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Project Title: Delayed Symptom Onset in Pediatric Sport Related Concussion

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Summary (250 words max single spaced):

The prognosis and management of pediatric sport related concussion (SRC) is highly dependent on prompt identification of the injury, which is associated with better outcomes and shorter recovery times. Identification can be challenging, as the signs and symptoms of SRC are highly variable among patients. Additionally, some patients experience delayed symptom onset (DSO), in which symptoms are not immediate, but instead arise over the course of hours to days. DSO is particularly problematic for youth athletes who may be inappropriately returned to play, and consequently put at risk of further, more catastrophic injuries. The current study recruited 145 youth athletes diagnosed with SRC. Interviews and chart reviews were conducted. The incidence of DSO was found to be17.24 per 100 athletes. Compared to participants who experienced symptoms right away, those with DSO did not differ significantly in terms of baseline characteristics or time to medical clearance. Those with DSO were significantly less likely to be removed from play by a supervisory figure versus never removed or self-removed than those with ESO ($p < 0.001$). Those with DSO were also more likely to remove themselves from play versus supervisory removal or continued play compared to the ESO group ($p = 0.026$). Collectively, the results indicate all athletes who experience a suspected concussion be removed from play immediately, even if they report no immediate symptoms. The failure of supervisory figures to comply with SRC protocols will leave youth athletes, particularly those with DSO, at risk of potentially severe health related consequences.

Student Signature _____ Primary Supervisor Signature _____

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Delayed Symptom Onset in Pediatric Sport Related Concussion

Concussion is a subset of transiently induced traumatic brain injury that can be caused by both direct or indirect impulsive forces to the head, neck, face, or body.[1] The complex pathophysiological processes and biochemical dynamics that occur during concussion typically result in the rapid onset of acute neurological impairment. Although most symptoms are temporary and generally resolve spontaneously, there is extensive heterogeneity in symptom onset, type and number of symptoms, as well as recovery trajectory.[2] Signs and symptoms can include varying combinations of headache, dizziness, fogginess, sound and light sensitivity, concentration or difficulty remembering, nausea, emotional lability, and sleep disturbances.[3] While most adults experience symptom resolution within 7-10 days following injury,[4] children and adolescents typically recover within 4 weeks. However, in some cases, symptoms may persist for as long as a year.[5]

Epidemiological evidence suggests that the annual incidence of pediatric concussion is approximately 317 per 100,000, but this is likely an underestimation due to the barriers related to seeking and accessing care[3,6]. Additionally, individuals who suffer a concussion may not immediately report their symptoms or seek medical attention due to several different factors, including not recognizing a concussion may have occurred (because of delayed symptom onset, the assumption that the impact was too mild to cause injury, or a failure to attribute symptoms to the impact), not being aware of the consequences of playing concussed, or not wanting to be removed from play.[7–9] This is further complicated by noncompliance and underutilization of current concussion guidelines and management tools by coaches, athletic trainers, and other sports medicine personnel during sideline assessments and emergency department evaluations.[10,11]

Among children and adolescents, a significant proportion of concussions occur in the context of recreational and organized sport.[12] The prognosis and management of sport related concussion (SRC) is highly dependent on prompt identification of the injury, as earlier identification is associated with better outcomes and shorter recovery times.[13] Standardized sideline assessment guides such as the Sport Concussion Assessment Tool 5 (SCAT5) and the Child SCAT5 have been created to assist in the recognition of these injuries at the time of impact and document neurological status.[14,15] The SCAT5 is intended to be used by medical professionals assessing athletes aged 13 years or older, whereas the Child SCAT5 is used to assess athletes aged 5 – 12 years old. The multistep battery requires a minimum of 10 minutes to complete, and involves the evaluation of observable signs and red flags indicating a potentially more severe injury, an immediate memory assessment, examination on the Glasgow Coma Scale,[16] and assessment of the cervical spine. The SCAT5 and Child SCAT5 also incorporate a more extensive evaluation intended to be completed off-field or in a medical office, and includes a comprehensive symptom assessment, cognitive screening tools to test orientation and concentration, neurological screening, and delayed recall.

The 2017 consensus statement on concussion in sport provides the updated evidence of concussion prevention, recognition, assessment, and management for physicians and other healthcare providers involved in athlete care.[1] As per the recommendations of the Consensus Statement, should the results of the SCAT5 or

Child SCAT indicate a suspected concussion, the child should be immediately removed from play.[1] The Canadian Guidelines on Concussion in Sport have taken this recommendation one step further, publishing a position statement that recommends any child with a suspected concussion, regardless of SCAT findings, should be removed from play, evaluated by a physician or nurse practitioner, and not be returned to play until medically cleared by the physician or nurse practitioner.[17] Immediate removal from play is particularly important, as it effectively eliminates the chance of sustaining a second concussion prior to the resolution of the first. This is critical, because a second concussion can result in Second Impact Syndrome (SIS)—a very rare condition with potentially catastrophic and fatal effects. Pathophysiological research has revealed that receiving a second impact before the brain has recovered results in detrimental metabolic changes within neurons and neural support tissue that can result in marked morbidity or mortality.[2,18] In an effort to avoid this devastating outcome, the state of Washington passed the Zack Lystedt Law in 2009, necessitating pre-season concussion education, immediate removal from play if a suspected concussion may have occurred, and medical clearance by a medical professional.[19] Analogous laws now exist in each American state, and Canadian provinces are exploring similar legislation to guide the education, prevention, and management of suspected youth SRC.[21] In March 2018, Ontario passed Rowan's Law, an act that establishes strict removal-from-play, return-to-play, and return-to-learn protocols.[21] The law is named in memory of 17-year-old Rowan Stringer, who died from SIS after sustaining multiple concussions while playing rugby.

The ultimate success of concussion protocols and immediate removal from play is contingent upon the rapid recognition of a suspected concussion. Although symptoms typically occur immediately following the impact, some youth have delayed symptom onset (DSO), in which symptoms may not occur for up to 24 hours post-impact. If the signs and symptoms of a SRC are not present at the time of the sideline assessment (or if the athlete does not honestly report their symptoms), an athlete may be inappropriately returned to play and be at risk for subsequent concussions or SIS.

DSO in pediatric concussion has also been associated with an elevated risk of developing persistent postconcussion syndrome (PPCS), a condition in which patients experience at least three symptoms lasting for more than one month.[22] A recent study found that 25.0% of patients with PPCS had DSO, while the prevalence of DSO among patients who recovered within 3 weeks (a more typical prognosis) was only 2.5%.[23] However, the authors defined DSO as symptoms occurring more than three hours post-injury—a timeline significantly longer than a standard sideline assessment, which typically takes 10-15 minutes to complete. Additionally, the study did not examine risk factors for DSO. Identifying risk factors will assist coaches, trainers, and parents alike to recognize youth who are more likely to experience DSO and the related comorbidities.

The primary objectives of the present study were to determine the incidence of DSO and the time to physician documented recovery. Secondary objectives included determining the proportion of those who develop PPCS, risk factors for DSO, the frequency of truthful reporting by youth athletes, and the progression from injury to removal or non-removal among both groups. It was hypothesized that

athletes with DSO would experience a longer recovery period than those who experienced early symptom onset (ESO).

Methods

Participants

Between October 2016 and April 2018, 152 youth athletes were recruited from the Pan Am Concussion Program in Winnipeg, Canada to participate in this study. The Pan Am Concussion Program is Manitoba's only government-funded, multi-disciplinary pediatric concussion clinic where all patients are diagnosed and managed by one neurosurgeon after being referred by a family physician, emergency department, or sport specific protocol. To be eligible to participate in the study, athletes must have been between the ages of 10 and 19 years old (inclusive) at the time of diagnosis, have sustained a concussion during an organized or recreational sport, and have been diagnosed with a concussion according to the most up to date Consensus Statement protocols.[1,24]

Recruitment

Once determined to be eligible by the neurosurgeon, athletes were invited to participate in the study by a research assistant. Athletes and their accompanying parents or legal guardians provided written assent and consent, respectively. Youth athletes were interviewed by a research assistant in the examination room, and were asked questions pertaining to the history of the impact, which symptoms they experienced and when they began, whether they were removed from play or continued to participate following the incident, whether they had a sideline assessment, and if so, whether they chose to truthfully report their symptoms.

Demographic characteristics were also collected during the initial appointment. Information related to age, gender, personal and family medical histories, and whether the participant attended a public or private school was recorded. These characteristics were included due to a growing body of evidence that suggests females, individuals with a personal or family history of mental health conditions, migraines, learning disorders or attention deficit hyperactivity disorder, individuals previously diagnosed with a concussion, and individuals who attend private schools may be at greater risk for PPCS.[23,25–28] Participants were also asked to complete a paper and pencil battery at the time of interview that included the Pediatric Quality of Life PedsQL™ Teen Report Version 4.0 Inventory and Cognitive Functioning Scale,[29] and a modified version of the Post-Concussion Symptom Scale.[30] The scale is a symptom inventory comprised of 22 symptoms that are each rated on a 7-point Likert scale (0-6), where a 0 represents an absence of that symptom, and a 6 indicates the participant experiences that symptom severely. The entire interview took approximately 20 minutes to complete.

Classification of Delayed Symptom Onset

Depending on their responses, participants were categorized into two groups: those who reported experiencing symptoms 0.0 - 14.9 minutes following the impact were classified as early symptom onset (ESO), and those who reported experiencing initial symptoms 15.0 minutes or more post-injury were classified as delayed symptom onset (DSO). Symptom onset was dichotomized at 15 minutes because common sideline assessment tools such as the SCAT5 and Child SCAT typically

require 15 minutes to complete, and may therefore inappropriately identify an athlete with DSO as asymptomatic and return that athlete to play.

Course of Treatment and Follow-Up
All participants continued to be seen by the neurosurgeon for follow-up appointments at the discretion of the neurosurgeon, and participation in this study did not alter their clinical care (that is, patients received interventions to correct the pathophysiology that was responsible for their symptoms). Once cleared by the neurosurgeon in collaboration with multi-disciplinary team members as needed, the participants were asked to complete the Pediatric Quality of Life PedsQL™ Teen Report Version 4.0 Inventory and Cognitive Functioning Scale following their final appointment.

Outcomes
The primary outcome was days until physician documented clinical recovery and this was extracted from the patients' medical charts. This was defined as the number of days since injury until the participant had returned to school full-time without self-reported concussion symptoms (if during the school year), completed the Return to Play Protocol as per the Consensus Statement, and was assessed as having a normal neurological exam with no evidence of vestibulo-ocular dysfunction.[1,31] Considering the majority of pediatric patients with SRC recover within four weeks, and in accordance with previous studies, participants who achieved physician-documented clinical recovery greater than four weeks (≥ 29 days) were considered to have PPCS.[32,33]

Data Analysis
Concussed youth athletes with DSO were compared to those with ESO. Normally distributed data were calculated as the mean and standard deviation, and were compared using an unpaired t-test. Continuous variables with skewed data were reported as the median with the interquartile range (IQR), and statistical significance was assessed using a rank sum test. For dichotomous or polychotomous data, proportions were calculated, and group differences were compared using a chi squared test where applicable. A p-value less than 0.05 was defined as statistically significant.

Multivariate ordinal logistic regression was also conducted to examine risk factors for DSO. The time until physician-documented medical clearance was partitioned into four groups based on quartiles. Potential risk factors that were significant at $p = 0.20$ were included in the forward selection model. The odds ratios and 95% confidence intervals were reported. To ensure the parallel regression assumption was not violated, a Brant test was conducted.

To assess risk factors for PPCS, a multivariate logistic regression was conducted. Baseline characteristics that were significant at the 0.20 level were included in the model built using forward selection techniques. The odds ratios and 95% confidence intervals were reported.

Finally, a sensitivity analysis was performed to assess whether there were differences between those who were and were not lost to follow-up. The baseline characteristics of those lost to follow-up were compared to those who were medically cleared to examine whether differences existed between the two groups.

Also, the number of days between the initial clinical assessment and the last appointment date was calculated to determine if the length of time to the last follow-up appointment was associated with DSO.

Results

Recruitment and Patient Flow

Of the 152 participants who met inclusion criteria and consented, seven were excluded due to undefined mechanisms of injury. A total of 145 participants were recruited and included in the analysis. No one deemed eligible declined to participate.

Baseline Characteristics

The participants (n = 145) were assessed by the neurosurgeon at a median of 5.0 days (IQR 4.0 – 9.0) following injury. Those with DSO (n = 25) were evaluated at a median of 7.0 days (IQR 4.0 – 9.0) postinjury, and those with ESO (n = 125) were assessed at a median of 5.0 days (IQR 4.0 – 8.5) following injury (p = 0.386). The demographic information and baseline characteristics reported at initial consultation are described in Table 1. There were no significant differences in baseline characteristics among those with DSO and those with ESO when considering age, sex, personal and family medical histories, type of education, setting of sport, and type of sport played at the time of concussion. There were also no statistically significant differences in symptom severity or the initial PedsQL Cognitive Functioning Scale scores and PedsQL Composite scores between the two groups.

Incidence and Time to Physician Documented Medical Clearance

Overall, 25 participants were classified as DSO (incidence of 17.24 per 100 athletes) and 120 participants were classified as ESO (incidence of 82.76 per 100 athletes). Participants were medically cleared at a median of 22.5 days (IQR 16.0 – 34.0) following injury. Those with DSO were medically cleared at a median of 24.5 days (IQR 18.0 – 34.5) postinjury, and those with ESO were medically cleared at a median of 22.0 days (IQR 15.0 – 34.0) following injury (p = 0.306). By the end of the study period, three participants (2.07%) remained in treatment for a median of 56 days (IQR 41.0 – 91.0), all of whom were from the early symptom onset group (2.50%; p = 0.424).

Persistent Postconcussion Syndrome

Of those medically cleared (n = 116), 42 participants (36.21%) were found to have PPCS. The incidence of PPCS within the DSO group (n = 9, 45.00%) did not differ significantly from the incidence within the ESO group (n = 33, 34.38%; p = 0.368).

Table 1.
Baseline clinical characteristics among pediatric patients with SRC with and without delayed symptom onset

Variable	Total N = 145 (100.00%)	DSO N = 25 (17.24%)	ESO N = 120 (82.76%)	p value
Mean age in years (SD)	14.59 (1.79)	14.16 (1.99)	14.68 (1.73)	0.184
Male	89 (61.38%)	16 (64.00%)	73 (60.83%)	0.767
Median number of days from injury to consult (IQR: 25th, 75th)	5.0 (4.0, 9.0)	7.0 (4.0, 9.0)	5.0 (4.0, 8.5)	0.386
Median PCSS Score (IQR: 25th, 75th)	20.0 (11.0, 32.0)	20.0 (8.0, 26.0)	20.0 (11.0, 32.5)	0.445
Posttraumatic amnesia	34 (23.45%)	3 (12.00%)	31 (25.83%)	0.149
Loss of consciousness	14 (31.11%)	0 (0.00%)	14 (11.67%)	0.072
VOD at initial assessment	38 (26.21%)	4 (16.00%)	34 (28.33%)	0.202
History of concussion	59 (40.69%)	10 (40.00%)	49 (40.83%)	0.938
History of headache or migraine headache	10 (6.90%)	1 (4.00%)	9 (7.50%)	0.530
History of a learning disorder or ADHD	7 (4.83%)	1 (4.00%)	6 (5.00%)	0.832
History of depression	4 (2.76%)	0 (0.00%)	4 (3.33%)	0.355
Family history of mental illness[1]	34 (23.44%)	4 (16.00%)	30 (25.00%)	0.334
Mean PedsQL Cognitive Functioning Scale score (SD) Missing	64.10 (22.90) 1 (0.69%)	63.17 (21.97) 0 (0.00%)	64.30 (23.18) 1 (0.83%)	0.924
Mean PedsQL Composite score[2] **(SD)** Missing Not applicable[3]	74.97 (15.93) 1 (0.69%) 43 (29.66%)	73.78 (16.28) 0 (0.00%) 6 (24.00%)	75.25 (15.94) 1 (0.83%) 37 (30.83%)	0.412

Number of patients enrolled in a private school	16 (18.60%)	4 (22.22%)	12 (17.65%)	0.657
Missing	59 (40.69%)	7 (28.00%)	52 (43.33%)	
Number of concussions that occurred in a game setting[4]	116 (80.00%)	19 (76.00%)	97 (80.83%)	0.583
Number of concussions that occurred during a contact sport[5]	137 (94.48%)	23 (94.48%)	114 (95.00%)	0.550
Sport played at time of concussion				
Hockey	61 (42.07%)	10 (40.00%)	51 (42.50%)	
Football	24 (16.55%)	4 (16.00%)	20 (16.67%)	
Soccer	18 (12.40%)	4 (16.00%)	14 (11.67%)	
Basketball	11 (7.59%)	0 (0.00%)	11 (9.17%)	
Other[6]	31 (21.38%)	7 (28.00%)	24 (20.00%)	

[1]Mental health conditions included in analysis: depression (n = 32), bipolar disorder (n = 2), anxiety (n = 1), and OCD (n = 1).
[2]Composite score calculated by averaging PedsQL physical, emotional, social, and school subdomain scores.
[3]Participants were not in school or had not returned to school at time of assessment, therefore an overall composite score was not calculated.
[4]Compared to concussions that occurred during an organized practice (n = 24) or a supervised gym class (n = 5).
[5]Contact sports included: basketball (n = 11), dodgeball (n = 2), football (n = 24), hockey (n = 61), judo (n = 1), ringette (n = 9), rugby (n = 3), soccer (n = 18), volleyball (n = 6), waterpolo (n = 1), and wrestling (n=1). Non-contact sports included: dance (n = 1), gymnastics (n = 2), snowboarding (n = 2), and speedskating (n = 3).
[6]Other sports included in analysis: ringette (n = 9), volleyball (n = 6), rugby (n = 3), speed skating (n = 3), dodgeball (n = 2), gymnastics (n = 2), snowboarding (n=2), dance (n = 1), judo (n = 1), waterpolo (n = 1), and wrestling (n = 1).

Risk Factors for PPCS
Those who experienced DSO had a 1.76 higher odds (95% CI 0.68 – 4.52) of developing PPCS than those who had ESO, after controlling for age, post-traumatic amnesia, and vestibulo-ocular dysfunction. However, this was not statistically significant (p = 0.244). Age (p = 0.265), post-traumatic amnesia (p = 0.947), and vestibulo-ocular dysfunction (p = 0.098) were also not found to be statistically significant risk factors for the development of PPCS.

Recovery Trajectories
The association between the number of days to recovery and DSO was not statistically significant (OR: 1.77; 95% CI 0.75 – 4.19; p = 0.192). Age (p = 0.413) and post-traumatic amnesia (p = 0.529) were also not found to be significantly associated with the number of days to recovery. Those who were diagnosed with vestibulo-ocular dysfunction at initial consult had a 2.73 higher odds (95% CI 1.27 – 5.86) of having a lengthened recovery trajectory compared to those with a shorter recovery trajectory. This finding was significant (p = 0.010). The results of the Brant test confirmed that the clinical categorization of length of recovery was appropriate, as the parallel regression assumption was not violated (p = 0.423).

Sensitivity Analysis on Lost to Follow-Up
In total, 26 participants (17.93%) were lost to follow-up. Five participants (20.00%) belonged to the DSO group, and 21 participants (17.50%) were from the ESO group (p = 0.767). A sensitivity analysis was conducted to compare those who were lost to follow-up and those who were medically cleared. There were no significant differences in baseline characteristics between the two groups, except that those lost to follow-up were more likely to have had a family history of mental illness (p = 0.046).

Additionally, the length of time from injury to clearance for those who were medically cleared was combined with the length of time from injury to the last appointment date for those who were lost to follow-up, and the DSO and ESO groups were compared. Among all participants, the median number of days from injury to clearance or last appointment attended was 21.5 days (IQR 16.0 – 32.0 days). Those with DSO were cleared or attended their last follow-up appointment at a median of 23.0 days (IQR 17.0 – 32.0 days) from the date of injury, and those with ESO were cleared or attended their last follow-up appointment at a median of 21.0 days (IQR 15.0 – 32.0 days) following injury (p = 0.527).

Final PedsQL Cognitive Functioning Scale and Composite Scores
Among those who achieved physician documented medical clearance, 105 participants (90.52%) completed the PedsQL Cognitive Functioning Scale and Composite Scale at their final appointment. Overall, the mean score on the Cognitive Functioning Scale was 91.45 (SD = 14.25). Those with DSO had a mean score of 88.99 (SD = 12.98), and those with ESO had a mean score of 91.93 (SD = 14.51; p = 0.129). The overall mean score on the Composite Scale was 97.12 (SD = 26.12). Those with DSO had a mean score of 93.06 (SD = 9.26), and those with ESO had a mean score of 97.90 (SD = 28.22; p = 0.487).

Symptom Onset

Among the 25 participants who experienced DSO following their SRC, the length of time from injury to the initial onset of the delayed symptoms ranged from 15 to 10,080 minutes (Figure 1).

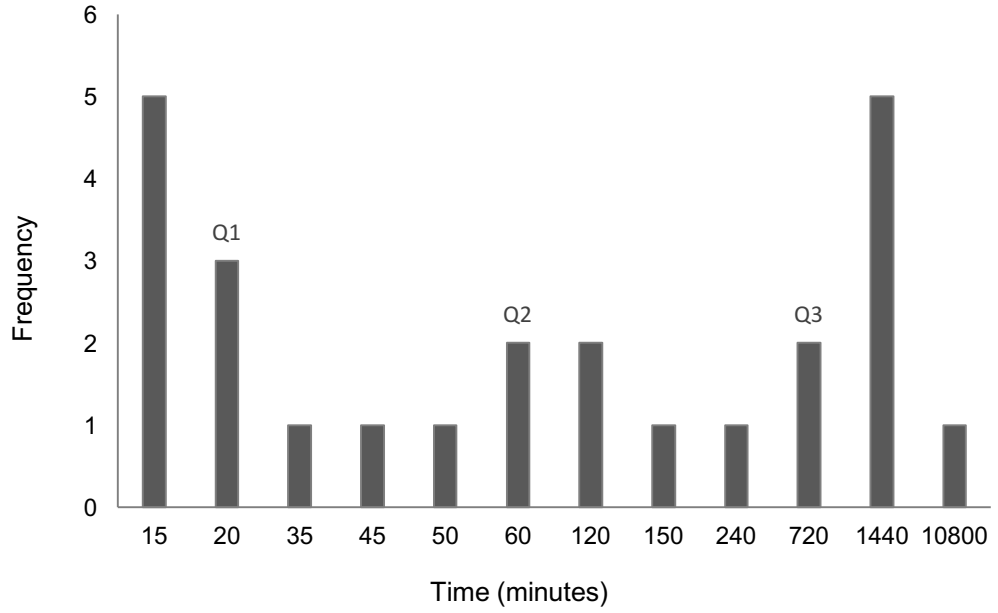

Figure1. Length of time from injury to onset of delayed symptoms among the DSO group.

Upon onset, the most commonly experienced symptom was headache: 22 participants from the DSO group (88.00%) and 114 participants from the ESO group (75.86%; p = 0.559) reported headache. The second most commonly experienced symptom was dizziness: 16 participants from the DSO group (64.00%) and 60 participants from the ESO group (41.38%; p = 0.202) experienced dizziness. Additional symptoms that were reported exclusively by the ESO group included loss or alteration of consciousness, transient tinnitus, and general weakness.

Removal or Continuation of Play

The sequence of events from injury to removal from play for those with and without DSO is described in Figure 2A and 2B. There were 77 participants (53.10%) who received a sideline assessment. Participants with DSO were less likely to be immediately removed from play (28.00%) than those with ESO (73.33%; p < 0.001). Those with DSO were also more likely to quit playing their current game or sport on their own (16.00%) when compared to the ESO group (4.17%; p = 0.026). Among the participants who remained in their game or practice (that is, were never removed following concussion; n = 36), two participants with DSO and two

participants with ESO reported being hit at least one more time following their initial concussion. Finally, among the participants who were immediately removed from play, received a sideline assessment, and were truthful during the assessment, there were no statistically significant differences between the DSO group (50.00%) and the ESO group (22.81%) in terms of their likelihood to be returned to their current practice or game ($p = 0.374$).

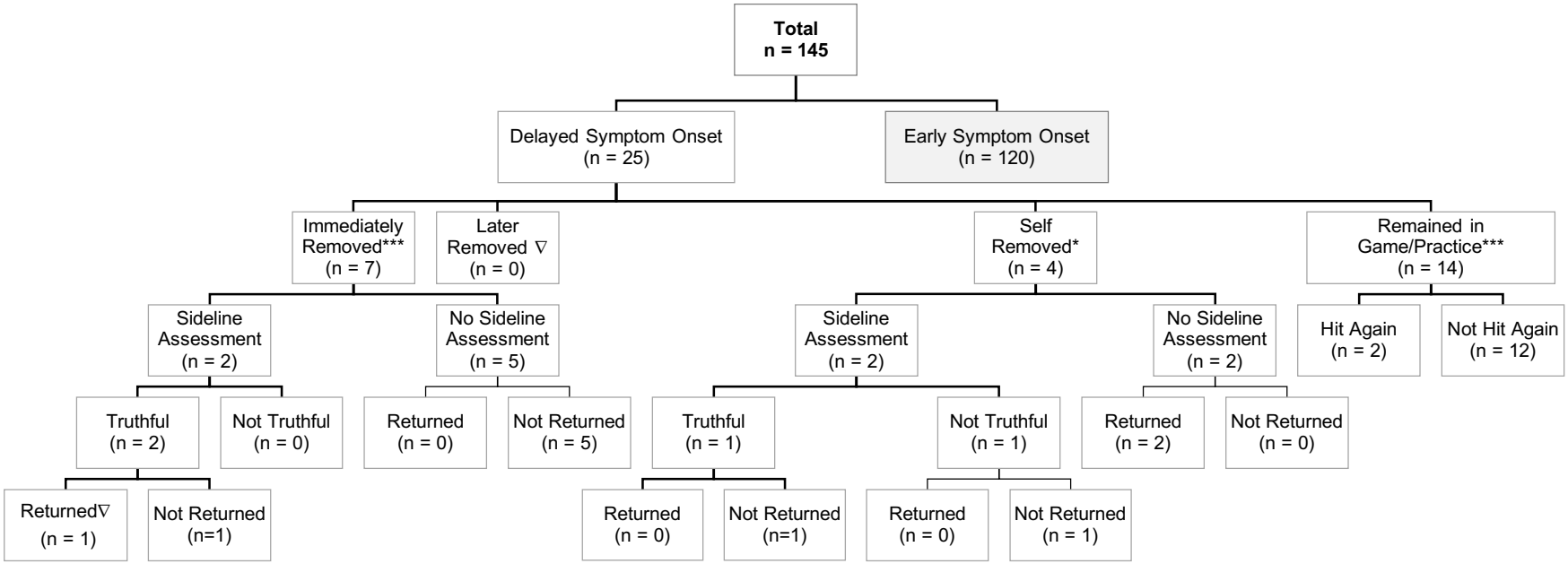

Figure 2A. Sequence of events from injury to removal of play for participants with DSO.
Participants with DSO were compared to those with ESO, and analyzed using a chi-square test.
***p < 0.001
*p = 0.026
∇ analyzed, but results were non-significant

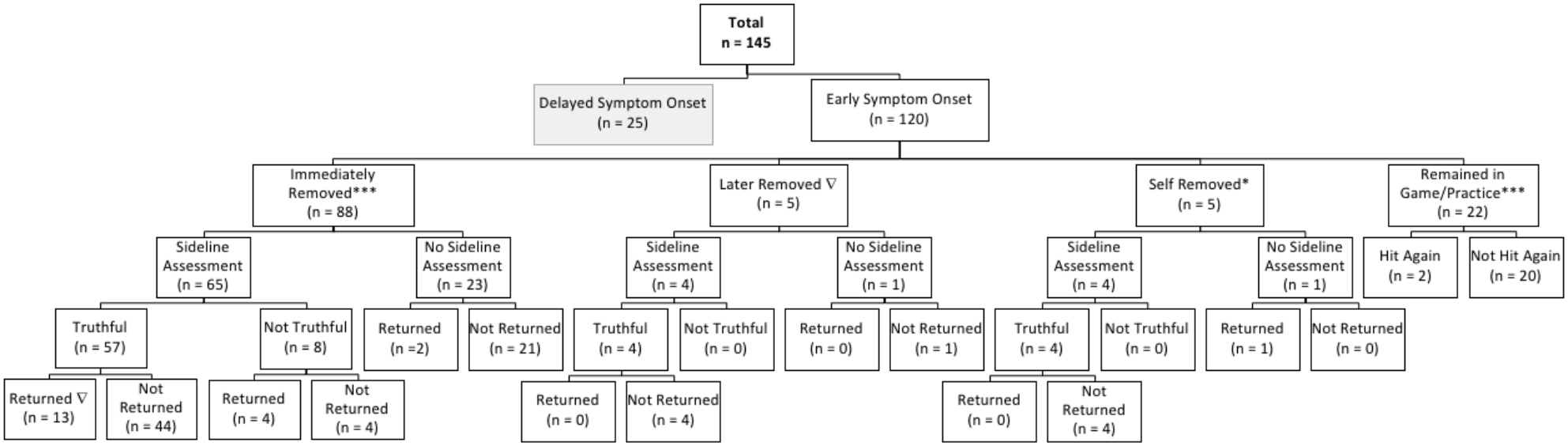

Figure 2B. Sequence of events from injury to removal of play for participants with ESO.
Participants with ESO were compared to those with DSO, and analyzed using a chi-square test.
***$p < 0.001$
*$p = 0.026$
∇ analyzed, but results were non-significant

Discussion

This study provides important information related to the epidemiology of DSO in pediatric SRC. The incidence of DSO was found to be 17.24%. In a previous study examining a similar population, the reported incidence of DSO was 2.50%.[23] However, the authors classified patients as having DSO if they were asymptomatic for up to three hours post-injury. Had the current study used the same operational definition of DSO, the incidence would have been found to be 6.21%. Collectively, these findings suggest the incidence of DSO in pediatric SRC is likely higher than what has previously been reported.

The design and definition of DSO implemented in the current study aimed to ensure that all concussed youth who may have been overlooked during a standard sideline assessment were classified as DSO. The results of the current study indicated there were no significant differences in the length of time to physician diagnosed medical clearance between those with DSO or ESO. Those who had DSO were also no more likely to develop PPCS. Collectively, these results suggest the prognosis of pediatric SRC does not depend on the length of time until the onset of symptoms or the symptom severity following impact.

The current study also sought to identify risk factors for the development of DSO. Many baseline characteristics were examined, but no independent risk factors were identified. These findings are important, as they suggest youth who sustain SRC are equally likely to have ESO or DSO.

In terms of sideline management, participants with ESO were significantly more likely to be removed from play by a coach, trainer, parent, or referee than participants who experienced DSO. This difference is likely because some signs experienced exclusively by the ESO group such as loss of consciousness or peripheral weakness are typically objective indicators of a potential concussion. When considering the participants who were immediately removed from play by a supervisory figure, received a sideline assessment, and were truthful about their symptoms during the assessment, those with DSO and ESO were equally likely to be returned to play (Figure 2A and 2B). In total, 14 participants were returned to their game or practice despite being truthful about experiencing concussion symptoms. Five participants were returned to the game or practice without receiving a sideline assessment, and four were returned after being dishonest about their symptoms during the assessment. Additionally, participants with DSO were significantly more likely to remove themselves from play than be removed by a supervisory figure when compared to the ESO group. Collectively, during this study, 59 youth athletes were put at risk of sustaining a second concussion and the associated consequences. The results from this study indicate that despite clear regulations related to removal of play when a concussion is suspected to have occurred,[3,17,34] the implementation of these protocols remains inconsistent.

It is important to acknowledge that the efficacy of sideline assessment tools depends on the truthful reporting of symptoms by athletes following their injury. In the current study, 88% of participants who received a sideline assessment claimed to have been truthful about their respective symptoms, and there were no differences in terms of truthful reporting between the two groups (Figure 2). During the initial interview, it was unclear which sideline assessments were being used, and how frequently validated tools like the SCAT5 were being employed. Overall,

the results from this study suggest truthfulness was likely not a barrier to interpreting the findings from the sideline assessment.

The current study did not identify any risk factors for the development of DSO. Similarly, there were no statistically significant differences between the DSO and ESO groups in relation to the development of PCSS. While variables such as age and post-traumatic amnesia were not found to be predictive of PCSS, the diagnosis of vestibular-ocular dysfunction was associated with a longer recovery trajectory. These findings are in accordance with previous research.[31]

There are several important limitations of this study to consider. Firstly, a substantial proportion of data collected were self-reported and there is the potential for recall bias. Although some of the scales used in analysis such as the PCSS and PedsQL have been validated, information such as the timing of symptom onset depended on accurate reporting by participants and the parents who provided collateral history. However, this is a common limitation of concussion research[31,33] and without employing technology such as video relay, it is not possible to determine the specific timing of concussion injury and symptom onset.

Secondly, 17.93% of participants were lost to follow-up. To ensure that those who were and were not lost to follow-up were similar, a sensitivity analysis was conducted comparing baseline characteristics among the two groups. The only significant difference between those who were and were not lost to follow-up was family history of psychiatric disorders. Those with DSO were no more likely than those with ESO to be lost to follow-up.

Thirdly, resilience and somatization are just two examples of additional variables that have previously been reported to influence symptom burden and length of recovery, but these potential confounders were not measured in this study.[35,36] It is possible the respective scores for these variables and others may have differed between the DSO and ESO groups, and may have been found to be potential risk factors for the development of DSO. The inclusion of such variables should be considered in future studies.

Fourthly, a substantial proportion of participants (29.66%) were not attending school at the time of assessment, either due to the time of year, or as a consequence of their injury. For that reason, the PedsQL Composite score, which includes the PedsQL school sub-score, could not be uniformly assessed. However, the cognitive functioning scores were similar among the two groups, and cognitive functioning is likely related to school quality of life.

Finally, it is possible that the results related to the length of time to medical clearance were impacted by participant scheduling and availability since participants are not seen at pre-determined intervals. The scheduling of appointments was at the discretion of the neurosurgeon and the patients' availability, and this may have influenced the documented time to recovery. However, this should have affected both groups equally.

The participants included in this study were referred to a multidisciplinary pediatric concussion program, and may therefore represent a population with more severe injuries. Because of this, it is possible that the incidence of delayed symptom onset

reported in this study may not reflect the incidence in the general pediatric SRC population. However, it is likely an accurate estimation of those who are referred to a tertiary clinic.

In conclusion, the current study suggests that concussed youth athletes with DSO and ESO did not differ in terms of demographic or baseline characteristics, symptom burden and severity, or prognosis and recovery time. There were, however, significant differences related to how concussions were handled at the time of suspected injury between the two groups. The results of the study indicate those with ESO were more likely to be removed either immediately or at a later point in play by a supervisory figure, and those with DSO were more likely to remove themselves or remain in the game. This disparity in management at the time of impact is problematic, as it shifts the responsibility from a supervisory figure to the youth athletes, who may or may not have the knowledge or awareness to remove themselves from play. If the athletes are not being removed by either a supervisory figure or by themselves following injury, then they are at risk of sustaining a second concussion and developing SIS.

The results of this study call for increased education of concussion symptoms for athletes, coaches, and other stakeholders who may be involved in the identification and management of pediatric SRC. Previous research has found that Canadian youth athletes, parents, coaches, and medical professionals struggle with identifying symptoms associated with concussion—especially symptoms related to mental health.[37] Therefore, future educational endeavors should draw attention to the heterogeneous nature of pediatric SRC symptoms, specifically the breadth, depth, and variable onset of symptoms described in this study.

Current protocols emphasize removal from play based on a *suspected* concussion, and the results of this study offer significant support for this position. All participants could identify a very specific point of impact, whether it involved another player or a playing surface, and when their concussion occurred. Therefore, it is recommended that all future guidelines, protocols, and educational resources stress the importance of recognizing a mechanism of injury that could potentially result in concussion. Collectively, the results indicate all athletes who experience a suspected concussion should be removed from play immediately, even if they report no immediate symptoms. The failure of supervisory figures to comply with SRC protocols will leave youth athletes, particularly those with DSO, at risk of potentially severe health related consequences.

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