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Head impacts in youth national hockey leagues in Slovakia: a retrospective analysis of four seasons

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Abstract. Traumatic brain injury in contact sports can lead to serious health consequences either immediately or later in the life of injured subjects. The objective of this study was to estimate the incidence of head impacts in the Under 18 (U18) and Under 20 (U20) junior ice-hockey leagues in Slovakia over the seasons 2013/2014–2016/2017 using data from official game statistics. Incidence risks (IR) *per* 1000 athlete exposures were calculated for the season and stratified by a period of the game, by month, round, and part of the season. IR of head impacts ranged from 2.09 (95%CI: 2.07–2.12) to 2.89 (95%CI: 2.87–2.92) in the U18 league and from 2.14 (95%CI: 2.12–2.17) to 4.06 (95%CI: 4.02–4.09) in the U20. Higher IR was observed in the latter periods of games. This study brings first data on the incidence of concussions in youth ice-hockey leagues in Slovakia and calls for immediate implementation of measures to prevent these injuries.

Key words: Traumatic brain injury — Head impact — Neuropathology — Epidemiology

Introduction

Traumatic brain injuries (TBI) are a major public health and societal challenge on a global scale. Every year, an estimated 57,000 people die and 1.5 million are admitted to a hospital due to a TBI in the European Union (Majdan et al. 2016), with each TBI-related death associated with about 25 years of lost life (Majdan et al. 2017). Based on a cohort of over 4500 patients from 58 European centres enrolled in the CENTER-TBI study, most TBI cases are mild (68%), with proportions of over 95% of mild TBI (mTBI) in those only admitted to Emergency department or to normal hospital wards (e.g. not treated at Intensive care unit) (Steyerberg et al. 2019). The major problem with head impact associated injuries is that they can cause illnesses, which are not recognized early enough, therefore are not reported and patient can live for a long period of time with chronic subclinical disease. Diagnostics of TBI and thereafter prediction of consequences in context of neurodegenerative and neuropsychiatric disorders are still under development. The estimation of TBI severity and degree of brain damage relies recently on several different tests. The method of choice is Glasgow Coma Scale, which although developed more than 40 years ago, still represents the most recommended non-invasive test (Teasdale et al. 2014; Jain and Iverson 2021). Neuroimaging

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is highly informative and efficient approaches for estimation of TBI consequences, however, at the level of microstructural and cellular changes, are not yet sensitive enough to make a definitive *in vivo* diagnosis; the strengths and limitations of neuroimaging were reviewed recently (Mayer and Quinn 2021). Development of biochemical markers, either proteins or nucleic acid, specifically those identified in peripheral tissues (Guedes et al. 2020; Sandmo et al. 2020), can not only serve as a diagnostics, but they can point to the molecular mechanisms associated with pathological processes induced by TBI and help to predict the treatment strategy.

Recent studies show that mTBI and specifically repeated mTBI can have long-term consequences and increase the risk of neurodegenerative diseases later in life (Ling et al. 2015; Pan et al. 2016). In addition, evidence suggests that even a single mild TBI may lead to the dementia (Graham and Sharp 2019). Thus, TBI should be considered a major risk factor for various forms of neuropathy, including severe chronic neurodegenerative disorders such as Parkinson's disease and Alzheimer's disease, which were linked to the history of TBI (Phillips and Woessner 2015; Kulbe and Geddes 2016; Washington et al. 2016; Mackay et al. 2019). The link from TBI to neurodegeneration is represented by the presence of molecular markers such as beta amyloid, tau protein, α-synuclein and TDP-43, which can be released from injured neurons. As published a time ago and recently reviewed (Blennow et al. 2012; Delic et al. 2020) the formation of amyloid plaques, neurofibrillary tangles and TDP-43 neuropathologies goes hand in hand with the appearance of post-TBI syndromes. It is well known that these high molecular aggregates are difficult to dissolve, they are prone to propagate throughout the brain and exert the toxicity to different brain structures (Walker 2018). Disruption of blood brain barrier and persistent neuroinflammation are further events which are initiated by TBI and can significantly accelerate processes of subclinical neurodegeneration. Once the neuropathological symptoms become obvious it is too late to start with the treatment. Moreover the neurodegenerative and neuropsychiatric disorders are not yet pharmacologically treatable. Although some forms of the symptomatic treatment are available (Duraes et al. 2018; Cummings 2021), no efficient disease-modifying therapy exists. Such a situation persists in spite of the fact that there are currently about 121 agents focused to treatment of neuropsychiatric diseases in different phases of clinical trials, and 80% of them are focused on disease modification (Gijbels et al. 1994). Still holds true, that prevention is the only and readily available tool in the fight against TBI-induced neurodegeneration.

Specifically, it has been well documented that sport-associated TBI can lead to chronic traumatic encephalopathy (CTE), which was recognised officially as a new clinical unit in American football players and professional wrestlers (Omalu et al. 2005). Ten years later, The National Institute of Neurological Disorders and Stroke determined the neuropathological definition of CTE (McKee et al. 2016). CTE was later diagnosed post-mortem in players of American football, basketball, rugby, in professional soldiers, as well as in brains of ice hockey players (McKee et al. 2014). At the molecular level CTE is defined as tauopathy and is characterized by intracellular tau protein inclusions similar as observed in Alzheimer‘s disease. However. the occurrence of head impact in different part of the head can most probably lead to various forms of neuropathy which can include different forms of dementia.

Sports-related injuries are a frequent cause of TBI in general (Maas et al. 2017). A review of 11 population-based studies revealed that 1.2–30% of all TBI are sport-related (Theadom et al. 2020). The highest incidence rates of concussions were in rugby, ice-hockey and American football – the pooled rate for ice-hockey was estimated at 1.2 *per* 1000 athlete exposures (AE) (Pfister et al. 2016). Another systematic review estimated that in European hockey leagues, between 2–7% of all sustained injuries lead to a concussion (Ruhe et al. 2014). In general, however, research into incidence of TBI in ice-hockey in Europe is lagging behind whereas most existing data comes from North American studies (Ruhe et al. 2014; Pfister et al. 2016; Theadom et al. 2020).

This lack of information is alarming, especially in countries of Central Eastern Europe, where ice hockey has been traditionally a widely popular sport, such as Slovakia or the Czech Republic. Slovakia, a nation of about 5.5 million has 10,910 officially registered ice hockey players with 8819 (81%) of them being under 20 years and 631 being females. There are 110 ice hockey clubs, 71 indoor and 28 outdoor rinks (Slovakia 2020). These numbers do not reflect players in amateur leagues, and thus the number of active players is presumably even higher. Yet, there is no existing study that produced estimates of TBI incidence in any of the Slovak hockey leagues that could be compared to data published for other leagues or used as input information for prevention strategies.

One of the key issues in comparing TBI incidence in ice hockey across studies is the difference in case definitions and in the used indicators (Ruhe et al. 2014; Pfister et al. 2016; Maas et al. 2017). Optimally, all cases reported as concussions or TBI are confirmed by a medical exam. While this approach ensures medical confirmation of an injury to the brain, it may also cause selection bias due to non-unified procedures applied or due to potential exclusion of falsely negative cases. Our approach in this study relies on game statistics, where head impacts are being recorded as defined by the Ice hockey rules of game published by the International Ice Hockey Federation (IIHF 2018). This ensures, that all head impacts potentially involving a TBI are recorded using a unified definition.

The aim of this study was to estimate the incidence of head impacts and their patterns in the Under 18 (U18) and Under 20 (U20) youth ice-hockey leagues in Slovakia over four seasons using data from official game statistics. Our data can be used as arguments for implementation of measures to strengthen the prevention of head injuries in youth ice-hockey players and to intensify a call for further research into the early diagnostics and treatment of traumatic brain injuries after the sport-related head impacts.

Methods

The presented study is a cross-sectional analysis of head impacts in the U18 and U20 ice hockey leagues in Slovakia. The U18 league includes players ages 16 to 18 years old, while the U20 includes players 19 or 20 years old. A total of four seasons were followed up in their entirety (e.g. all games were included): 2013/2014, 2014/2015, 2015/2016 and 2016/2017. Both, the U18 and the U20 leagues are leagues officially managed by the SIHF. The basic characteristics of the hockey leagues were analyzed are presented in Table 1.

The data used in this study were retrospectively extracted from official game reports which are archived by the SIHF. These reports include all game statistics including the number of fouls and specifically the number of head impacts. The number of such impacts and their time of occurrence (e.g. the date of the game, the period of the game and the minute of game) were extracted by three of the authors (IT, PB and SP) in parallel, and after extraction the numbers were crosschecked in order to prevent errors. These data were then entered into a database and further analysed.

An event was defined as head impact occurring during the game and judged as such by the main referee, in accordance with the Ice hockey rules of play. These impacts are presented as counts and as incidence risks *per* 1000 AE. The incidence risks (IR) were calculated as

$$IR = \frac{\Sigma\, Attacks}{\Sigma\, AE} \times 1000$$

Table 1. Characteristics of the analyzed youth hockey leagues

Season	U18 league		U20 league	
	Teams	Players	Teams	Players
2013/2014	15	375	12	300
2014/2015	15	375	12	300
2015/2016	16	400	18	450
2016/2017	16	400	13	325

U18, hockey players from 16 to 18 years old; U20, hockey players 19 or 20 years old.

and are presented along with a 95% confidence interval (CI). To calculate AE, a unified value of 20 players involved was used for all games.

In order to compare the rates by various aspects, incidence risk ratios (IRR) were calculated along with 95%CI. These ratios quantify the difference between IR, e.g. an IRR of 2 means that the respective group has twice the risk compared to the reference.

All results are presented separately for the U18 and U20 leagues. First, we present summary counts and IR for each season. Seasons were then divided into the basic part and play-offs and separate counts and IR are presented for each part. Secondly, various aspects were used to divide the games and season and the respective IR were compared using IRR. In such manner, IR were compared between the thirds of the game (separate for each season), the months during the season and by round of game (all seasons combined). The R statistical language was used for all analyses (Team R Core 2017).

Results

Comparison of the U18 and U20 league

The number of reported head impacts ranged from 34 in seasons 2013/2014 and 2014/2015 to the highest observed 48 head impacts in season 2015/16. On average, there were 38.5 head impacts *per* season, with most of them occurring during the basic part (ranging from 82% in the 2013/2014 season to 89% in the 2016–2017 season; 86% on average for the four seasons). Table 2 presents the summary of the

Table 2. Incidence risk of suspected TBI *per* 1000 athlete exposures in youth hockey players in the Under 18 national hockey league in Slovakia by season and season part

Season	Season part	Head impacts	Games	IR	95%CI
2013/2014	Overall	34	406	2.09	2.07–2.12
	Basic	28	352	1.99	1.97–2.01
	Play offs	6	54	2.78	2.71–2.85
2014/2015	Overall	34	416	2.04	2.02–2.07
	Basic	29	352	2.06	2.04–2.08
	Play offs	5	64	1.96	1.91–2.01
2015/2016	Overall	48	415	2.89	2.87–2.92
	Basic	41	352	2.91	2.88–2.94
	Play offs	7	63	2.78	2.71–2.84
2016/2017	Overall	38	416	2.28	2.26–2.31
	Basic	34	348	2.44	2.42–2.47
	Play offs	4	68	1.47	1.43–1.52

IR, incidence risk; CI, confidence interval.

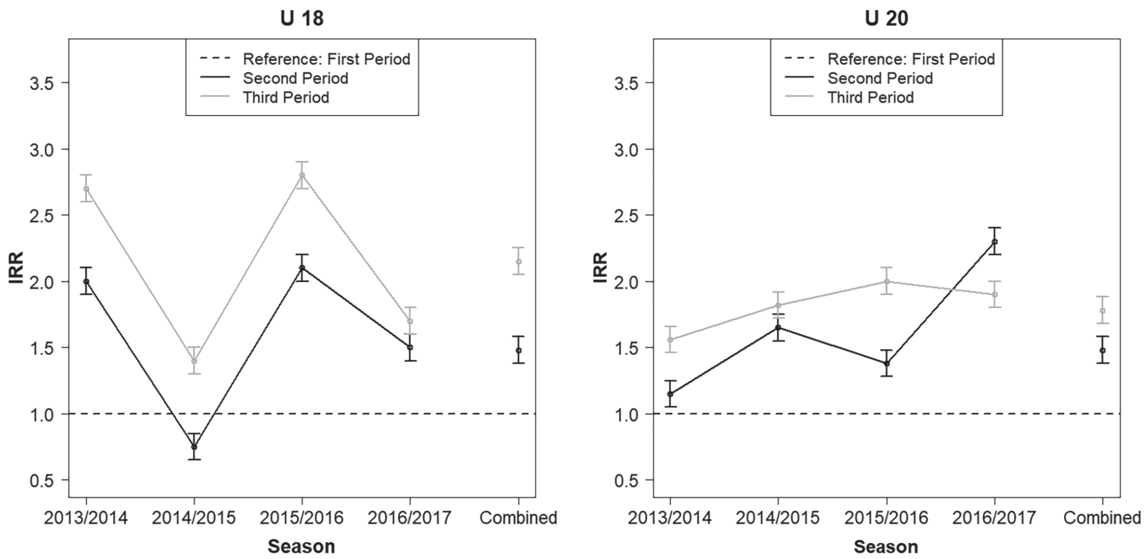

Figure 1. Incidence risk ratios (IRR) with 95%CI of head impacts between periods of game for each analyzed season and all seasons combined in the Under 18 (U18) and Under 20 (U20) national hockey leagues in Slovakia. IRR are calculated using the incidence risk (IR) for the first period of the games in each season as reference, to which IR for the second and third periods are compared. CI, confidence interval. Periods of game refer to the three 20 minute parts of a hockey game.

number of head impacts as counts and recalculated to IR for the four seasons presented separately for each part of the season for the U18 league.

These translated into overall IR (e.g, including games during the basic part and during the play-offs) ranging from 2.04 head impacts *per* 1000 AE in the 2014/2015 season to 2.89 head impacts *per* 1000 AE in the 2015/2016 season. While the IR for the play-off games was higher in the 2013–2014 season, than during the basic part (2.78 *vs.* 1.99 head impacts *per* 1000 AE), in seasons 2014/2015 to 2016/2017, the IR were higher in the basic part. Thus, no clear patterns of variation between the basic part and play-offs were observed, that would apply for all analyzed seasons.

Table 3. Incidence risk of suspected TBI *per* 1000 athlete exposures in youth hockey players in the Under 20 national hockey league in Slovakia by season and season part

Season	Season part	Head impacts	Games	IR	95%CI
2013/2014	Overall	26	303	2.14	2.12–2.17
	Basic	21	264	1.99	1.96–2.02
	Play offs	5	39	3.21	3.12–3.29
2014/2015	Overall	50	308	4.06	4.02–4.09
	Basic	44	264	4.16	4.12–4.21
	Play offs	6	44	3.41	3.32–3.49
2015/2016	Overall	40	458	2.18	2.16–2.21
	Basic	31	306	2.53	2.51–2.56
	Play offs	9	152	1.48	1.45–1.51
2016/2017	Overall	51	345	3.7	3.66–3.73
	Basic	46	313	3.67	3.64–3.71
	Play offs	5	32	3.91	3.8–4.02

IR, incidence risk; CI, confidence interval.

Overall, the number of observed head impacts for the U20 hockey league for the whole season ranged from 26 in the 2013/2014 season to 51 in the 2016/2017 season. Similarly to the U18 league, most of the head impacts were observed during the basic part games – ranging from 78% in the 2015/2016 season to 90% in the 2016/2017 season; on average 85% of head impacts occurred during the basic part of the season. Table 3 presents the summary of the number of head impacts as counts and recalculated to IR for the four seasons presented separately for each part of the season for the U20 league.

The corresponding IR ranged from 2.14 in the 2013/2014 season to 4.06 head impacts *per* 1000 AE in the 2014/2015 season (95%CI: 4.02–4.09). As in the U18 league, the rates were interchangeably higher in the basic part or play-offs with no apparent trend observed: in the 2013/2014 and the 2016/2017 seasons, higher IR were observed during play-offs (1.99 *vs.* 3.21 head impacts *per* 100 AE, and 3.67 *vs.* 3.91 head impacts *per* 1000 AE, respectively), while a reversed trend was observed for 2014/2015 and 2015/2016.

In general, in the U20 league compared to the U18 league, the rates were higher for overall as well as for each part of the season in all seasons, except 2015/2016 where this was reversed. This indicates, that the risk of head impacts can in general be considered higher in the U20 league.

Risk of head impacts by period of the game

Differences in rates of head impacts were observed between the periods of the game (presented as IRR of head impacts by period of the game in Figure 1). The first period is taken for baseline and all presented ratios are related to the rate for this period. In both leagues, there is a clear pattern which shows an increasing risk of head impacts in the later periods (with an exception of season 2014/15 in the U18 league where the IR was lowest in the second period). IRR are presented for all seasons separately and overall for all analyzed games together. The summary estimates suggest that the risk of head impacts in the U18 league was higher in the second period by a factor of 1.5 (95%CI: 1.47–1.52), and in the comparison of third *versus* first period the IRR was 2.02 (95%CI: 1.99–2.06). Similarly, in the U20 league, the risk was significantly higher in later periods compared to the first. The overall IRR were 1.48 (95%CI: 1.45–1.51) for the second *vs*. first period comparison and 1.81 (95%CI: 1.78–1.85) for third *vs*. first period.

Incidence risk by month of season

Differences in risk of head impacts were also observed between months of the season; in Figure 2, IR are plotted for each month of the season for both leagues in order to present the trends in this respect. Clearly, the least risky were the end of season games (e.g. the play-offs) where no head impacts were recorded in any of the analyzed seasons. Overall, the IR appear to be similar for games between January and April, whereas larger variation is present between September and December, with mostly higher rates in the U20 league.

Discussion

We conducted a cross-sectional analysis of the incidence of head impacts in the U18 and U20 youth ice hockey leagues in Slovakia during four seasons. We found that in the U18, the IR of head impacts ranged from 2.04 to 2.89 and in the U20 from 2.14 to 4.06 *per* 1000 AE for the analysed seasons. Significantly higher IR were observed in later periods of games: overall, the risk of head impact was higher by a factor of 1.5 in the second and by 2.02 in the third period compared to the IR for the first period in the U18. In the U20 these factors were 1.48 and 1.81.

Although, a number of previous studies estimated the incidence of concussions or head injuries and concussions in youth hockey leagues, it is difficult to directly compare these findings with our results as there are methodological differences between studies. However, a cautious general level of comparison is possible.

A recent systematic review used estimates from four studies (all from North America) to generate a pooled incidence of 1.2 concussions *per* 1000 AE (Pfister et al. 2016). A study following 397 youth ice hockey players in the US estimated an IR of 1.58 concussions *per* 1000 AE (Kontos et al. 2016). These estimates are lower than our findings, which could partly be caused by the fact that all concussions were confirmed medically or using a standardized tool resulting to stricter inclusion criteria. Another systematic review reports IR ranging between 0.72 and 1.81 per 1000 AE based on 17 studies (Ruhe et al. 2014), and observes that the proportions of concussions from the overall number of injuries in youth ice hockey from North American studies is substantially lower that in studies from Europe (2–7% *vs*. 5.3–18.6%) – which may be yet another cause of higher IR in our study. An extensive review of concussions in contact sports reports season incidences for men's ice hockey ranging from 0.41 to 1.55 *per* 1000 AE (matches and practice combined), with higher estimates for match-only based analyses (1.49 to 7.50 *per* 1000 AE) (Prien et al. 2018).

Thus, in general, considering the above-mentioned explanations of generally higher IR in our study compared to the published literature, our results seem to fall within the

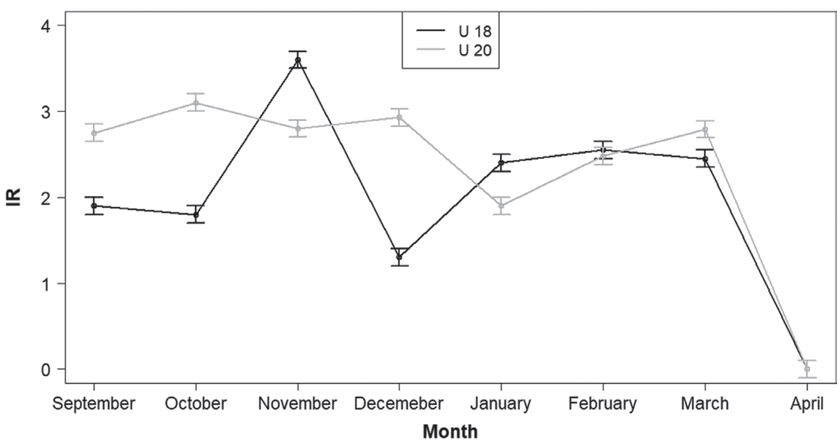

Figure 2. Incidence risk (IR) with 95%CI of head impacts by months of the season in youth hockey players in the Under 18 (U18) and Under 20 (U20) national hockey leagues in Slovakia in seasons 2013/2014–2016/2017. CI, confidence interval; AE, athlete exposure.

range of incidences expected based on the available knowledge on the topic.

Several factors could influence the observed differences in head impacts rates between seasons, including varying long-term fatigue (especially among key players), varying composition of teams (e.g, players changing teams) which influences the overall pattern of play of the team (e.g, more „physical“), longer-term game strategies, or individual situational differences during fouls or physical contacts (e.g, body posture at the time of head impacts). On the other hand, the observed differences within the game (between the thirds) may be attributed to factors, such as increasing fatigue of players during the game, or the importance of the game, which has an impact on the overall effort and risk-taking behaviour. The data available for this study did not allow to evaluate these associations in detail. However, the magnitude of the observed differences warrants for further studies that could elucidate on these relationships.

By analysing the incidence of head impacts, we attempted to indirectly estimate the incidence of concussions in two youth hockey leagues in Slovakia. As suggested by the similarity of our results to the findings of previous studies with more rigid case definition (e.g. medically confirmed concussion), this method may be robust enough to be used as a surrogate method to estimate the incidence of concussions. As it is based on routinely collected data, they may be used to routinely monitor the trends and circumstances of the resulting injuries in official hockey leagues in Slovakia or elsewhere. We do not provide evidence about the sensitivity of head impacts to estimate concussions, but such studies may be suggested for further research based on our findings.

To our knowledge, this is the first study using a scientific approach to estimate the incidence of head impacts in ice hockey in Slovakia. Given the popularity and involvement in the sport in Slovakia (Slovakia, Hockey 2020; https://www.hockeyslovakia.sk/en.), it can serve to call for implementation of measures to tackle these types of injuries. Although several tools and programs exist to prevent head injuries in ice hockey (Emery et al. 2017), or assess them on side-line (Smith et al. 2017), their implementation in Slovak ice hockey leagues is lagging behind.

There are limitations to our study pertaining mainly to the character of the data used in the analyses. First, there is no evidence evaluating the sensitivity of using head impacts to estimate TBI – our findings may therefore overestimate the number of concussions when used for such purposes. Second, additional selection bias may have occurred by the fact that the head impacts are recorded in the game statistics only if they are judged like that by the referee – individual variation of the judging practice between the referees could cause some over- or under-estimation of the true number of impacts.

Our study suggests that the incidence of concussions in youth ice-hockey leagues in Slovakia may be on levels similar to those reported in other leagues. Immediate implementation of measures to prevent these injuries is needed. The latter is the period of the game, the higher is the risk of head impact – this should be considered when planning prevention.

Conflicts of interest. All authors declare no conflicts of interests.

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Authors’ contributions. MM, IT and PF designed the study and drafted the manuscript. All authors substantially contributed to the conception and design of the work, the acquisition, analysis and interpretation of data, revised it critically for important intellectual content, approved the final version of the manuscript and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval. This study is based on publicly available secondary data and no ethics approval was required.

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