCI occurrence for each sport across countries, as well as examination of the specific characteristics of SCI incurred for individual sports will assist in directing efforts for prevention.

Keywords: Sport, Spinal cord, Injury, Epidemiology

Introduction

Spinal cord injury (SCI) is a devastating injury with life-long impact on an individual's health and quality of life. Given this, preventative medicine has increasingly been acknowledged as a priority within the field of SCI. Understanding the causes of SCI is a crucial step towards developing appropriate and effective prevention efforts. From an epidemiologic study updated in 2011, the global incidence rate of traumatic spinal cord injury (TSCI) is estimated at 23 per million, or 179,312 new TSCI cases per year.[1] Though the etiology of traumatic SCI has been reported to be most commonly due to motor vehicle accidents and falls, sports injuries also play a substantial role in causing SCI.[1]

Spinal cord injury is an uncommon, yet far from unheard of, outcome of sport participation. However, sport participation has been shown to be an important factor in not only physical health, but also overall well-being.[2] In 2003, the World Health Organization reported that physical activity and sport supported improved diet and discouraged the use of tobacco, alcohol and drugs.[3] Sport participation was also found to increase sense of belonging as well as foster social interaction and emotional support through clubs and organizations.[4] Sport participation, at 28%, was found to be the most common social activity for Canadians who participated in at least one social group in 2003.[4] Given this, forgoing sport participation in order to mitigate risk of incurring an SCI seems unreasonable. However, spinal cord injury has not only a serious long-term impact on an individual's health, it also

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results in a high financial burden for the patient, their family, and society. A Canadian study showed that the lifetime economic burden per individual with traumatic SCI ranges from $1.5 million to $3.0 million, and that the total annual economic burden associated with 1,389 people surviving traumatic SCI and their initial hospitalization is estimated at $2.67 billion.[5] Beyond the primary trauma, secondary health complications significantly diminish quality of life for individuals with SCI as well as generate a considerable burden on the healthcare system.[6]

Given the substantial emotional and physical repercussions for the individual and the financial burden for society that comes with an SCI, a deeper understanding of the epidemiology is important. A greater understanding of the patterns and occurrence rates will help inform the development of interventions for prevention of sport-related SCIs.

We systematically reviewed the literature in order to: (1) establish the proportion of sport-related SCIs relative to all-cause traumatic SCIs in different countries; (2) compare the proportion of SCI caused by different sports; (3) compare the proportion of sport-related SCIs due to specific sports across countries; and (4) examine the characteristics of SCI (e.g. lesion level) across different sports. This will help with focusing prevention efforts and research on countries and sports with higher rates of SCIs. Comparing SCI occurrence for each sport across countries and examining the characteristics of SCI sustained may help with identification of specific problems and development of regulations, programs, and equipment to protect sport participants.

Methods

We searched for all published articles that were either epidemiological studies on SCI or studies focused on sport-related injuries including SCI. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for this systematic review.[7] To be included, the study must have reported at least one of the following outcome statistics on their cohort: the proportion of sport-related SCI relative to all-cause traumatic SCIs; the proportion of SCI for specific sports relative to all sport-related SCIs; or the neurological consequences that resulted from specific sports. Exclusion criteria included epidemiological articles with a study population not drawn from at least a region-wide centre (e.g. acute hospital, rehabilitation centre with SCI services). The literature search was conducted in MEDLINE/PubMed, CINAHL, EMBASE, HaPI, PsycINFO and Sportdiscus with date limits 1980 through to July 2015. The search was completed by combining terms related to sports, such as "hockey" or "diving" or "sport", and terms related to epidemiology such as "incidence" or "proportion", with those related to spinal cord injury, such as "paraplegia" or "quadriplegia" and so forth. The exact keywords used for the search can be found in the Appendix.

All publications were entered into a reference manager system (Refworks), where duplicates were removed. The reference list of included papers was then hand-searched to identify additional papers. Review at the title level was performed independently by two reviewers. The authors identified papers for inclusion with full agreement (i.e. no discrepancies needed to be resolved through discussion). For more information on the methods of the literature search, see the SCIRE Methods manual.[8]

Data were extracted independently by two reviewers. For each study, the first author, year of publication, sample size and relevant outcomes (described in the inclusion criteria above) were extracted. In addition, whenever there was more than one reported data value for each category, we averaged the data. For example, there are several papers reporting the proportion of sport-related SCI relative to all-cause SCIs in the United States; we averaged these to get the final value we report in this paper.

Results

A total of 1001 articles were identified and assessed for relevance based on the title and abstract. This yielded 63 articles for full-text review. After checking against inclusion and exclusion criteria, 29 papers were included. 34 papers were excluded for the following reasons: did not report any of the required values (N = 22); study population was not from a region-wide centre (N = 8); data only reported on spinal injuries, not specifically SCI (N = 3); or only included cervical SCIs (N = 1). An additional 25 papers were identified by hand-searching, for a total of 54 articles included (Fig. 1).

World-wide demographics of sport-related SCIs relative to non sport-related SCIs

A total of 54 studies across 25 countries provided information on the proportion of sport-related SCIs relative to all traumatic SCIs and the average for each country was calculated and graphed, with 95% confidence intervals expressed as error bars (Fig. 2). A number of countries do not have 95% confidence intervals as

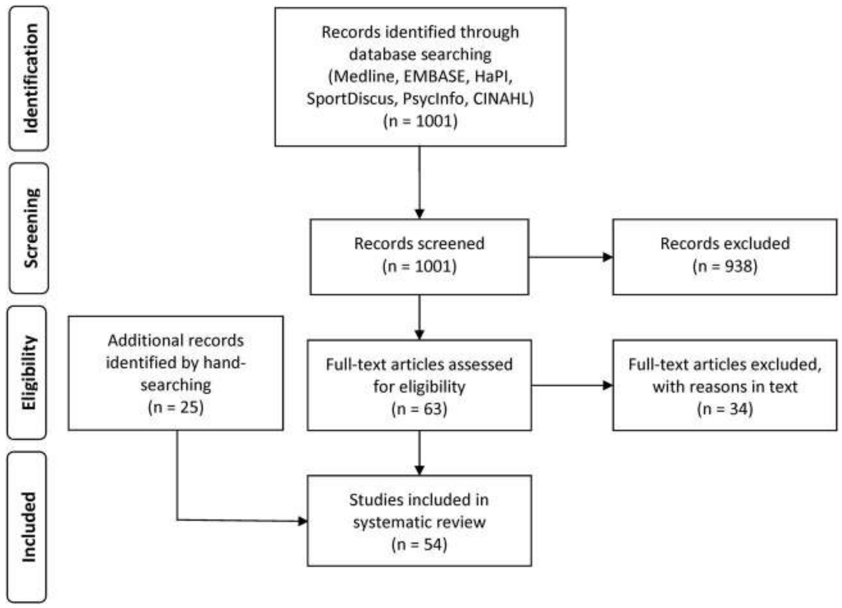

Figure 1 Flow diagram of study selection process (systematic review of the epidemiology of sport-related spinal cord injuries).

there was only one paper reporting data. The six countries with the highest proportion of SCI caused by sports were Russia (32.9% of all TSCIs were caused by sports),[9] Fiji (32.0%),[10] New Zealand (20.0%),[11] Iceland (18.8%),[12] France (15.8%),[13] and Canada (13.1%).[14–20] The six countries with the lowest proportion of SCIs caused by sports were Turkey (3.0% of all TSCIs were caused by sports),[21] Jordan (2.6%),[22] Nepal (2.0%),[23] Malaysia (2.0%),[24] China (1.8%),[25–27] and Nigeria (1.7%).[28]

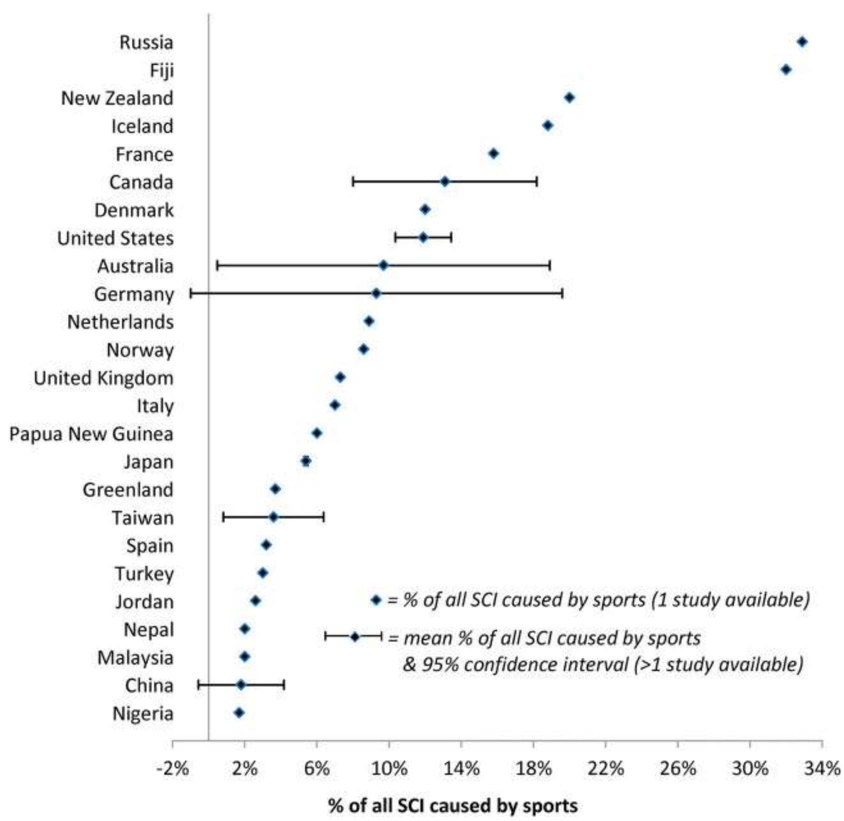

Figure 2 Worldwide demographics of sport-related spinal cord injuries relative to non sport-related injuries. The graph shows the percentage of sport-related SCIs relative to all TSCIs in 25 countries, based on 54 studies.

Sports causing the most SCIs worldwide

The proportion of SCI caused by each of 9 different sports relative to total sport-related SCIs was averaged over 9 countries, with the error bar representing the 95% confidence intervals (Fig. 3). The sport causing the greatest number of SCIs in the most countries was diving, ranging from 7.7% in Germany to 64.9% in China, with a mean of 35.3%.[11,14,15,17,29–40] Skiing also accounted for a large percentage of sport-related SCIs in some countries, ranging from 1.2% in Ireland to 48.3% in Norway, with a mean of 11.3%.[14,15,32–35,38–40] Rugby claimed the highest proportion of SCI caused by any one sport (74% in New Zealand) and had a mean of 23.4%, with its lowest contribution in Germany, where it accounted for only 0.7% of sports-related SCIs.[11,14,15,17,32,33,35,38–40] Spinal cord injuries due to horseback riding ranged from 1.3% of all sport-related SCIs in Japan to 41.8% in Ireland, for a mean of 11.4%.[14,15,17,29,31,34,35,37,40,41]

Sports causing the most SCIs by country:

Eighteen studies covering 9 countries reported the percentage of sport-related SCIs due to 10 specific sports (Fig. 4). The error bars on the figure are 95% confidence intervals. In 5 of the 9 countries (USA, Canada, Japan, China and Denmark), diving had the highest contribution to sport-related SCIs out of all the other sports included, ranging from 22.4% in Japan,[32–34] to 64.9% in China.[38] Skiing accounted for the highest proportion of sport-related SCI in Norway (48.3%)[39] and Germany (10.9%).[35] Horseback riding accounted for the largest portion of sport-related SCIs in Ireland (41.8%)[40] and rugby had the highest contribution in New Zealand (74.0%).[11]

Characteristics of SCI for individual sports

For 6 sports (horseback riding, ice hockey, skiing, snowboarding, diving, and American football), information was available on injury breakdown by neurological level (Fig. 5). Cervical injury is by far the most predominant level of injury for four sports when a SCI occurs: hockey (81.5% cervical),[42–43] skiing (81.1%),[34,44] diving (98.2%),[16,34,45] and American football (96.3%).[34,46] For horseback riding, cervical injuries account for the largest proportion (46%), but thoracic (25.8%) and lumbo-sacral (24.4%) injuries are also common.[41,47] Similarly, snowboarding carries a fair risk for thoracic (27.6%) and thoraco-lumbar (28.9%) injury.[44,48,49]

Several of the studies described specific neurological levels most commonly affected in diving and rugby. In diving, C4 was identified to be the most common level of injury[13,50] and C4–C6 injuries were most common in rugby.[51–53]

Characteristics of SCI for all sports-related SCI

For sport-related SCI as a whole, data collected from the USA's National Spinal Cord Injury Statistical Center (NSCISC) over 1973–2013 reports that the most frequent neurological outcome at discharge for individuals with a sport-related SCI is incomplete tetraplegia (46.9%), followed by complete tetraplegia (37.4%), incomplete paraplegia (5.9%) and complete paraplegia (5.7%).[54] Fewer than 1% of persons experienced

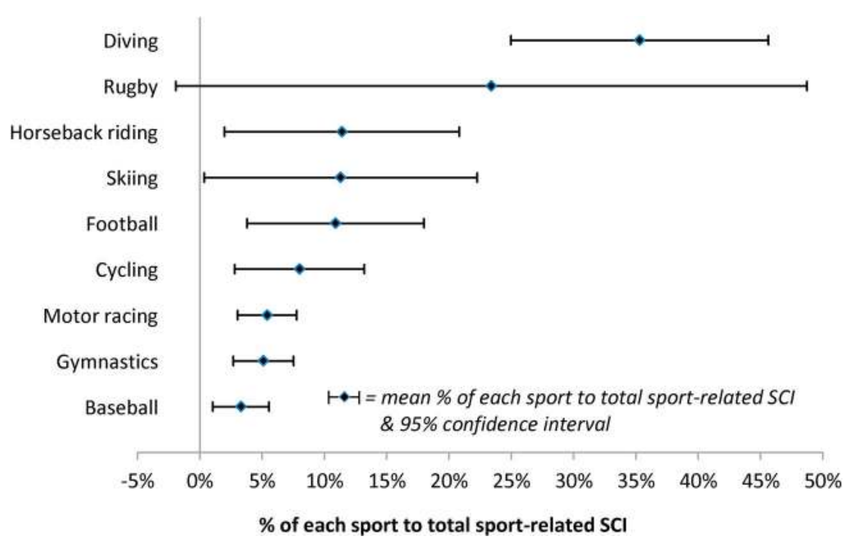

Figure 3 The percentage of SCI due to 9 individual sports relative to all sport-related spinal cord injuries is presented, with data drawn from 9 countries. Data were reported for diving (15 studies), rugby (5), horseback riding (8), skiing (8), football (5), cycling (8), motor racing (7), gymnastics (8), and baseball (4).

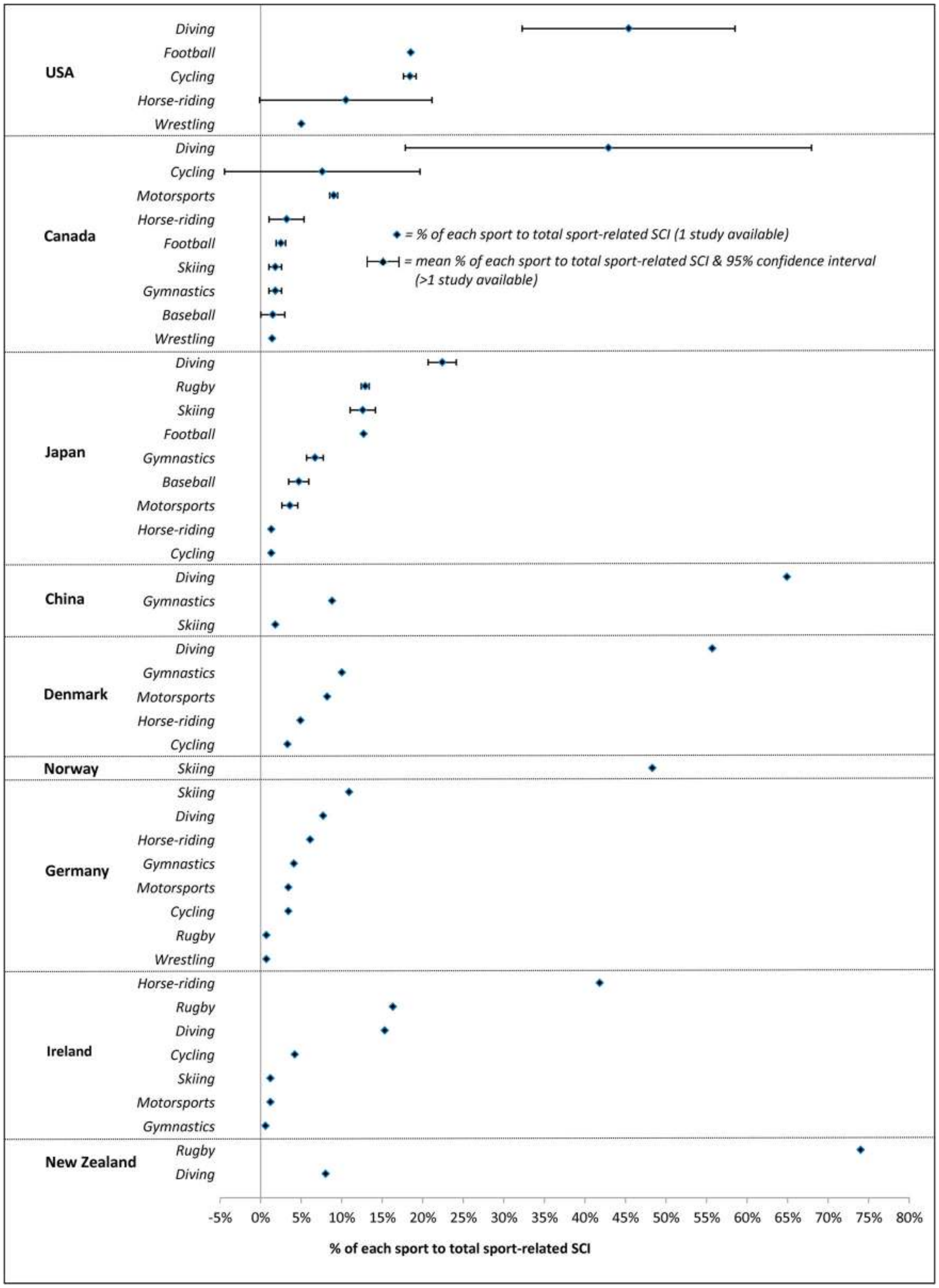

Figure 4 Breakdown of contributions of 10 individual sports to total sport-related SCI in 9 countries. Data were reported from 18 studies.

complete neurologic recovery by hospital discharge.[5] The NSCISC 2011 report also found that over the last 15 years, injuries are increasingly incomplete. The percentage of persons with incomplete tetraplegia has increased while incidence of complete paraplegia and complete tetraplegia has decreased slightly.[55]

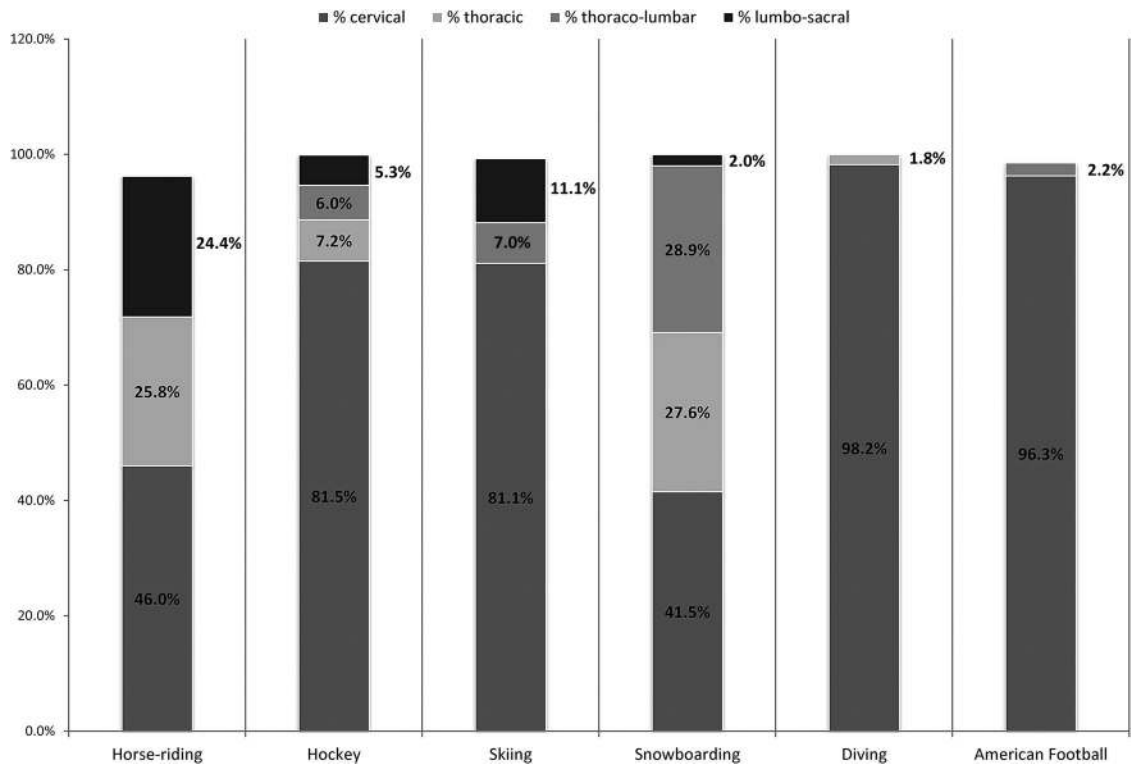

Figure 5 Level of spinal cord injury caused by 6 individual sports. Data were averaged for the following sports: horse-riding (2 studies), hockey (2), skiing (2), snowboarding (3), diving (3), and American football (2).

Discussion

Despite the fact that people all over the world participate in sports, only 25 countries have any published epidemiological data regarding sport-related SCIs. There were multiple studies for some countries; for example, 15 studies for the USA (7.1–19.0%)[30,31,37,54,56–66]; 3 studies for Italy[67–69]; 3 studies for Taiwan[70–72]; 2 studies for Germany[35,73]; and 2 studies for Japan[32,33]; but there was only one available study for a number of countries such as Denmark[29]; Great Britain[74]; Greenland[75]; the Netherlands[76]; Spain[21]; Norway[39]; and Papua New Guinea.[77] Clearly, there is a gap in reporting of data for the large majority of countries, indicating a dire need for implementation of reporting systems to accurately track the epidemiology and etiology of SCIs.[78] Collecting accurate statistics on the sport-related occurrence of SCI is crucial for each country to identify areas where prevention efforts would be most efficacious. Additionally, the collection of data concerning SCI occurrence from individual sports is inadequate. Though the availability of organized sports and their popularity vary from country to country, the collection of data for SCI occurrence for each organized sport—if not all sports—is important for prevention planning. For example, although there is a national rugby union team in each of the 9 countries for which we compared individual sport-related SCI occurrences (Japan, Canada, Germany, Ireland, USA, Denmark, China, New Zealand and Norway), only Japan, Germany, Ireland and New Zealand had published rugby-related SCI data. Similarly, although all 9 countries have national teams for American football, only Japan, Canada and USA have reported data. Only for diving are values reported for every country.

The six countries with the highest reported percentages of sport-related SCI (Russia,[9] Fiji,[10] New Zealand,[11] Iceland,[12] France,[13] and Canada,[14–20]) had more than 13% of all-cause TSCIs attributed to sports. There may be a number of contributing factors, one being that sports with an inherently higher risk of SCI (ice hockey, skiing, snowboarding and rugby) are very popular in these six countries while they may not be played as much in other countries.[79] On another hand, this increased SCI incidence may suggest an area for improvement in terms of regulations, equipment, or attitudes towards safety. First, a closer examination of the specific sports that account for the majority of these countries' sport-related SCIs may provide some focus for interventions.

It is clear that some sports have a higher risk for SCI than others. Determining the cause of the increased risk is important in designing effective interventions. Rugby, for example, consistently had some of the highest reported rates of injury throughout this review. It is well known that the scrum (short for scrummage), a play that restarts the game after stoppage, accounts for the majority of SCIs in rugby.[80–84] The scrum involves eight players (collectively referred to as 'forwards') from each opposing team organizing themselves in a set formation to physically collide with each other, locking head and shoulders and pushing in a competition for possession of the ball.[85] The front-row players were found to be at greatest risk of hyperflexion trauma causing cervical spine injury as players behind them push, increasing the force of impact.[80] The literature showed that the most common level of injury from rugby play was C4-C5[86] and C5-C6.[51–53] By elucidating the specific play causing the majority of injuries and the mechanism of injury, new rules were implemented that required a four-stage "crouch, touch, pause, engage" sequence designed to decrease collision force at engagement. These changes were found to significantly decrease SCI occurrence in both New Zealand and South Africa, with a reported 48% reduction in scrum-caused SCI in South Africa.[84,87]

A large number of studies reported high rates of diving-related SCI over many different countries,[36,39,54] with the US reporting that SCI due to diving accounted for up to 64% of sport-related SCI.[30] Cultural differences may play a role in the difference in occurrence rates. For example, Shingu *et al.*[32] reports that 3.4% of all SCIs in Japan were sport-related under the influence of alcohol, while 30% of sport-related SCIs were under the influence of alcohol in the US. Another factor to consider is the location of these injuries. Diving may take place in many different settings, from supervised community centre pools to private backyard pools, as well as unregulated bodies of water (lakes, swimming holes, etc.).[88] The many unsupervised and remote swimming locations in the US, as well as private swimming locations may encourage risky behaviours and distance from the hospital may prevent the care critically needed in the first hours after injury.[45] A possible intervention for the US would be an educational program discouraging risky behaviours such as alcohol intake before swimming/diving and teaching about diving safety in outdoor locations.[45,88–89] An additional suggestion would be park boards ensuring spaces are safe to swim, providing lifeguards, marking swimming depths, and clearly marking spaces that are unsafe to swim or dive.[88–91]

For 6 sports (horseback riding, ice hockey, skiing, snowboarding, diving, and American football), data was available on injury breakdown by neurological level (Fig. 5). Scrutinizing the data may suggest areas for design improvement in equipment for engineers and designers, as well as possible regulation changes. For four sports, there is a notably higher chance of injury at the cervical level: hockey (81.5% of SCIs are cervical), skiing (81.1%), diving (98.2%) and American football (96.3%). Clearly, any intervention to reduce SCI risk in these sports should be designed with this information in mind. This has successfully been demonstrated in hockey through improvements in the padding materials of helmets.[92] Additionally, the International Ice Hockey Federation has now prohibited charging and checking from behind, a dangerous play that can cause players to careen into side boards head-first since they often do not see the hit coming and cannot raise their arms protectively. This rule change has significantly decreased the number of severe spinal injuries as well as the percentage of spinal injuries due to checking from behind from 36.6% in 1982–1984 to 25% in 2000–2005.[43,93,94] Strides towards additional improvement should be made, given that ice hockey is a popular sport in a number of countries and accounts for a substantial number of SCIs.

Another example is illustrated through American football. Torg *et al.*[95] discovered through the national football head and neck injury registry that most SCIs were sustained at the cervical level and found that a majority of these could be attributed to a "spearing" or head-first motion made during tackles. A rule change prohibiting the use of head-first blocking and tackling techniques was subsequently imposed in 1975 and was found to significantly decrease the occurrence of quadriplegia in the sport.[95–98] Torg[96] reported a decrease from 90 occurrences in 1976–1981 (16 per year) to 15 in 1991–1993 (5 per year).

One point of consideration is that reporting systems vary in accuracy, and definitions for statistics collected in different countries may be different which may bias the results. For example, Nepal reports that of all SCIs in the country, only 2.0% are related to sports. Shrestha *et al.*[23] reports that falls from heights account for a majority of SCIs (60%) in Nepal, but does not mention whether rock-climbing is included in sports (2%) or in falls from heights. Rock-climbing is an extremely popular sport in Nepal where the world-famous Himalaya mountains are located.[99] One might reasonably expect that the sport-related SCI percentage would be much higher if rock-climbing was indeed included in the sports category.

There is a need for improved record-keeping of SCI, as well as publication of the findings, in many parts of the world.[23,24,28,53,83] This survey strongly advocates for uniformity in methodology. The data show that the reported incidence and prevalence have not changed substantially over the past 30 years. Data from North

America and Europe show higher figures for incidence, but figures for prevalence have remained the same. Epidemiology of SCI seems to have changed during the last decades with a higher percentage of tetraplegia and of incomplete lesions. If such evolution is present worldwide, how this affects development of prevention policies needs further study.[100]

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Appendix

Epidemiology search

(Spinal cord injuries or paraplegia or tetraplegia or quadriplegia OR spinal cord lesion)

AND

(baseball OR bicycling OR cycling OR gliding OR gymnastics OR hockey OR diving OR swimming OR football OR rugby OR snowboarding OR snow-boarding OR skiing OR horse riding OR horseback OR surfing OR surfboard OR motocross OR sport OR sports)

AND

(epidemiology OR incidence OR prevalence OR etiology OR cause OR mode of injury)