RATES OF HEAD CONTACTS, BODY CONTACTS, SUSPECTED INJURIES, AND MECHANISMS OF INJURY IN CLUB VERSUS UNIVERSITY VOLLEYBALL: A VIDEO ANALYSIS STUDY

by

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Abstract

Background:
Despite being classified as a non-contact sport, volleyball has a high injury burden among youth in Canada. Recent data rank it among the top five sports for injury prevalence in adolescents, with a notable proportion of concussion reported in both youth and university-level play (from 1.0% in boy's youth volleyball to 19.8% in men's university volleyball).

Objective:
To compare the incidence rate of head contacts (HCs), body contacts (BCs), and non-contact suspected injuries (NCSIs) between 1) male Winnipeg 15U-17U club, 2) female Winnipeg 15U-17U club, 3) men's CanadaWest USPORTS, and 4) women's CanadaWest USPORTS volleyball athletes in the 2023-2024 volleyball season and to understand the contact and injury mechanisms.

Methods:
Game-footage of male and female athletes from Winnipeg 15U-17U club teams and Canada West USPORTS teams were analyzed from the 2023-2024 season. Using validated coding protocols in Dartfish, HCs, BCs, and NCSIs were identified as well as other contextual gameplay characteristics. Poisson regression was used to calculate incidence rate ratios (IRRs) per 100 player-match hours, comparing by sex and competition level.

Results:
USPORTS athletes had lower BC rates than club athletes in both females (IRR = 0.74; 95% CI: 0.67–0.82) and males (IRR = 0.74; 95% CI: 0.68–0.80). HC rates did not differ significantly between leagues for females (IRR = 1.86; 95% CI: 0.89–3.89) or males (IRR = 0.61; 95% CI: 0.36–1.03). Across leagues, males had higher BC rates than females (M:F club IRR = 1.60; 95% CI: 1.47–1.73; M:F USPORTS IRR = 1.60; 95% CI: 1.45–1.76), and male club athletes had higher HC rates (IRR = 3.21; 95% CI: 1.61–6.37). Contextual analyses showed BCs and HCs occurred most often during blocking (BC IR = 95.64; 95% CI: 88.40–103.31; HC IR = 6.23; 95% CI: 4.49–8.42) and defense (BC IR = 95.34; 95% CI: 88.12–103.01; HC IR = 8.16; 95% CI: 6.14–10.62) compared to other action types (e.g., serve receive, attacking, setting). Eighteen suspected injuries were identified, including two suspected concussions. Most contacts were low intensity; moderate/high intensity events were less frequent (BC IRR = 0.20; 95% CI: 0.19–0.21; HC IRR = 0.40; 95% CI: 0.26–0.63). No differences were found in contact or injury rates between regular season and playoffs.

Conclusion:
Male club volleyball athletes are exposed to more frequent contact events, compared to female club and male and female university athletes. Although most contacts were minor, findings support the development of position- and level-specific prevention strategies. These could include increased educational interventions or policy adjustments such as automatic stoppages following head contact.

Keywords: Volleyball, Video-Analysis, Youth, University, Sports, Injury, Concussion

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Dedication

To the athletes, your passion, resilience, and growth continue to inspire my work as a coach and researcher.

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I share this accomplishment with you.

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List of Symbols, Abbreviations, and Nomenclature

Symbol or Abbreviation	Definition
15U	Ages 15 and under
16U	Ages 16 and under
17U	Ages 17 and under
AI	Artificial Intelligence
BC	Body Contact
FIVB	Fédération Internationale de Volleyball (International Volleyball Federation)
HC	Head Contact
HC1	Head Contact Type 1
HC2	Head Contact Type 2
IR	Incidence rate
IRR	Incidence rate ratio
NCAA	National Collegiate Athletic Association
NCSI	Non-Contact Suspected Injury
SHRed Concussions	Surveillance in High School to Reduce Concussions and Consequences of Concussions in Canadian Youth
SC	Suspected Concussion
SI	Suspected Injury
SRC	Sport Related Concussion
USPORTS	University Sport in Canada

1. Chapter 1: Introduction

1.1. Rationale

Physical activity and sport participation is associated with many positive mental and physical health outcomes (1). However, injuries are always a concern. Volleyball is one of the top five most popular sports in the world with over 200 national federations currently represented in the International Volleyball Federation (FIVB) (2,3). In Canada, volleyball is becoming a prominent sport with over 50,000 registered athletes in indoor volleyball alone in the 2023-2024 season (4). This has increased from less than 43,000 in the 2022-2023 season and 32,000 in 2021-2022 (5,6). A 2021 study found that volleyball was the second most popular school-specific sport for girls and ranked fourth overall in sport-specific participation among 2,000 Alberta students aged 14-19 years (11%) (7).

Volleyball has become an incredibly fast paced game with serving speeds recorded over 120 kilometres per hour at professional and Olympic level competitions (8). Due to the significant speed of the volleyball in game play and training, it requires an exceptional reaction speed and the ability to quickly change direction. According to a 2021 self-reported injury history survey, volleyball ranks among the top five sports with the highest proportion of 'most serious injury' in the last year among Canadian students aged 14 to 19 years (7). Ankle injuries represented the highest proportion of injuries (31%), followed by knee injuries (19%), and wrist or hand injuries (17%), 25% were joint or ligament sprain, followed by fracture (17%) (7). Volleyball injuries can be acute (e.g., ankle sprain), or overuse injuries which are common in the shoulders, knees, and lower back (2). Concussions are also common in volleyball. In youth girls volleyball, concussions account for a notable proportion of all injuries (4.6%), even higher than that of some contact sports like boys' basketball (4.1%), boys' and girls' judo (3.7%, 3.9%), and girls' wrestling (2.8%) (9). Additionally, in a 4 year review of women's National Collegiate Athletic Association (NCAA) volleyball, concussions represented 5% of all injuries (10). However, likely due to the non-contact nature of volleyball, injury rates, and more specifically sport-related concussion (SRC) rates have been understudied. Volleyball's increasing popularity in Canada provides the opportunity to assess and understand injury rates across age and sex, mechanism of injuries, and identify future opportunities for injury prevention.

1.2. Purpose of this Research

To promote athlete health and encourage life-long sport participation, injury prevention is of the utmost importance. Therefore, understanding injury incidence rates, including concussions, is critical to informing athletes and community leaders about the risks associated with volleyball participation. This is the first step in creating safer sport participation.

According to van Mechelen's sport injury prevention model, the first step is to understand the burden of injury (11). This includes quantifying and assessing the incidence and severity of injury. The second step involves identifying risk factors and mechanisms of injury. This can be done by identifying game characteristics such as court location, the player action that resulted in the injury, or the position of the player when the injury occurred. Step 3 involves introducing an intervention to reduce or modify the risk factors and mechanisms. In step 4, the intervention is evaluated by measuring the new burden of injury after implementation of the intervention (11). The TRIPP model expands upon Van Mechelen's work. Steps one and two are to perform injury surveillance to establish a wholistic understanding on injury aetiology and mechanism (12). The TRIPP model varies from the van Mechelen model in step three and four as it requires one to first develop a prevention measure (step 3) and test it in ideal conditions (step 4). After understanding the implementation environment (step 5), the intervention is evaluated (step 6)

(12). Notably, these stepwise approaches toward injury prevention agree with epidemiological theorists such as Hernan who claim that to introduce an intervention, one must first identify the exact instances of injury so that one can develop well defined and specific interventions (13). The current study uses video analysis to understand the incidence rate of head contacts, body contacts, and suspected injuries of both male and female 15U-17U club volleyball athletes in Winnipeg, Manitoba, and USPORTS varsity volleyball athletes in the CanadaWest division throughout the 2023-2024 volleyball season.

2. Chapter 2: Background

2.1. Introduction

Sport injury researchers have historically focused on collision sports (5,14). Despite the increasing popularity of volleyball in Canada, there is minimal Canadian research describing volleyball injury rates, aetiology, and mechanisms.

While the majority of sport injury research has traditionally focused on men's sports, most research in volleyball has focused on women's volleyball as volleyball is more common among women in North America (15,10). For example, of the 50,095 indoor volleyball athletes who registered with Volleyball Canada in the 2023-2024 season, 36,201 were registered in the female athlete category, as classified by Volleyball Canada (72%) (4). For this reason, the current study includes male and female athletes in evaluating volleyball-related contacts and injuries in club and university volleyball.

Comparing injury and concussion rates between youth club and university volleyball is important for two reasons. Firstly, it sheds light on the unique risks associated with different levels of play, informing coaches, parents, and players about potential areas of concern and strategies for injury prevention within each subgroup. Secondly, understanding the disparities in injury rates can aid in the development of tailored training programs, protocols, and possible rule changes aimed at mitigating the injury risks within each group, thus enhancing the overall safety and longevity of athletes' careers (10).

2.2. Literature Review

2.2.1. Injuries in Volleyball

Volleyball is responsible for roughly 6% of all sport-related injuries among Canadian youth (7). Opanowska et al., found that 85.7% of 16-19 years old volleyball athletes experienced an injury over the course of a season (25-40 matches) when using self-reported survey data (16). This study found training was responsible for most injuries (70%) while competition was only responsible for 23% (16). While this study provides valuable prevalence data, relying on retrospective self-report data increases the likelihood of recall bias, particularly for minor injuries. Furthermore, injuries did not require medical verification.

Azuma et al., examined injury occurrence, type, site, exposure time, and injury rates per 1,000 player-hours over a two-year study period among high school boys' volleyball players (17). They determined that the injury rate was 1.51/1000 player-hours with trauma injuries accounting for 58.8% of all injury types (17). The strength of this study lies in its prospective design and use of exposure-based denominators; however, it included only boys. McGuine et al., studied girls' high school volleyball players and found that 22.5% of the players sustained an injury that required medical attention over a 1 year study period, resulting in an injury rate of 5.31/1000 athlete volleyball exposures as diagnosed by an athletic therapist (18). The proportion of injured girl players is remarkably lower than a self-reported injury study of boys' volleyball athletes of the same age over the same 12 month period, which found that 79% of boy players were injured (19). These discrepancies likely reflect differences in injury definitions, data collection methods (i.e., athletic therapist report versus self-administered questionnaire), and denominators used, underscoring how methodological choices can influence reported injury rates and limit direct comparisons across studies.

In a study analyzing injuries at the 2022 Volleyball Canada youth club National Championships among 1876 athletes surveyed, 35.8% reported a previous volleyball injury, defined as any physical concern that prompted medical attention (14). The injury rate was 6.8 injuries/1000 athlete exposures with an "athlete exposure" representing any player participation in a game or practice. This study also found that 14U players (players aged 14 and under) exhibited a higher injury rate than 18U players (players aged 18 and under) (incidence rate ratio [IRR] = 2.57; 95% CI: 1.11-5.98) (14). This large sample size strengthens the generalizability of findings within the Canadian context, though reliance on a single event and retrospective recall may limit accuracy. Moreover, athletes with prior injuries may have been more likely to recall or report them, introducing potential reporting bias. However, an American study compared women's NCAA volleyball athletes and girls' high school volleyball athletes and the injury rate among university athletes was 3 times higher than high school athletes (IRR = 3.3; 95% CI: 3.0-3.6) (10). This study benefits from multi-level comparison, however, variability in surveillance methods between NCAA and high school cohorts complicates direct comparison. Together, these findings highlight how differences in study design, surveillance methods, and athlete populations can yield markedly different injury rates, emphasizing the need for cautious interpretation when comparing results across levels of play.

A 2023 systematic review of 5 studies investigating youth (ages 12-18 years old) volleyball injury found that the injury incidence rate ranged from 1.2 to 5.3 injuries/1000 athlete exposures (2). Limitations included variations in data collection methods and follow-up periods across studies. Specifically, this review highlighted heterogeneity in study quality, definitions, and surveillance periods, which limited their analysis. While systematic reviews may offer the strongest level of evidence (20), the small number of included studies and their methodological variability limit the certainty of conclusions.

Overall, the injury rate ranged from 1.2 to 6.8/1000 athlete exposures, with a 1 year injury prevalence between 22.5% and 85.7% in volleyball populations aged 12-19 (2,14,16,18). Such wide variation reflects inconsistent use of injury definitions (time-loss, medical attention, self-report), data capture methods (prospective surveillance, retrospective recall), and exposure metrics (player-hours, athlete-exposures). Without standardized definitions and surveillance approaches, such as those recommended by the International Olympic Committee consensus statements as utilized in this study, it is difficult to identify the true burden of youth volleyball injuries.

2.2.2. Types of Injuries in Volleyball

Volleyball injuries vary in the body part injured, type of injury, and severity of the injury. According to Augustsson, 62% of injuries were minor injuries, which were defined as an absence of no more than one week (21). This aligns with Haupenthal et al., who found that 57% of the injuries resulted in less than 7 days of absence (3). Both studies used time-loss as the defining criterion, which risks underestimating the true burden of minor injuries that do not prevent athletes from continuing to train or compete.

Relatively minor injuries to the upper and lower limbs are the most common among volleyball athletes ages 14-19 years old. Among high school and youth club athletes (ages 14-19 years old), the most common injuries were to the ankle (28% to 31%), specifically sprains (25%

to 40%) (7,14,18). While ankle injuries are consistently reported across studies, reliance on medical attention or time-loss definitions may underestimate less severe sprains, highlighting that methodological differences influence how ankle injuries are characterized rather than whether they are a leading injury in youth volleyball. Obana et al., highlighted that the finger (43.0%), wrist (22.8%), and shoulder (12.2%) injuries were the most commonly injured body locations among youth volleyball players (<18 years old) recorded in their administrative data (22). Finally, joint dislocations were common, with 93.3% of participants (ages 16-19) reporting a joint dislocation at some point in their career (16). This high prevalence likely reflects both recall bias and the broad injury definition used in the study.

In university athlete populations, knee injuries were the most common (19.5%) among women's NCAA athletes (23). This agrees with De Azevedo Sodre Silva et al.'s systemic review findings of lower extremities being the most common amongst elite players (2). However, lower back injuries are also common: 4.89 injuries/10,000 athlete exposures (24).

In summary, the most common type of injury to youth volleyball players was to the ankle (31%), followed by knee, and wrist or hand. Of these injuries, joint sprain or strain injuries were the most cited injury type (40%) (7,18), particularly among youth players (22). However, the USPORTS and elite level athletes exhibit a different pattern, with knee injuries being most frequent and highlighting the potential of lower back injuries (23,24). This difference may reflect variations in athlete strength, jumping load, and level of play, but may also reflect differing injury definitions and surveillance rigor between youth and university cohorts. Future research should seek to understand injury prevention strategies tailored to both different levels of play and specific body parts or types of injuries.

2.2.3. Injury Mechanism in Volleyball

Injuries can occur through many mechanisms, such as player contact, surface contact, ball contact, no contact, or overuse (25). Identifying the most frequent injury mechanisms is essential for developing interventions. Interestingly, although volleyball is a non-contact sport, Baugh et al., found that player contact was the most common mechanism of injury for women's NCAA volleyball (24.9%) while ball contact was highest for men's NCAA volleyball (35.5%) (26). This is likely due to differences in the playing styles of women's versus men's volleyball with ball speeds being higher in men's volleyball (26). The second most common mechanism of injury was non-contact injuries in women's (23.3%) and a tie between non-contact and player contact for men's (both 22.6%) (26). However, surface contact injuries were also common (college, 42.0%; high school, 65.8%) (10).

When comparing contact versus non-contact injuries, the results vary by age and league. For example, Sole et al., found that non-contact injuries (79.7%) were more common than contact injuries (20.3%) among NCAA Division I women's volleyball athletes (23). However, Knobloch et al., and Vanderlei at al. observed direct contact as the main cause of injury (49.2%), specifically ball contact (59%), amongst high school athletes (27,28). These discrepancies may stem from methodological variations: Sole et al., used a prospective surveillance design with certified athletic trainers, while Knobloch et al., relied on retrospective questionnaires.

Bere et al., found that 23% of injuries were classified as contact injuries in their survey of FIVB players, followed by overuse injuries (20.7%) (29). Of overuse injuries, knee injuries were the most common (15%) (29). Women exhibited a higher overall injury rate than men (IRR = 1.51; 95% CI: 1.19-1.90) (26). Of the contact injuries, the majority occurred close to the net, in positions 2, 3, and 4 (see Appendix A, Figure 2). Of these contact injuries, 47.4% of ankle injuries resulted from contact with another player, specifically due to a blocker landing on the foot of an opponent or their own teammate (29). Additional studies found that play along the net was the most dangerous, as 54% of injuries were related to blocking at the net and 30% due to spiking at the net amongst elite adult volleyball players (15,21). Furthermore, single leg landings after spiking close to the net were the most common cause of anterior cruciate ligament injury, particularly among women when injuring the knee opposite to their dominant hand (30,31).

In conclusion, volleyball injuries manifest through diverse mechanisms, including player, ball, and non-contact incidents, alongside overuse injuries (25). Interestingly, player contact was responsible for a significant proportion of injuries despite volleyball being a non-contact sport (26). The literature on volleyball injuries is marked by considerable variability, with differences in study design, athlete populations, and operational definitions of injury complicating direct comparison. For example, elite-level studies often have stronger methodological rigor, such as prospective injury tracking at international tournaments; however, their findings may not generalize to youth or recreational levels where contact patterns differ. Without consistent approaches, findings may be difficult to reconcile, reinforcing the value of adopting standardized definitions, such as those proposed in the International Olympic Committee's consensus statements, to enable more reliable synthesis of evidence.

2.2.4. Injury Risk Factors in Volleyball

2.2.4.1. *Intrinsic Risk Factors*

Research including high school aged volleyball players has identified intrinsic risk factors (18). Vanderlei et al., found that previous injury and specific strength imbalances were risk factors for ankle sprains and acute knee injuries as 50% of injured athletes suffered a repeat injury in the 12 months post injury (28). Additionally, when interviewing 522 Brazilian high school volleyball players, Vanderlei et al., determined that increased age, weight, height, body mass index, and training duration were all associated with higher rates of injury (28).

De Azevedo Sodre Silva et al.'s systematic review also found that an athlete's increasing age, tall stature, and increased body mass index can increase one's risk of injury (2). For example, athletes older than 23 years of age had a higher frequency of injuries than younger players, with middle blockers over 23 years old reporting the highest frequency of injuries (3).

2.2.4.2. *Extrinsic Risk Factors*

Higher injury risk is associated with certain player positions (3,25). For example, Haupenthal et al., found that elite middle blockers, a position that requires the athlete to spend the majority of their time at the net to block both sides from position 2 to position 4 (Figure 2), experienced the highest rate of injury (50%), followed by outside hitters (25%), opposite hitters (14%), and setters (11%) (3). Baugh et al., also found that in NCAA men's and women's volleyball, competition injury rates were higher than practice injury rates (IRR = 1.75; 95% CI: 1.08- 2.85) (26). However, there was no difference in injury rates between preseason and regular season competition, indicating that the intensity of gameplay may not influence injury risk among NCAA athletes (26).

In summary, research including high school-aged volleyball players underscores the multifaceted nature of both the intrinsic and extrinsic injury risk factors. While efforts have been made to identify and address these factors, including technique evaluation and preseason strength training, there are inherent differences in risk for each player and position, suggesting a more nuanced approach is needed.

2.2.5. Concussions in Volleyball

Despite the non-contact nature of volleyball, concussions are a concern and can potentially have serious neurological consequences (14,32). As stated previously, serving speeds can exceed

120 kilometers per hour, making ball-to-head contacts a significant mechanisms for concussions (8). Understanding the risk factors for concussions is vital for protecting athletes' health.

Based on annual surveys of 92,966 Alberta high school athletes over six years, girls' volleyball ranked 7th in number of concussions per year (prevalence of 3.5%) and boys' volleyball ranked 14th (prevalence of 0.99%) (9). However, this study relied on self-reported survey data, which may underestimate concussion incidence due to recall bias or nondisclosure. More concerning, Vaandering et al., found that concussions were the second most common injury (25.7%) at the 2018 Volleyball Canada National Championships (ages 14U to 18U) (14). While this study benefits from prospective data collection in a national tournament setting, the relatively short competition period and selective sample of high-level athletes may inflate incidence compared to typical season-long exposure. Among Canadian adolescent volleyball players, the one-year cumulative concussion incidence was 7.1 concussions per 100 athletes per year (95% CI: 4.3 to 11.4) for males and 7.5 (95% CI: 5.4 to 10.3) for females, with over half of the concussions involving ball-to-head contact (95% CI: 46.2 to 67.5), with the majority occurring in practice or training scenarios (61.6%) (32). When surveying youth and university volleyball athletes, Reeser et al., found concussions were 3.4 times more likely in NCAA athletes versus the high school athletes (10). Concussions were most likely to occur due to a ball-to-head incidents (56.0%) and playing defense (60.9%), regardless of age group (10). Because this was a cross-sectional survey, it cannot determine causality, and NCAA–high school comparisons may be confounded by differences in training intensity, match exposure, and medical surveillance quality.

Chandran et al., examined the prevalence of concussions in NCAA women's volleyball (33). They found that concussions represented 7.3% of injuries, of which 60.5% were the direct result of a ball-to-head contact (33). In a similar study Baugh et al., found that concussion represented a higher proportion of all injuries in men's NCAA volleyball (19.4%) compared to women (14.8%) (26). Even though concussions are less common than some other injuries, they were the most common injury that resulted in time loss in men's NCAA volleyball and second in women's NCAA volleyball (26). Both NCAA-based studies included detailed injury surveillance systems, but the findings may not translate to youth or recreational settings where diagnostic support and medical staff are lacking. Similarly in younger age groups, according to Meeuwisse et al.'s 2017 study of 663 Volleyball Canada athletes, 57.1% of all concussions were a direct result of ball-to-head contact, followed by with player contact (20.2%) (21). Concussions occurred most commonly while blocking, followed by digging (26). Additionally, 61.6% of concussions occurred outside of competitive game play: 46.5% occurred during practice and 15.1% during warm up (15.1%) (32).

Overall, concussions are a significant concern, particularly among female athletes and in noncompetitive settings. Attention must be paid to preventive measures during practices and warm-ups (32). Moreover, the disparity in concussion risk between NCAA men's and women's volleyball highlights the necessity for sex-specific concussion prevention strategies (26,33). A comprehensive approach that integrates risk identification, improved management protocols, and targeted educational efforts is crucial to safeguarding athlete well-being.

2.2.6. Existing Volleyball Injury Prevention Interventions

Injury prevention strategies are classified by the three Es of education, engineering, and enforcement (34). Education involves raising injury awareness, learning risk and protective factors, what to do if an injury is suspected and teaching proper techniques to reduce injury risk. Engineering focuses on designing safer environments, such as safer sports equipment.

Enforcement ensures adherence to safety rules and regulations. These strategies can be further categorized into active and passive approaches: active strategies require conscious effort and behavioral changes by individuals such as following training programs or rule changes, while passive strategies involve modifications that work without requiring active participation from athletes such as changes to the court and its surroundings (35). Together, these approaches highlight considerations on minimizing sports injuries and promoting a safer sporting experience.

2.2.6.1. *Warm-Up and Training Interventions*

Gouttebarge et al., attempted to understand the feasibility and uptake of 'VolleyVeilig', an intervention aimed at preventing musculoskeletal injuries in adult recreational volleyball players (36). The intervention, focusing on warm-up exercises, received positive feedback from players and coaches regarding its relevancy, suitability, and usability. Verhagen et al., then evaluated the effectiveness of VolleyVeilig and found a lower injury rate among players who participated in the program compared to those who did not (HR = 0.72; 95% CI: 0.39 to 1.33). The results were not statistically significant, however, only 44% of teams full adhered to the program (37).

Neuromuscular training (NMT) has proven to be an effective approach to prevent sports-related injuries (38). The overarching objective of NMT is to develop joint stability, proprioception, balance, mobility, and strength (39). This training regimen has been introduced into volleyball warm up routines and encompasses a diverse range techniques such as yoga, strength training, reaction time exercises, balance drills, and isometrics (38); however, it has yet to be evaluated in volleyball. Additional volleyball-specific training programs recommend including shoulder rotator cuff and scapular strength training to stabilize the shoulder joint to reduce overuse injuries due to hitting (15). Zarei et al., conducted a randomized controlled trial comparing regular training to shoulder stability exercises such as the "FIFA11+S" and found that shoulder stability increased in the intervention group compared to regular training group ($p=0.03$) (40).

In conclusion, few volleyball injury prevention programs have been developed, implemented, or evaluated. While tailored interventions such as NMT and sport-specific warm-up programs have shown promise in reducing injury risk in other sports, particularly for athletes with recurrent injuries, their effectiveness requires further evaluation (36).

2.2.6.2. *Equipment*

Volleyball does not require any additional equipment to participate other than one's jersey, shorts, socks, and court shoes. However, some athletes wear additional personal protective equipment aimed to prevent injury. For example, ankle and knee braces, knee pads, and finger taping are commonly used among athletes who have persistent injuries or wish to prevent injuries (41); however, they are not mandatory.

Ankle braces are commonly worn among those with and without previous ankle injuries (15,41), despite inconclusive evidence of effectiveness (42). While studies in soccer suggest up to a five-fold reduction in ankle injury incidence, studies conducted in volleyball report no significant difference in injury rates between braced and unbraced athletes over short periods of use (42,43). Further investigation is needed into the efficacy of ankle braces as a preventative measure against acute or repeat ankle injuries in volleyball athletes over a long period of time. Knee pads and knee braces are commonly used to reduce floor burns and knee knocks when diving along the floor, or to support the knee joint in those athletes who have chronic injuries (44). To date, knee braces have not been evaluated in volleyball (45). Finger taping, or "buddy taping," involves wrapping injured fingers together to provide stability and support (29).

However, there is little evidence to support a reduction in finger sprains or dislocations. Nonetheless, it is common among players aiming to maintain hand health and performance (46).

2.2.6.3. *Rule Modification*

Due to the high incidence of concussion in non-competitive volleyball settings compared to game play, the official rules of Volleyball Canada include a concussion policy and rule changes (47). In 2018, Volleyball Canada introduced a new rule which banned players from running under the net or to the opposite side of the court during warm up in an effort to decrease warm up related concussions from ball-to-head contacts (48). During gameplay, if a player experiences a head contact, a coach can request a concussion symptom check where a one-minute time out is called by the referee and not charged to the team to allow for the athlete to be briefly assessed before determining if a full substitution is required (47). If a substitution is required, one will be granted even if a legal substitution is not permitted. In this case, the athlete cannot return to the game until the set is finished. If a team has no substitute available, the athlete will be given a three-minute recovery period, at the end of which the player must either return to the match to continue play, or forfeit the match (47). Additionally, referees are encouraged to end the play if players are chasing a ball on their opponents side of the court after the second contact in scenarios where the ball cannot be played back and is judged as out the moment it crosses the net plane (47).

2.2.7. Video Analysis in Sports Injury Epidemiology

Video analysis is a novel tool that can be utilized in steps 1 and 2 of van Mechelen's sport injury prevention model or the TRIPP model to determine injury aetiology and mechanisms (49). It allows for researchers to review contacts and suspected injuries in a more accurate manner than live viewing and can ensure that multiple reviewers can code each event in an accurate manner. Video analysis has been used successfully to understand suspected injury and concussion incidence rates and injury mechanisms, and identify opportunities for injury prevention in several sports including rugby, hockey, and ringette (49–51). Using video footage, researchers can analyze games to quantify head contacts, body contacts, suspected injuries, and the events leading up to the incident in a cost effective and detailed manner (51).

Video analysis has many strengths. The simplicity of the video data collection process allows researchers to systematically quantify injuries or contact events to identify the aetiology and mechanisms of injury which allows policy makers to make informed, evidence-based decisions (51). Video analysis also allows for re-reviewing footage to ensure accuracy as well as the ability to include multiple reviewers or coders to ensure reliability (50). Furthermore, video analysis allows researchers to investigate multiple event characteristics relating to injury or non-injury events (50).

There are also limitations associated with video analysis. For example, access to video footage in youth or non-elite level sports can be challenging to obtain or must be filmed by the researcher. Additionally, video analysis can be time consuming when done rigorously and can include subjectivity surrounding the definition and identification of some variables, such as if the play was necessary or reasonable within the gameplay scenario (50). This can be mitigated by using precise definitions and relying on accurate inter-coder reliability methods to limit subjectivity. Finally, video analysis is unable to identify how intrinsic risk factors impact injury events which can lead to incidence-prevalence bias (50).

2.2.8. Limitations of Previous Research

While existing literature provides valuable insights into injury rates, injury profiles, and risk factors in volleyball, there remains a gap in understanding related mechanisms underlying injury occurrence, particularly concerning differences between youth and university levels of play. One of the main limitations identified in this literature review is that the populations are often limited to national or professional players, or NCAA university athletes (3,10,14) and may not be generalizable to younger players. There is minimal research conducted among Canadian youth volleyball players. The current study addresses this gap by identifying injury rates in ages 15U to 17U and comparing this to university athletes over the course of a full season.

van Mechelen et al., discussed the methodological challenges in injury surveillance and highlighted the importance of standardized data collection protocols for accurate injury reporting (11). Past injury epidemiology research uses a mix of proportions, prevalence and incidence rates (IRs) to report findings. Without standardized reporting of results, it makes it challenging for community leaders and volleyball athletes to understand and compare injury outcomes across studies. Additionally, it is necessary to understand how court and player location-based injury mechanisms vary and how this knowledge can inform targeted injury prevention strategies for all positions and areas of the court. For example, the higher injury rate observed along the net brings into question the safety of games that are played without the presence of a second referee, a practice common in youth tournament games. As stated, the second referee is responsible for calling infractions regarding centre line faults under the net, and without their presence, these calls may be missed. This could increase the risk of injury if athletes are more likely to commit centre line faults when a second referee is not present (47). However, this has not been studied.

Many previous studies may suffer from measurement bias as they have relied on self-reported injuries. In volleyball, many of the injuries are considered minor and athletes may not disclose an injury and continue to play (21). This could lead to unreported injuries. Video analysis allows researchers to overcome this limitation as the researcher can quantify all levels of body contact, head contact, and suspected injuries without the need for the athlete to report the injury. This may lead to the current study presenting a higher rate of contact or suspected injury than that of previously reported studies. However, video analysis can only identify contacts and suspected injury, not confirm causal outcomes. Observed associations may also be influenced by unmeasured confounding variables such as previous injury history (7,52), physical conditioning (2,3), training regimen (15,36,37,40), or playing position (3,25,29). This is a limitation of video analysis as it cannot assess causality unless linked to objective injury surveillance data or other covariate data. Similarly, video analysis cannot capture intrinsic risk factors (e.g., history of injury, musculoskeletal imbalances) or extrinsic factors (e.g., training load, competition schedule) that may influence injury risk (26). Additionally, under-reporting of injuries can occur in video analysis studies if the athlete does not show any immediate symptoms or if the contact or injury occurs off screen or is not visible due to camera angle or obstruction. Finally, selection bias may occur if the matches or teams analyzed are not representative of the broader volleyball population, and limited sample size or number of observed events will reduce statistical power to detect true differences between groups.

2.2.9. Summary

Volleyball, while perceived as relatively safe compared to collision sports, still poses significant injury risks, particularly among adolescent and youth players. Studies indicate varying injury rates ranging from 1.2 to 6.8 per 1000 athlete exposures, with lower extremity injuries being the most common (2,14); however, evidence suggests that the injury risk is greater than previously reported (7). Mechanisms of injury encompass player contact, ball contact, non-contact incidents, and overuse injuries, with research emphasizing the importance of targeted interventions to mitigate injury risk to specific body locations (25). Concussions remain a concern, especially among female athletes and in noncompetitive settings (32). Risk factors include intrinsic characteristics like previous injury history, physical attributes, and player positions and underscore the need for tailored injury prevention strategies (52). Training programs focusing on technical, proprioceptive, and neuromuscular training, along with interventions like shoulder strengthening exercises, highlight injury prevention efforts in volleyball, though further research is needed to assess their real-world effectiveness and feasibility across diverse player populations and positions (36). Further investigation should focus on refining injury prevention strategies tailored to specific player demographics and positions, while also considering the evolving dynamics of gameplay and training intensity. Research is needed to understand location-based injury mechanism differences and how this information may aid in targeted injury prevention strategies. By addressing existing gaps in the literature, the current study aims to enhance our understanding of volleyball-related injuries and provide insight into potential opportunities for injury prevention initiatives.

3. Chapter 3: Objectives, Research Questions, and Hypotheses

The primary objective of the current study is to determine the incidence rates of head contacts, body contacts, and non-contact suspected injuries among 1) male Winnipeg 15U-17U club, 2) female Winnipeg 15U-17U club, 3) men's CanadaWest USPORTS university, and 4) women's CanadaWest USPORTS university volleyball athletes and to compare these rates across sex and league categories in the 2023-2024 volleyball season. The secondary objectives are to: 1) understand the injury mechanism, including the events preceding the contact or suspected injury, the area of the court, the severity of the injury or contact, the body part(s) involved in the event, and player position associated with the contact or suspected injury; and, 2) determine the outcomes of head contacts, body contacts, and suspected injuries, including the intensity of the contact, if the contact was a suspected concussion, if the play was stopped by the referee, and if the rate of contact or level of intensity changes depending on season phase (regular season or playoff).

3.1. Research Questions and Hypotheses

Research Question 1: What are the incidence rates of head contacts, body contacts, and non-contact suspected injuries among male and female Winnipeg 15U-17U club and male and female Western Canadian university volleyball athletes in the 2023-2024 volleyball season and do the rates differ by league and sex categories?

Hypothesis 1: University male athletes participating in the 2023-2024 USPORTS volleyball season in Canada will experience a higher incidence rate of head contacts, body contacts, and non-contact suspected injuries compared to adolescent club male and female athletes (15U-17U) and university female athletes.

Research Question 2: What are the circumstances preceding head contacts, body contacts, and suspected injuries (i.e., contact mechanism, area of the court, player position, player action, body part involved in the contact or suspected injury) among Winnipeg 15U-17U club and Western Canadian university volleyball athletes in the 2023-2024 volleyball season?

Research Question 3: What are the outcomes of the head contacts, body contacts, and suspected injuries, including intensity of contacts, all suspected concussion or suspected injury outcomes, if the play was stopped due to a violation, and do these outcomes or rates change in regular season or playoff matches among Winnipeg 15U-17U club and Western Canadian university volleyball athletes in the 2023-2024 volleyball season?

Research questions 2 and 3 are exploratory in nature and are therefore not accompanied by hypotheses.

4. Chapter 4: Methods

4.1. Design and Participants

This is a cross-sectional study assessing eighteen regular season and two playoff games from USPORTS varsity and youth club volleyball settings for a total of 40 matches. Participants include male and female 15U, 16U, and 17U club players, as well as male and female CanadaWest USPORTS university volleyball athletes during one full volleyball season (2023-2024).

The USPORTS athletes consist of male and female athletes who play university volleyball at a university recognized by USPORTS. USPORTS is the national governing body for university level sports in Canada (53). The club volleyball age groups are male and female 15U, 16U, and 17U athletes who play club volleyball registered with Volleyball Canada (4). The age groups of 15U, 16U, and 17U were chosen to avoid potential age-based overlap between 18U athletes and young university athletes who are also 18 years of age. Excluding 18U athletes also avoids contamination between the two groups as athletes playing 18U are pursued by post-secondary schools and able to practice with post-secondary schools while being recruited. Club volleyball was chosen over high school volleyball as club volleyball more closely reflects the playing season, intensity, and skill of university volleyball therefore limiting game play mechanics as covariates.

The current study involved video analysis of volleyball matches, and as such, individual-level sex and gender information were not collected, and it is not possible to ascertain a person's gender identity through video observation alone. Therefore, categorization in the current study was based on the competition categories designated by the teams and leagues. Volleyball Canada encourages athletes to compete in alignment with their gender identity and in accordance with provincial sport regulations. The organization prohibits discrimination based on sexual orientation, gender identity, or gender expression, and supports inclusive participation for all athletes (54). Notably, Volleyball Canada uses the terms "male" and "female" to define all registered player populations within their annual report and because of this, the current study will use the same terms (4).

At the university level, six substitutions are available per set not including the libero. In youth club volleyball, unlimited substitutions may be permitted based on the tournament rules. The libero can be substituted in and out of the game at any time specifically for use in the back row defense. In both club and USPORTS volleyball, six athletes are allowed on the court per team. However, with the presence of the libero, seven athletes are listed on the game sheet as members of the active line up. Each team is allowed to dress 14-16 individuals per game depending on league rules.

4.2. Video Collection

Games were collected through video footage. Games were collected for university level USPORTS volleyball games by downloading video footage from Canada West TV (Visaic, San Diego, CA, USA). Canada West TV is the online video streaming service provider for the Canada West conference of USPORTS. Canada West TV livestreams all Canada West conference games and houses these games on their video-on-demand platform. This platform allows paid subscribers to access game clips or download full games. This downloading feature has been provided to the researchers with the expressed approval from the Canada West managing director (Appendix C).

Winnipeg club volleyball games are not filmed by a specific organization. Therefore, club volleyball games were filmed by the researcher to achieve high-quality recordings of consenting athletes and teams participating in the 2023-2024 club volleyball season (Appendix D). Measurement error was reduced by ensuring a consistent camera angle and framing. In cases where the coach, other team staff, or volunteers were already filming the games for their own purpose, the researcher provided them with filming instructions, and the videos were obtained by the researcher through secure file share software or unlisted link. Volleyball games were filmed from the base line or end of the court, five to six feet off the ground, with the full playing surface in frame.

4.3. Team Recruitment

The current study is part of the **S**urveillance in **H**igh Schools and Community Sport to **Red**uce **Concussions** and their Consequences in Canadian Youth (SHRed Concussions) Study (further described in section 4.8 Ethics). Eligible club volleyball teams were contacted through their club director or head coach. In the club volleyball age group, 15 teams were approached to join the study: 7 male teams and 8 female teams aged 15U-17U. The researcher then met with the team or shared study information virtually, and consent was gathered from parents and assent was obtained from the athletes. USPORTS game footage was accessed through the Canada West TV library which made all Canada West teams eligible for inclusion.

4.4. Game Selection

At the club level, 6 games were randomly selected from each eligible team's season schedule in the hope of obtaining a representative sample of games that are generalizable to the larger club volleyball population and to try to remove selection bias for specific venues, event types, or other unmeasured confounders. The researcher randomly selected 4 regular season games and 2 playoff games from each team's full season schedule to film.

Briefly, each club volleyball team's full season schedule was uploaded to Excel, with each tournament given a unique number identifier. Then, Excel's random number generator formula was used to identify which tournament the researcher would attend. This was done as a tournament game schedules are generally not released until days prior to the tournament. Once a tournament was selected and the game schedule was released, the researcher repeated the same process by assigning a number to each game and randomly selecting which games to film based on a random number generator formula.

Filming 4 regular season games and 2 playoff games from each team provided an excess of game footage and a subset was selected for training/validation purposes. After all game footage was collected, each video was given a unique number identifier, and the researcher randomly selected 9 regular season games and 1 playoff game from each sex to provide a total of 18 regular season games, and 2 playoff matches for the club volleyball group. Extra footage was stored in case of error such as lost footage, corrupted files, or poor-quality videos.

For the university age group, the researcher had access to the entirety of the Canada West division through Canada West TV. All games were given a unique number identifier, and games were randomly selected using Excel's random number generator to obtain 9 regular season matches and 1 playoff match for each sex for a total of 18 regular season games and 2 playoffs matches for the USPORTS age group.

In total, a minimum of 9 regular season games and 1 playoff game from each male and female club, and male and female USPORTS, were randomly selected for analysis. This provided 18 regular season games and 2 playoff games for each age group (club and USPORTS) for a total of 40 games (see Section 4.5 for sample size justification). Playoff games were included because these games may result in athletes playing more aggressively in high stakes games which may result in more contacts and/or injury. The proportion of 90% regular season and 10% playoff games was chosen because this is similar to a full season of play.

Games were selected instead of practice or training sessions for several methodological and practical reasons. First, obtaining ethics approval and consent was more feasible in game settings, as matches are public events that are often filmed for performance analysis or broadcast, reducing barriers to access and data collection. Second, analyzing games allowed for a more diverse sample, as multiple teams could be observed across different competitions without requiring direct entry into private training environments. Third, games provide the most ecologically valid representation of volleyball demands, with standardized structures (sets, points, rotations, and scoring systems) that ensure comparability across teams and levels of play. The competitive nature of matches also elicits higher-intensity actions, such as maximal jumping, blocking, and attacking, which may be less frequent or less representative in controlled practice drills. Finally, game play directly informs practice settings, as training environments are designed to rehearse and refine the mechanics and situations that occur during competition; however, the reverse may not hold true, as practice activities are not always generalizable to match play. Together, these factors make games the most appropriate setting for capturing injury events and understanding their underlying contexts.

4.5. Sample Size and Power

Because this is the first video analysis of volleyball contacts, a review of two randomly selected full university volleyball games was conducted to collect pilot data. In the two games, there were 8 head contacts, 39 body contacts, and 1 non-contact suspected injury between two teams throughout 141 minutes of gameplay or 2.35 hours. This resulted in 28.2 player-match hours when multiplied by the 12 athletes on the court for an average total of 14.1 match hours per game. This equates to a head contact rate of 28/100 player-match hours, a body contact rate of 138.29/100 player-match hours, and a non-contact suspected injury rate of 3.5/100 player-match hours among university players. Both games were 3 set matches and resulted in a conservative approach to the power calculations as any match that goes over 3 sets provided additional contacts, resulting in additional power (matches are generally played as a best of 5 sets, as described in Section 4.6.1.1).

It is hypothesized that university volleyball will have a higher rate of contacts than club volleyball based on evidence outlined in section 2.2.1 (9). Based on the pilot data collected, using a two-side alpha of 0.05, the current study has 80% power to detect a head contact rate of 28/100 player-match hours in USPORTS and 18.08/100 player-match hours in club volleyball, or, 90% power with a head contact rate of 16.67/100 active team minutes in club volleyball (as shown in Appendix A, Supplementary Table 1).

Additionally, the current study has 80% power to detect a body contact rate of 138.29/100 player-match hours in USPORTS and 66.85/100 player-match hours in club volleyball, or, 90% power with a body contact rate of 57.45/100 player-match hours in club volleyball. Finally, the current study has 80% power to detect a non-contact suspected injury rate of 3.5/100 player-match hours among USPORTS and 0.29/100 player-match hours in club volleyball, or, 89% power to detect 0 non-contact suspected injuries per 100 player-match hours in club volleyball.

No suspected concussions were identified during the pilot data collection. However, the literature review identified similar rates and proportions of concussion in youth volleyball and youth basketball (8). Therefore, basketball concussion rates from video analysis studies were used to extrapolate what proportion of head contacts might result in concussion in volleyball. Based on a survey of existing video analysis literature, the researchers found that in youth basketball gameplay, there were 29 suspected concussions per 902 head contacts (55). Assuming a similar proportion in volleyball, one would expect a suspected concussion rate of 0.11/100 player-match hours among youth athletes when compared to the pilot data on head contact rate as described above. Therefore, the current study has 80% power to detect 3.05 suspected concussions per 100 player-match hours in USPORTS volleyball or a difference of 2.94 suspected concussions per 100 player-match hours between the two groups.

4.6. Data Collection

Recorded video (club volleyball) or downloaded video from Canada West TV (USPORTS) was stored on a secure University of Manitoba server. It was then uploaded into Dartfish video analysis software (Dartfish, Fribourg, Switzerland). Games were analyzed using Dartfish software based on criteria used on previous video analysis studies in other sports (49). Dartfish allows researchers to tag singular or continuous events to identify event characteristics (50). Events of interest include head contacts, body contacts, or non-contact suspected injuries. Notably, non-contact suspected injuries (NCSI) are treated separately from all suspected injuries to account for overlap in categorization. For example, suspected injuries resulting from body contact are included under the body contact event descriptor, while NCSI only includes suspected injuries that do not include a body contact or head contact categories (e.g., a player running forward and rupturing their Achilles tendon). This approach ensures that events are not counted twice when comparing head contact, body contact, and non-contact suspected injuries in research questions 1. Total suspected injuries, including all mechanisms (i.e., BC, HC, NCSI), are evaluated in research question 2. Event descriptors and keywords are described in Supplementary Table 2 (Appendix A). The event descriptors were created based on previously published coding templates and were adapted based on review by experienced sports researchers, the SHRed Concussions Youth Advisory Committee, former players, coaches, and other community leaders in volleyball to achieve face validity (49,51,56). Briefly, previous coding templates from other video analysis studies of other sports were reviewed and adjusted to reflect volleyball. The revised coding templates where also reviewed by the SHRed Concussions Youth Advisory Committee, former players, coaches, and other community leaders in volleyball who were able to voice their concerns, comments, or suggestions until all parties accepted the final definitions provided in Section 4.6.1. To achieve face validity, these revisions were then brought to experienced sport injury researchers with significant experience in video analysis for the purposes of sports injury epidemiology. Final adjustments were made by the coding team during training to address items missed during the development of the coding dashboard. For example, the action type “screening” was added after coders observed multiple contacts during this action that did not fit into any existing action categories.

To code events of interest within the video, a coding dashboard with relevant categories and keywords was created and saved to Dartfish as described in Section 4.6.1 and further in Appendix A. Then, a video was uploaded into the software and viewed by the coders. Coders add event tags to notable events of the video. Coders can pause, rewind, slow down, or speed up the video to ensure rigor. When an event tag is applied to the video, that section of the video is saved as a clip that includes the 5 second before and the 5 seconds after the specific frame the tag has been applied to. Once an event tag is applied, the coders can add keywords to this clip, outlined in Supplementary Table 2, to provide further context. Upon error, tags or keywords can be deleted and changed. Dartfish sorts all tags and produces statistical information such as the frequency of each tag. The tags (and keywords) are then saved to the metadata embedded in the video file itself.

Location on the court was recorded using the standard volleyball court positions based on Figure 2 (i.e., position 1 (right back), position 2 (right front), position 3 (middle front), position 4 (left front), position 5 (left back), and position 6 (middle back)). Player positions were identified as described in Figure 1. Finally, total points played, rally length and the game length in seconds were recorded.

4.6.1. Coding Definitions

4.6.1.1. Volleyball

For the current study, volleyball was defined as indoor volleyball only and not beach volleyball. Indoor volleyball is a team sport played on a 9-meter by 18-meter court (47). Each court is separated into two 9 by 9-meter squares by a net that runs down the centre line of the court. The height of the net changes depending on the team's age and sex. In men's volleyball, the net height stands at 2.35 meters for 15U-16U athletes and 2.43 meters for those 17U and older (including university athletes). In women's volleyball, the net height stands at 2.20 meters for 15U athletes and 2.24 meters for those 16U and older (including university athletes) (47). Each side is represented by 6 athletes on the court for a total of 12 athletes on the court at any given time.

Gameplay, called a "rally," is initiated by serving the ball over the net into the opponent's court. Each team is allowed to use a total of 3 contacts to return the ball over the net to their opponent's area of the court in either an attempt to score a point, or to continue play (47). Play continues with teams returning the ball back and forth to each other until a point is scored. A point is scored if the ball touches the ground within the boundary of the court, the other team scores a point. One can also score a point if the opponent fails to return the ball over the net and into your court, if the opponent contacts the ball or the net illegally, or numerous other methods. Matches are broken down into smaller games called sets. The first team to reach 25 points and win by 2 more points wins the set. If one team reaches 25 points but is not leading by 2 points or more, (i.e., 25-24) the set will continue until one team wins by 2 points (e.g., 26-24).

In some tournament style games, capped scores are used to speed up gameplay (e.g., 30 points), in these cases regular play will continue until scores reach the previously established upon cap, in which case the "win by 2" rule no longer applies (e.g., 30-29 final score). In general, matches are determined through a best of 5 sets series where the first team to win the majority of sets in the series wins the match (i.e., in a best of 5 sets series, the first team to win 3 sets win the match). However, best of 3 sets matches are often used in tournament play to shorten the length of matches. If any series is tied and requires the final set, (i.e., if a best of 5 series is tied 2-2 after 4 sets and requires a tie-breaking 5th set) this tie-breaking 5th is played to 15 points instead of 25. Whoever wins this final set, by 2 points or more, wins the match (47). For example, a best of 5 sets match that needs all 5 sets could be represented with a final game score of 3-2 for team A, with individual set scores displayed as 25-23, 22-25, 26-24, 20-25, 15-12. In this case, team A won sets 1, 3, and 5, and team B won sets 2 and 4.

Volleyball games can be refereed by one to eight official referees. These include the first referee, second referee, challenge referee, reserve referee, and up to four line judges (47). The first referee stands on an elevated platform along the height of the volleyball net across from the scorer's table and is the head official of the match. The first referee has authority over all other referees and reserves the final say regarding all points, including the right to overrule fellow referees. The first referee is traditionally responsible for calling serving faults, faults above the net, and contact faults (47). The second referee stands on the ground at the base of the net next to the scorer's table and is responsible for timeouts, substitutions, faults under the net, net contact faults, and rotational faults. Challenge referees are used in scenarios that allow for coaches to challenge a call made by the head referee when applicable. Line judges are responsible for calling if the ball lands in or out on their designated sideline and/or baseline (47). While all eight referee positions may not be filled for every game, every volleyball game will have at least the first referee. In these cases, the first referee will adopt the responsibility of all other referees (47).

There are 5 positions in volleyball: setters, outsides, opposites, middle blockers, and liberos. Setters are responsible for passing or setting the ball to their teammates. The attacking players try to hit the ball onto the opponent's side of the court to score points. Attacking players can be broken down into three positions. "Outsides" (also called Left-sides) play on the left side of the court and are responsible for passing opponent serves, hitting, blocking, and defense. "Opposites" (also called Right-sides) play on the right side of the court and are responsible for hitting, blocking, and defense. "Middle blockers" (Middles) play in the middle of the court and are only responsible for hitting and blocking. All players rotate clockwise and will play in front and back row positions. Finally, the libero (adapted from the Italian word for "free") is a unique position as they are free to substitute in and out of the game between points without stopping play for a formal substitution. Liberos strictly play in the back row and are responsible for passing opponent serves and playing defense. In Canada, liberos are permitted for ages 16U and older. Additionally, liberos in Canada are not allowed to serve, so if the person they are substituting for is serving they must wait until their team loses the serve (loses the point) before coming onto the court to replace the serving player (47). When the time comes for a libero to rotate to the front row, they must be replaced by the player they originally substituted in for. Liberos are used defensively and can substitute in for any player on the court (47).

4.6.1.2. Body Contact

A body contact is defined as an intentional or unintentional contact to the trunk or extremities with another player or with the environment, or unintentional contact with the ball or the ground (celebratory contact such as high fives or pats on the back were not reported as a body contact) (56). Further definitions for contact, including ball, player, and environmental contacts are described in section 4.6.1.5.3.

4.6.1.3. Head Contact

A head contact is any contact to the head or face by another player, ball, equipment, or the ground (celebratory contact such as pats on the head were not reported as a head contact). Head contacts are separated into two different categories. "Head Contact 1" (HC1) is defined as a contact directly to the head from a player, ball, equipment, or the ground. "Head Contact 2" (HC2) is defined as a contact to the head as a result from a secondary mechanism, such as the player being knocked to the ground and their head contacts the ground (56).

4.6.1.4. Non-Contact Suspected Injury and Suspected Injury

Non-contact suspected injuries and suspected injuries were assessed using previously validated definitions of a suspected injury adapted from rugby adapted for the purpose of assessing contact or non-contact volleyball injuries: the player reacts with pain or discomfort without the presence of a contact, the player remained down for more than 10 seconds, the point was stopped by the referee for a player in distress, or the player received medical attention (51,57).

4.6.1.5. Category Descriptors and Keyword Definitions

4.6.1.5.1. *Suspected Concussion*

Suspected concussions were assessed using the International Consensus Definition of Video Protocol criteria: incoordination, uncontrolled fall, lying motionless, no protective action (floppy or tonic), dazed, slow to get up, clutching the head, disorientated, confusion, seizure, walking away disengaged, behaviour change, facial or head injury (58). Suspected concussions were identified as a binary variable.

4.6.1.5.2. *Head Contact, Body Contact, and Non-contact suspected injury Intensity Rating*

Head contacts, body contacts, and non-contact suspected injuries were rated in intensity from 1 to 3 (49,56).

1. Level 1 represents a minor inconsequential contact or non-contact suspected injury where the player or players were not affected by the event and the event did not result in a stoppage of play or their ability to execute their skill.
2. Level 2 represents an event where the player or play is visibly affected or disrupted by the contact or non-contact suspected injury but does not require removal of the player from the game (e.g., a collision causing the player to slow down or stop movement).
3. Level 3 represents an event where the player is unable to execute the play or skill due to the contact or non-contact suspected injury with evident consequence and/or the contact or non-contact suspected injury resulted in a stoppage in play and/or the athlete requires removal from the court and/or the need for first responders (e.g., player falls over with injury, the referee stops the play, and/or the athlete requires a substitution).

4.6.1.5.3. *Ball Contact, Player Contact, and Environmental Contact*

Since volleyball requires regular contact with both the ball, it is important to distinguish between purposeful, intentional ball contact that is a part of regular play, and ball contact that may lead to injury. For example, if a player anticipates contact and intentionally contacts the ball with their hands or arms using regular purposeful contact that is consistent with volleyball passing or defensive technique, this was not included as an event. However, if the player does not anticipate contact, or, if they player does not contact the ball with intentionality and proper form, or, if the contact occurs on a body part not typically used in regular play, such as contact with the head, face, chest, or trunk, this was noted as a relevant event. For example, if a player makes an intentional move to block the ball, but the ball collides with the top of their hand, rather than their palm or forearm, and dislocates the finger, this was coded as a "body contact" with the keyword identifier of "ball contact."

Volleyball is a sport that does not require contact between players. Therefore, player contact was used as a keyword to identify all instances where two active players, either on the same team or on opposite teams, contact each other, either intentionally (e.g., pushing someone out of the way) or unintentionally (e.g., a collision between two or more athletes while chasing a ball). Notably, celebratory contact such as high fives or pats on the back were not recorded.

Environmental contacts were defined as contacts between a player and an item in the playing environment such as the floor, net, stanchion, wall, table, bleachers, equipment, or any persons not actively participating in the volleyball match.

To ensure that all event types or injurious events would be categorized properly, non-contact injuries were included as a descriptor for this tag. This keyword was used to identify any injury where contact with another player, the ball, or the environment did not occur (e.g., jumping, landing, and rolling their ankle without contacting the ball, a player, or an environmental feature).

4.6.1.5.4. *Low-Risk and High-Risk Actions*

Low-risk actions are defined as actions that are typical, necessary, and reasonable within the gameplay scenario.

High-risk actions are defined as actions that are not deemed to be necessary or reasonable within the gameplay scenario and put themselves or other players at a higher risk for body contact, head contact, or injury. For example, running into the stands, jumping on top of another player, jumping into the net or into the opponent's court area, or staying on the ground for a prolonged period of time following a dive or fall.

4.6.2. Coder Training and Validation

Three coders, including the researcher and two student research assistants, with considerable experience and knowledge of volleyball (i.e., previous or current university athletes and/or coaches) independently watched the game footage and collected the data. Additionally, a fourth coder who is currently an athletic therapist for a post-secondary volleyball team was included.

Similar to previous studies, all coders were trained by and compared to a "gold-standard" through a series of strategies (51). The gold-standard coder was trained by other experts in video analysis both in-person and online using a similar approach used to establish reliability in this study (49–51,56,59,60). The gold-standard coder has 11 years of experience playing club and collegiate volleyball, with an additional 5 years of coaching experience in both club and university settings and was responsible for developing the coding template. First, coders were shown the definitions for each event and keyword and were then shown pre-selected event clips as examples. Then, coders tagged the events and keywords for the event with the gold-standard coder present to review their outcomes and make corrections. Finally, coders were given the same section of games and full game footage and asked to code the footage. Coders were assessed based on a "hit or miss" chart developed by previous video analysis researchers to identify percent agreement (57). This "hit or miss" chart was then used to measure inter-rater reliability. In this chart, agreement or disagreement was tracked and weighted. For example, if two coders agree that a contact is present, but disagree on the body location of the contact, this was weighted higher compared to a scenario where two coders disagree whether a contact is present at all. Coders proceeded to the data collection phase once they achieved a total percent agreement of 90%, a threshold used in previous research in place of kappa, as kappa can underestimate agreement when category distributions are unbalanced (61). During the data collection phase, if the coders did not agree, the anomalies were reviewed to come to consensus.

4.7. Data Analysis

4.7.1. Denominator Selection

Player-match hours are a calculation of the total time the match took, multiplied by 12 to represent the 12 individual athletes on the court to account for their person-time. "Player-match hours" is commonly used in sports injury epidemiology and will allow the results of this study to be compared to other sports injury and video analysis research (60). Head contacts, body contacts, and non-contact suspected injuries were reported predominantly using player-match hours.

A sensitivity analysis on denominator choice was performed to examine the effects of using player-rally hours, player-points played, and player-sets played as the denominator. Player-rally hours only include time when the ball is in play (i.e., between whistles). The rate per point played allowed the current study to account for differences in scores. Since volleyball is not a time-based sport, set times can change based on set scores. For example, a set score of 25-0 takes less time than a set score of 26-24 as only 25 points must be scored rather than 50. Lastly, the rate per set played directly translates to volleyball match scoring formats.

4.7.2. Research Question 1 Analysis

All data analyses were performed using STATA version 16.1 (College Station, Texas, USA). For all statistical tests, a two-sided alpha of .05 was used to determine statistical significance. In situations when 0 events were reported, a one-sided alpha of 0.025 was used to determine statistical significance. Incidence rates were used to report the rate of each event type described in section 4.6.1. (i.e., head contact, body contact, and non-contact suspected injury).

Poisson regression was used to estimate IRRs with 95% confidence intervals of head contacts, body contacts, and non-contact suspected injuries between each league category with adjustment for clustering by team and offset by player-match hours to determine if the incidence rates differ between club and CanadaWest athletes.

4.7.3. Research Question 2 Analysis

IRs were used to determine the rate of head contacts, body contacts, and suspected injuries across each contextual characteristic (e.g., position, action type, contact type, area of the court, body part). The same denominators were used as described above. Game events and keywords described in section 4.6.1 were reported as incidence rates.

4.7.4. Research Question 3 Analysis

IRRs were calculated to compare incidence rates for the three levels of contact intensity. A subgroup analyses were performed focusing specifically on head contact injuries and suspected concussions. Finally, regular season and playoff games were compared to understand whether game intensity impacts the rate of contact or injury events.

4.8. Ethics

The current thesis is a part of a larger study called SHRed Concussions. SHRed Concussions is a national longitudinal cohort study including school and community-based sport injuries and concussions specifically in high injury risk sports such as volleyball. Ethics approval for SHRed Concussions was obtained through the University of Calgary Conjoint Heath Research Ethics Board as well as the University of Manitoba's Bannatyne Health Research Ethics Board (Appendix E, HS22581[H2019:064]). Ethics amendments were filed with the University of Manitoba's Bannatyne Research Ethics Board to include all relevant information to the current study (i.e., addition of the thesis student, video collection) (HS22581 [H2019:064]) as well as full ethics approval for this thesis under the student's name (HS26674 [H2024:307]). Risks associated with involvement in the study posed no greater risk than participating in the athlete's sport of choice. All volleyball games are played in a public venue and are subject to regular attendance as well as photographed and video recorded by the public. However, stringent privacy and confidentiality measures were instituted, including anonymization of data and secure storage protocols on a dedicated server and on computers housed in locked areas. Consent and assent were collected from enrolled teams. Only one athlete per team must consent in order for match filming to occur. No participants were identified through the videos, and the videos were not stored with identifiable information. No personal health information was available at any time. All videos and video links were securely stored and viewed at the University of Manitoba on a password protected computer connected to the University of Manitoba's server system.

5. Chapter 5: Results

Results are organized according to the study's research questions, focusing on overall contact rates, differences by sex and league level, the circumstances surrounding contact events, and the intensity of contact. Where appropriate IRs (95% CIs), IRRs (95% CIs), and significance-values are reported to support group comparisons and identify patterns relevant to injury risk.

Of the 15 club volleyball teams contacted, 6 male and 5 female teams expressed interest, and 6 male teams and 3 female teams provided consent and were enrolled. At the USPORTS level, the Canada West division includes 14 women's teams and 13 men's teams. Since the researchers have access to the entire Canada West TV library, all teams were eligible for inclusion. The enrolled teams represented at least one team at each age group.

The total player-match hours across each sex and league category were found to be 96.20 player-match hours for club males, 109.80 for club females, 254.20 for USPORTS males, and 214.20 for USPORTS females. The mean time to complete a rally differed across sex and competition level. In male club volleyball, rallies averaged 7.74 seconds (±0.72), compared to 7.85 seconds (±0.42) in male USPORTS. Female rallies were longer, averaging 9.01 seconds (±0.83) at the club level and 9.26 seconds (±0.47) in USPORTS. Overall, player-rally hours totalled 38.14 in male club volleyball (accounting for only 39.64% of player-match hours), 28.76 in female club (26.20%), 46.36 in male USPORTS (18.24%), and 50.34 in female USPORTS (23.50%). Further information regarding the difference between player-match hours and player-rally hours and their impact on IR and IRR calculations can be found in Supplementary Table 3.

5.1. Research Question 1 Findings

Among female athletes, USPORTS participants experienced a lower rate of body contacts (IR = 203.55; 95% CI: 184.89-223.58) compared to club participants (IR = 274.13; 95% CI: 244.72-307.78) (Table 1). This difference was statistically significant (IRR = 0.74; 95% CI: 0.67-0.82, $p < 0.001$). While the head contact rate was 86% higher in USPORTS female athletes (IR = 18.67; 95% CI: 13.34-25.43) than club athletes (IR = 10.02; 95% CI: 5.02-17.98), the rates were not significantly different (IRR = 1.86; 95% CI: 0.89-3.89, $p = 0.100$). Only one non-contact suspected injury occurred among female club athletes and none in female USPORTS athletes.

Table 1. Body Contact, Head Contact, and Non-Contact Suspected Injury Incidence rates per 100 Player-Match Hours and IRRs by League among Female Athletes

Event Type	League	Events (n)	Exposure time (Match Hours)	IR (95%CI)	IRR (95%CI)	p-value
Body Contact	Club	301	109.8	274.13 (244.72, 307.78)	ref	
	USPORTS	436	214.2	203.55 (184.89, 223.58)	0.74 (0.67, 0.82)*	<0.001
Head Contact	Club	11	109.8	10.02 (5.02, 17.98)	ref	
	USPORTS	40	214.2	18.67 (13.34, 25.43)	1.86 (0.89, 3.89)	0.10
Non-Contact	Club	1	109.8	0.91 (0.02, 5.09)	ref	
Suspected Injury	USPORTS	0	214.2	0.00 (0.00, 1.72)	1.94e-08 (3.12e-09, 1.21e-07)*	<0.001

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

In male athletes, USPORTS athletes had a significantly lower rate of body contacts (IR = 324.94; 95% CI: 303.16-347.88) than club athletes (IR = 438.67; 95% CI: 397.81-482.59) (IRR = 0.74; 95% CI: 0.68-0.80, $p < 0.001$) as shown in Table 2. Head contact rate was lower in male USPORTS athletes (IR = 19.67; 95% CI: 14.60-25.93) versus male club athletes (IR = 32.22; 95% CI: 21.90-45.74) but this was not statistically significant (IRR = 0.61; 95% CI: 0.36-1.03, $p = 0.06$). No significant difference was found for non-contact suspected injury rates ($p = 0.708$).

Table 2. Body Contact, Head Contact, and Non-Contact Suspected Injury Incidence rates per 100 Player-Match Hours and IRRs by League among Male Athletes

Event Type	League	Events (n)	Exposure time (Match Hours)	IR (95%CI)	IRR (95%CI)	p-value
Body Contact	Club	422	96.2	438.67 (397.81, 482.59)	ref	
	USPORTS	826	254.2	324.94 (303.16, 347.88)	0.74 (0.68, 0.80)*	<0.001
Head Contact	Club	31	96.2	32.22 (21.90, 45.74)	ref	
	USPORTS	50	254.2	19.67 (14.60, 25.93)	0.61 (0.36, 1.03)	0.06
Non-Contact Suspected Injury	Club	1	96.2	1.04 (0.03, 5.79)	ref	
	USPORTS	4	254.2	1.57 (0.43, 4.03)	1.51 (0.17, 13.30)	0.71

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; $\alpha = 0.05$ (two-sided) or 0.025 (one-sided for 0 events)

Within club volleyball, male athletes demonstrated a significantly higher body contact rate (IR = 438.67; 95% CI: 397.81-482.59) compared to female athletes (IR = 274.13; 95% CI: 244.72-307.78), with an IRR of 1.60 (95% CI: 1.47-1.73, $p < 0.001$) as shown in Table 3. Head contact rates were also significantly higher in male club athletes than female club athletes (IRR: 3.21; 95% CI: 1.61-6.37, $p = 0.001$). There was no significant difference in non-contact suspected injury rates between sexes in club athletes (IRR = 1.14; 95% CI: 0.08-15.96, $p = 0.924$).

Table 3. Body Contact, Head Contact, and Non-Contact Suspected Injury Incidence rates per 100 Player-Match Hours and IRRs by Sex among Club Athletes

Event Type	Sex	Events (n)	Exposure time (Player-Match Hours)	IR (95%CI)	IRR (95%CI)	p-value
Body Contact	Female	301	109.8	274.13 (244.72, 307.78)	ref	
	Male	422	96.2	438.67 (397.81, 482.59)	1.60 (1.47, 1.73)*	<0.001
Head Contact	Female	11	109.8	10.02 (5.02, 17.98)	ref	
	Male	31	96.2	32.22 (21.90, 45.74)	3.21 (1.61, 6.37)*	<0.001
Non-Contact Suspected Injury	Female	1	109.8	0.91 (0.02, 5.09)	ref	
	Male	1	96.2	1.04 (0.03, 5.79)	1.14 (0.08, 15.96)	0.92

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

As described in Table 4, USPORTS male athletes had a significantly higher body contact rate (IR = 324.94; 95% CI: 303.16-347.88) compared to USPORT female athletes (IR = 203.55; 95% CI: 184.89-223.58), with an IRR of 1.60 (95% CI: 1.45-1.76, $p < 0.001$). No statistically significant difference was found in head contact rates between male and female university athletes (IRR = 1.05; 95% CI: 0.58-1.90, $p = 0.863$). All four non-contact suspected injuries at the university level were reported in male athletes.

Table 4. Body Contact, Head Contact, and Non-Contact Suspected Injury Incidence rates per 100 Player-Match Hours and IRRs by Sex Among USPORTS Athletes

Event Type	Sex	Events (n)	Exposure time (Player-Match Hours)	IR (95%CI)	IRR (95%CI)	p-value
Body Contact	Female	436	214.2	203.55 (184.89, 223.58)	ref	
	Male	826	254.2	324.94 (303.16, 347.88)	1.60 (1.45, 1.76)*	<0.001
Head Contact	Female	40	214.2	18.67 (13.34, 25.43)	ref	
	Male	50	254.2	19.67 (14.60, 25.93)	1.05 (0.58, 1.90)	0.86
Non-Contact Suspected Injury	Female	0	214.2	0.00 (0.00, 1.72)	ref	
	Male	4	254.2	1.57 (0.43, 4.03)	2.33e+07 (9.07e+06, 5.98e+07)*	<0.001

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; $\alpha = 0.05$ (two-sided) or 0.025 (one-sided for 0 events).

A supplementary table is included in Appendix A, which presents a comparison of incidence rates and incidence rate ratios using different exposure denominators (player-rally hours, player-match hours, player-points played, and player-sets played). While the choice of denominator had minimal impact on most comparisons, notable discrepancies were observed in specific subgroups, particularly among male athletes when comparing body contact rates across league levels (Supplementary Table 3).

5.2. Research Question 2 Findings

5.2.1. Body Contacts

The IRs for body contacts varied across multiple contextual variables (Table 5). Across player positions, liberos had the lowest IRs of body contacts, whereas all other positions had higher rates as indicated by the non-overlapping confidence intervals. Outsides (IR = 85.11; 95% CI: 78.29–92.37) and middle blockers (IR = 86.74; 95% CI: 79.86–94.07) recorded the highest IRs of body contacts, followed by setters and opposites. When comparing mechanisms of injury, ball contact (IR = 7.86; 95% CI: 5.89–10.28), environmental contact (IR = 19.28; 95% CI: 16.11–22.89), and non-contact injuries (IR = 0.00; 95% CI: 0.00–0.55) had the lowest IRs overall, whereas player-contact had the highest rate (IR = 267.20; 95% CI: 255.00–279.83). Body contact IRs were highest in the front-court zones (2, 3, and 4). Zone 2 had the highest IR (72.81; 95% CI: 66.51–79.54), followed by Zone 3 (52.79; 95% CI: 47.45–58.57) and Zone 4 (51.75; 95% CI: 46.46–57.47). Back-court zones (1, 6, and 5) had lower rates, and body contacts occurring beyond the immediate playing court (e.g., baselines and sidelines) were uncommon. Blocking (IR = 95.64; 95% CI: 88.40–103.31) and defensive actions (IR = 95.34; 95% CI: 88.12–103.01) were associated with the highest body contact IRs of all actions. The IRs for body contacts related to serve reception (IR = 30.55; 95% CI: 26.52–35.01) and attacking (IR = 17.50; 95% CI: 14.48–20.95) were low, while other actions such as serving, screening, and jousting accounted for relatively few body contacts. Finally, the distribution of body parts involved in body contact events showed that the Shoulder/Arm region had the highest IR (97.86; 95% CI: 90.53–105.62), followed by the Hand/Wrist (IR = 70.58; 95% CI: 64.38–77.22) and the Trunk/Stomach/TSpine/Ribs (IR = 56.49; 95% CI: 50.96–62.46). The highest IR in the lower-extremities were to the Lower Leg/Ankle/Foot region (IR = 34.10; 95% CI: 29.84–38.81). The IRs of body contacts to the Head/Neck, LSpine/Pelvis/Groin, and Knee were low.

Table 5. Incidence rates per 100 Player-Match Hours and IRRs for Contextual Categories for Body Contacts

Category	Variable	Events (n)	IR (95%CI)
Contact Type	Player Contact	1802	267.20 (255.00, 279.83)
	Ball Contact	53	7.86 (5.89, 10.28)
	Environmental Contact	130	19.28 (16.11, 22.89)
	Noncontact Injury	0	0.00 (0.00, 0.55)
Court Location	Zone 1	136	20.17 (16.92, 23.85)
	Zone 2	491	72.81 (66.51, 79.54)
	Zone 3	356	52.79 (47.45, 58.57)
	Zone 4	349	51.75 (46.46, 57.47)
	Zone 5	130	19.28 (16.11, 22.89)
	Zone 6	293	43.44 (38.61, 48.72)
	Sideline	153	22.69 (19.23, 26.58)
	Baseline	27	4.00 (2.64, 5.82)
	Opp. Sideline	13	1.93 (1.03, 3.30)
	Opp. Baseline	1	0.15 (3.75e-03, 0.83)
	Opp. Court	36	5.34 (3.74, 7.39)
Action	Blocking	691	95.64 (88.40, 103.31)
	Defense	698	95.34 (88.12, 103.01)
	Serve Receive	210	30.55 (26.52, 35.01)
	Attacking	135	17.50 (14.48, 20.95)
	Chase	171	24.32 (20.74, 28.34)
	Setting	143	20.91 (17.60, 24.66)
	Serving	1	0.15 (3.75e-03, 0.83)
	Free Ball	45	6.52 (4.74, 8.76)
	Joust	17	2.52 (1.47, 4.04)
	Screening	12	0.89 (0.33, 1.94)
Position	Outside	574	85.11 (78.29, 92.37)
	Middle	585	86.74 (79.86, 94.07)
	Setter	338	50.12 (44.92, 55.76)
	Opposite	271	40.18 (35.54, 45.26)
	Libero	217	32.18 (28.04, 36.75)
Body Part	Head/Neck	1	0.15 (3.75e-03, 0.83)
	Shoulder/Arm	660	97.86 (90.53, 105.62)
	Trunk/Stomach/TSpine/Ribs	381	56.49 (50.96, 62.46)
	Hand/Wrist	476	70.58 (64.38, 77.22)
	LSpine/Pelvis/Groin	55	8.16 (6.14, 10.62)
	Hips/Thighs	124	18.39 (15.29, 21.92)
	Knee	58	8.60 (6.53, 11.11)
	LowerLeg/Ankle/Foot	230	34.10 (29.84, 38.81)

*$\alpha = 0.05$ (two-sided) or 0.025 (one-sided for 0 events).

5.2.2. Head Contacts

The IRs for head contacts varied across multiple contextual variables (Table 6). Middle blockers (IR = 6.82; 95% CI: 4.99–9.10) and outsides (IR = 5.48; 95% CI: 3.86–7.56) had the highest incidence rates, followed by setters (IR = 3.11; 95% CI: 1.93–4.76), opposites (IR = 2.22; 95% CI: 1.24–3.67), and liberos (IR = 1.93; 95% CI: 1.03–3.30). When comparing contact mechanisms, ball contacts accounted for the majority of head contact events (IR = 16.16; 95% CI: 13.3–19.5). Player contact (IR = 1.78; 95% CI: 0.92–3.11) and environmental contact (IR = 1.63; 95% CI: 0.81–2.92) were less frequent. Court location analyses showed that front-court zones had the highest IRs, particularly Zone 3 (IR = 5.34; 95% CI: 3.74–7.39) and Zone 2 (IR = 5.04; 95% CI: 3.49–7.05). Peripheral locations such as sidelines, baselines, and the opponent's court had few or no head contacts. Action-specific analyses indicated that defensive plays (IR = 8.16; 95% CI: 6.14–10.62) and blocking (IR = 6.23; 95% CI: 4.49–8.42) were associated with the highest head contact IRs. The IRs for attacking (IR = 2.37; 95% CI: 1.36–3.85), chasing (IR = 0.89; 95% CI: 0.33–1.94), screening (IR = 0.89; 95% CI: 0.33–1.94), and serve reception (IR = 0.59; 95% CI: 0.16–1.52) were lower, while setting, serving, free ball plays, and jousts demonstrated few or no head contacts.

Table 6. Incidence rates per 100 Player-Match Hours and IRRs for Contextual Categories for Head Contacts

Category	Variable	Events (n)	IR (95%CI)
Contact Type	Player Contact	12	1.78 (0.92, 3.11)
	Ball Contact	109	16.16 (13.3, 19.5)
	Environmental Contact	11	1.63 (0.81, 2.92)
	Noncontact Injury	0	0.00 (0.00, 0.55)
Court Location	Zone 1	11	1.63 (0.81, 2.92)
	Zone 2	34	5.04 (3.49, 7.05)
	Zone 3	36	5.34 (3.74, 7.39)
	Zone 4	23	3.41 (2.16, 5.12)
	Zone 5	10	1.48 (0.71, 2.73)
	Zone 6	15	2.22 (1.24, 3.67)
	Sideline	3	0.44 (0.09, 1.30)
	Baseline	0	0.00 (0.00, 0.55)
	Opp. Sideline	0	0.00 (0.00, 0.55)
	Opp. Baseline	0	0.00 (0.00, 0.55)
	Opp. Court	0	0.00 (0.00, 0.55)
Action	Blocking	42	6.23 (4.49, 8.42)
	Defense	55	8.16 (6.14, 10.62)
	Serve Receive	4	0.59 (0.16, 1.52)
	Attacking	16	2.37 (1.36, 3.85)
	Chase	6	0.89 (0.33, 1.94)
	Setting	2	0.3 (0.04, 1.07)
	Serving	0	0.00 (0.00, 0.55)
	Free Ball	1	0.15 (3.75e-03, 0.83)
	Joust	0	0.00 (0.00, 0.55)
	Screening	6	0.89 (0.33, 1.94)
Position	Outside	37	5.48 (3.86, 7.56)
	Middle	46	6.82 (4.99, 9.10)
	Setter	21	3.11 (1.93, 4.76)
	Opposite	15	2.22 (1.24, 3.67)
	Libero	13	1.93 (1.03, 3.30)

*$\alpha = 0.05$ (two-sided) or 0.025 (one-sided for 0 events).

5.2.3. Suspected Injuries

There were 18 video-suspected injuries across the leagues (Supplementary Table 4, Appendix A). Half of suspected injuries (50%) occurred during blocking actions and most (83%) occurred in front-court zones (zones 2, 3, and 4). Suspected injuries occurred most frequently to the lower leg (n = 8), followed by the head and neck (n = 4), and hand (n = 4). There were no suspected injuries to the trunk, pelvis, or knees. The IR for action type, contact type, court location, position, and body part for body contact, head contact, and suspected injury are presented in Figures 4-10.

5.2.4. Subgroup Analysis: Referee Presence and Missed Calls

A subgroup analysis by the number of referees on the court and missed calls was performed. Of the 20 club matches analyzed, 19 were officiated by only one referee, and 2 matches were officiated by community volunteers rather than certified volleyball referees. All USPORTS matches had a full complement of qualified Volleyball Canada referees present. Only two plays were stopped by a referee following a suspected injury event, both during male club matches. University volleyball had a significantly lower rate of missed calls compared to club volleyball (IRR = 0.29; 95% CI: 0.09-0.93, $p = 0.04$).

5.3. Research Question 3 Findings

Body contact events were predominantly of low intensity (84.4%). Moderate-intensity contacts made up 15.4% of body contact events, while high-intensity contacts were rare (0.2%). Moderate and high-intensity contacts were combined for analysis purposes. The risk of a moderate/high intensity body contact was significantly lower than a low intensity body contact (IRR = 0.20; 95% CI: 0.19-0.21, $p < 0.001$) (Table 7).

Head contact events followed a similar pattern, with 72.7% occurring at low intensity, 25.8% at moderate intensity, and 1.52% at high intensity. Compared to low intensity head contacts, the risk of moderate and high intensity contacts was significantly less (IRR = 0.40; 95% CI: 0.26-0.63, $p < 0.001$).

Non-contact suspected injuries were rare and 33.3% occurred at low intensity, 50.0% at moderate intensity, and 16.7% at high intensity. Compared to low intensity, the IRR for moderate and high intensity was 2.15 (95% CI: 0.39-12.0, $p = 0.38$) but not statistically significant.

Table 7. Intensity Level Outcomes by Event Type per 100 Player-Match Hours

Event Type	Intensity Level	Events (n)	Events (%)	IR (95%CI)	IRR (95%CI)	p-value
Body Contact	1	1676	84.4%	248.52 (236.81, 260.77)	ref	
	2-3	309	15.6%	45.82 (40.86, 51.23)	0.20 (0.19, 0.21)	<0.001
Head Contact	1	96	72.7%	14.23 (11.53, 17.39)	ref	
	2-3	36	27.3%	5.34 (3.74, 7.39)	0.40 (0.26, 0.63)	<0.001
Non-Contact	1	2	33.3%	0.30 (0.04, 1.70)	ref	
Suspected Injury	2-3	4	66.7%	0.59 (0.16, 1.52)	2.15 (0.39, 12.0)	0.38

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

5.3.1. Subgroup Analysis: Head Contacts, Suspected Concussions, and Suspected Injuries

Among all head contacts (n = 132, or 3.3 per match), suspected concussions were infrequent (Table 8). In the females' club group, one suspected concussion occurred due to a HC1-type event (direct ball-to-head contact) while playing defense in zone 6. In the males' club group, one suspected concussion occurred during a HC2-type contact (indirect contact to the head) in zone 3. Of the two suspected concussions, only one play was stopped by the referee. No suspected concussions were reported among university athletes. HC1-type contacts were more common than HC2 across all groups, particularly among university athletes. Suspected injuries were also rare and there was no difference by sex or league (Table 9).

Table 8. Subgroup Analysis: Head Contacts and Suspected Concussions

			HC Type (n)		Suspected Concussions (n)	
League	Sex	Total Head Contacts (n)	HC1	HC2	HC1	HC2
Club	Female	11	11	0	1	0
	Male	31	30	1	0	1
University	Female	40	40	0	0	0
	Male	50	49	1	0	0

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

Table 9. Subgroup – Total Suspected Injuries IR per 100 Player-Match Hours and IRR Stratified by League and Sex

League	Sex	Total SI (n)	IR (95%CI)	IRR (95%CI)	p-value
Club	Female	2	1.83 (0.22, 6.60)	ref	
	Male	6	6.24 (2.29, 13.58)	2.38 (0.51, 11.10)	0.27
University	Female	2	0.93 (0.11, 3.37)	ref	
	Male	8	3.15 (1.36, 6.20)	2.56 (0.52, 12.60)	0.25

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

5.3.2. Subgroup Analysis: Contact and Injury Rates by Season Phase

Body contact rates were consistent throughout the season, with no differences between regular season and playoff matches (IRR = 0.93; 95% CI: 0.73-1.17, $p = 0.523$) as shown in Table 10. Head contact rates were similar in playoff matches and the regular season (IRR = 1.07; 95% CI: 0.43-2.69, $p = 0.89$). There were no non-contact suspected injuries reported during the playoffs and six during the regular season.

Table 10. Contact and Injury Rates per 100 Player-Match Hours by Season Phase

Event Type	Phase	Events (n)	Exposure	IR (95%CI)	IRR (95%CI)	p-value
Body Contact	Regular Season	1827	616.5	296.36 (282.92, 310.26)	ref	
	Playoffs	158	57.6	274.28 (233.18, 320.54)	0.93 (0.73, 1.17)	0.52
Head Contact	Regular Season	120	616.5	19.47 (16.14, 23.28)	ref	
	Playoffs	12	57.6	20.83 (10.76, 36.39)	1.07 (0.43, 2.69)	0.89
Non-Contact Suspected Injury	Regular Season	6	616.5	0.97 (0.36, 2.12)	ref	
	Playoffs	0	57.6	0.00 (0.00, 6.40)	-	-

*Significance based on Poisson regression IRRs with 95% CIs, adjusted for team clustering; α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

6. Chapter 6: Discussion

The current study uniquely aimed to quantify incidence rates for head contacts, body contacts, and suspected injuries in male and female, adolescent club and university volleyball athletes using video analysis.

6.1. Research Question 1 Discussion

The first research question investigated whether incidence rates for body contacts, head contacts, and non-contact suspected injuries differed between four groups of players: list them. The hypothesis posited that male university athletes would experience higher rates of head contacts, body contacts, and non-contact suspected injuries compared to the other athletes.

In regard to the first statement in the hypothesis, the findings indicate that adolescent club athletes experienced a significantly higher rate of body contact events compared to USPORTS players. This trend was observed consistently across sex-stratified analyses, with both male and female club athletes demonstrating higher body contact rates compared to USPORTS athletes when using player-match hours as the denominator. Notably, adolescent club athletes displayed a 30% higher rate of body contacts compared to university athletes. Although body contacts were significantly more frequent among club athletes, no differences in head contact rates or non-contact suspected injury rates were found between leagues. Notably, head contact rate was 86% higher in USPORTS female athletes which may be clinically relevant, but this difference was not statistically significant. Among females, non-contact suspected injury rates were lower in USPORTS athletes compared to club athletes; however, this finding should be interpreted cautiously due to the low number of injuries.

Developmental and gameplay differences between club and USPORTS athletes may impact contact rates. This may be due to variations in training experience, spatial awareness, tactical discipline, or physical control between youth and university athletes. For example, club athletes may demonstrate less refined motor control or spatial awareness on the court due to inexperience which may contribute to more frequent contact (62). Additionally, in the club level, it is possible for athletes and coaches to change teams every year. This change in team composition could lead to an athlete changing positions, decreased awareness of the team's systems or structure, or less structured team systems overall, potentially increasing the likelihood of unintentional collisions and miscommunication between teammates during game play. Evidence suggests that university athletes have more advanced tactical and structural discipline and are able to train more and for longer periods under these same systems (10,24). Additionally, USPORTS athletes may have greater awareness of court positioning, and longer training histories in each position, which may help reduce body contact between teammates. However, the lack of significant difference in head contacts or non-contact suspected injury rates suggests that while contact may be more frequent in club settings, most contacts do not escalate to high intensity collisions, suspected injuries, or suspected concussions.

Differences in talent level within each league may also explain the findings. For example, in club volleyball, two players on the same team (or on opposite teams) may have vastly different playing experience or history which could lead to collisions or injury risk. Meanwhile, in USPORTS, it is expected that the athletes participating on the court will be more closely related in skill level or playing experience. These findings are consistent with prior sport injury research highlighting greater risk of physical contact and unanticipated events in youth sport due to developmental and cognitive immaturity in adolescent athletes (14,62). While volleyball is considered a non-contact sport, studies have noted the potential for incidental contact, particularly during blocks, dives, and congested net play (15,21,26,29). However, most existing literature has focused on reported injuries rather than video-observed contact events, making the current study a novel contribution. Importantly, previous epidemiological studies have found that injury risk generally increases with athlete age and competition level (3,10,28). However, our results do not show a significant difference in injury rates between USPORTS and club athletes, likely due to the low number of non-contact and total suspected injuries observed. Nonetheless, our findings suggest that overall contact frequency may decrease with age when player-match hours are used as the denominator.

In summary, body contact rates were significantly higher among both male and female club athletes compared to USPORTS athletes, when using player-match hours as the denominator. No statistically significant differences were observed in head contact rates between leagues. However, among female athletes, non-contact suspected injury rates were significantly higher in the club athletes. These findings highlight the need for age- and level-specific strategies aimed at reducing contact exposure and enhancing skill development, particularly during critical periods of physical and cognitive maturation in adolescent athletes ages 10-19 (62). While these player-match hour-based findings provide useful comparisons, the sensitivity analysis (section 6.5) suggests that denominator choice can meaningfully alter the interpretation of body contact risk between leagues. In particular, exposure metrics that capture only active play time, such as player-rally hours, indicate that the apparent lower contact rates in USPORTS athletes under match-hour calculations may reflect greater downtime rather than a true reduction in contact frequency. This change in interpretation shifts the result to agree with the original hypothesis, based on existing literature (10). This highlights the importance of considering sport-specific gameplay characteristics, such as rally duration, stoppages, and substitution patterns, when interpreting incidence rates, as different denominators may yield different conclusions about which group is truly at higher risk during active play.

The second half of this hypothesis predicted that male athletes would display a higher rate of body contacts, head contacts, and non-contact suspected injuries compared to female athletes within each league category. In club and USPORTS volleyball, male athletes displayed a 60% higher rate of body contacts compared to female athletes. While these findings support the hypothesis for body contacts, the results for head contacts and non-contact suspected injuries were less consistent across sexes. Notably, in club volleyball, male athletes experienced over three times the rate of head contacts compared to female athletes suggesting that sex-based differences in head contact exposure may be more pronounced at younger competitive levels. By contrast, no such difference was observed in the USPORTS population.

These findings may reflect differences in style of play, physicality, and strategy or decision making between male and female athletes. Previous research in volleyball has shown that male athletes are often more aggressive which can increase their exposure to contact (8,19). For example, faster ball speeds, higher net play, and increased physical size may lead to more frequent contact between male athletes during gameplay. Throughout the current study, the mean time to complete a point in male club volleyball was 7.74 seconds (+/-0.72 seconds) followed by 7.85 (+/-0.42) for male USPORTS, 9.01 (+/-0.83) for female club, and 9.26 (+/-0.47) for female USPORTS. Since the male volleyball sample displayed a shorter average time per point (7.80 +/-0.57) compared to the female sample (9.14 +/-0.65), this will impact the total exposure time. Despite this, males exhibited a higher number of contacts, suggesting that while rallies were shorter, the frequency of contact per rally was greater. The result highlights a notable difference in contact intensity between male and female athletes; if male players had rally durations equivalent to those observed in the female cohort, their total number of contacts would likely be even greater. The absence of significant differences in head contact, body contact, or non-contact suspected injury rates between the sexes among USPORTS athletes may reflect more refined anticipatory skills and situation-based reading ability among these older athletes. The fact that sex-based differences in head contacts were only significant in club settings may suggest that developmental factors such as lower situational awareness or anticipatory skills may disproportionately affect male club athletes as their gameplay is faster than their female peers with higher hitting velocities and higher net play (10,38,62).

Together, these findings support the need for sex-specific injury prevention strategies, particularly in males and in the club volleyball age group. Interventions focused on improving court communication, spatial awareness, and safe decision making may help reduce contact risk, especially among male youth athletes.

6.2. Research Question 2 Discussion

The second research question investigated the incidence rates for head contacts, body contacts, and suspected injuries across each contextual category such as events preceding the contact or suspected injury, the area of the court, the body part(s) involved in the event, and player position associated with the contact or suspected injury. Overall, the most common event occurred in the following scenario: a level 1 body contact between teammates to the shoulder-arm, to a Middle Blocker in zone 2 while blocking or playing defense.

For body contacts, contact rates varied by player position. Notably, outside hitters and middle blockers exhibited the highest rate of body contact events, likely reflecting their frequent involvement in net-front actions such as attacking and blocking which is similar to that found in the literature (3). Player contact accounted for most body contact events with rates substantially higher than those associated with ball contact, environmental contact, and non-contact mechanisms. This underscores the interpersonal nature of contact risk in volleyball and highlights the need for clear communication, spatial awareness, and structured play, particularly in congested net areas or actions such as blocking and defense. Body contacts varied by court location. Incidence rates were highest in the front-court zones (2, 3, and 4), corresponding to the zones most involved in blocking and attacking. In contrast, the peripheral areas of the court, including sidelines, baselines, and the opponent's side, contributed few events. This pattern underscores the concentration of contact exposure near the net, aligning with prior literature on volleyball-specific injury risk (15,21,29). In terms of game actions, blocking and defence carried the highest contact rates. This is expected, as blocking typically involves simultaneous vertical movement and close spacing between multiple front-row players, increasing collision potential. Defensive actions can be reactive and unpredictable, particularly during transitional phases when blockers and defenders move to create an attacking opportunity. Finally, the body regions involved in contact events further support the nature of these interactions. The shoulder-arm, hand-wrist, and trunk regions were most involved, consistent with the biomechanics of attacking and blocking. The head, spine, and lower extremities were rarely involved. Collectively, these findings point to predictable patterns of body contact risk in volleyball based on player role, court location, action type, and anatomical involvement. This information may guide targeted prevention strategies, such as position-specific training, net zone spacing, and technique refinement in blocking and defense to minimize collision risk without compromising performance.

Head contact incidence rates also varied across player positions, mechanisms, court locations, and actions, as indicated by non-overlapping confidence intervals. Middle blockers and outsides demonstrated the highest IRs, followed by setters, opposites, and liberos. This distribution reflects positional demands, as front-row players are frequently involved in offensive and blocking actions near the net, where above the net exposure and proximity to other players increase the likelihood of head contact. The elevated IRs associated with ball contacts further emphasize the importance of ball-to-head impacts as a primary mechanism of head contact events, aligning with prior research identifying ball contact as the most common source of head impacts in volleyball (10,32,39). In contrast, environmental and non-contact events were infrequent, suggesting that most head contacts result from direct gameplay interactions rather than incidental or uncontrolled movements. Spatially, the front-court zones (2, 3, and 4) exhibited highest rates of head contact. The most head contacts occurred from a ball contact to the middle blocker in Zone 2 while playing defense. This pattern is consistent with the positional findings and reflects the concentration of dynamic, high-speed actions such as blocking, attacking, and quick defensive transitions that occur near the net. Similarly, the elevated risk associated with defence and blocking actions supports previous observations that defensive actions leading to ball-to-head contact, as well as jumping and close quarters play contribute significantly to head contact risk (10,26,32,39).

Although suspected injuries were rare, their distribution mirrored that of head contacts. Player contact, blocking actions, and front-court locations were consistently implicated, with nearly all suspected injuries occurring in these settings. Taken together, these results highlight that head contacts and suspected injuries are concentrated in specific, predictable game contexts, with implications for targeted prevention strategies. Training interventions that emphasize safe blocking techniques, spatial awareness in front-court zones, and improved communication during congested plays may help reduce contact risk. For example, Volleyball Canada could integrate these findings into national coaching and athlete development frameworks by highlighting frontcourt contact risk as a teaching priority. This may include formalizing blocking and communication drills in the long-term athlete development pathway, reinforcing safe play principles during certification courses, and providing resources for clubs and universities to address frontcourt contact scenarios proactively. Embedding these strategies into coach education and player development would ensure that prevention measures are consistently applied across all competitive levels.

Additionally, club volleyball was further associated with missed calls which is concerning considering they are at higher risk for contacts and suspected injuries overall. Notably, club volleyball tournaments often do not utilize a full referee staff and may rely on unofficial referees for community tournaments, which may result in missed calls when using a larger dataset over the course of a full club season.

The current findings align with previous studies reporting that head and body contact events in volleyball most often occur at the net and involve defensive or blocking actions (21,26,29,44). Similar to prior research in youth volleyball, the current study observed that males are at greater risk of injury than females, particularly during high-intensity front court actions (18,19). The current study builds upon existing literature by identifying not just the frequency but the precise gameplay sequences leading to injury or contact. While previous injury surveillance works often lacked situational detail (28), the current findings highlight the injury risk by court location, player position, action type, body part involved, and rally characteristics, factors that have been underexplored in volleyball epidemiology. Further research into these areas may identify modifiable elements of the sport or athlete characteristics, enabling more targeted and sport-specific injury prevention strategies. Additionally, the elevated risk of contact associated with same-team player contacts echoes similar findings to those in the NCAA, where internal team collisions are a significant and preventable injury mechanism (26).

6.3. Research Question 3 Discussion

The third research question investigated the level of contact intensity of each contact or non-contact suspected injury, as well as subgroup analysis on head contact injuries, suspected concussions, total suspected injuries, missed calls, and season phase (regular season or playoff).

The analysis of contact intensity revealed that most of the body contacts and head contacts occurred at a low intensity (Level 1). Specifically, 84.4% of body contacts and 72.7% of head contacts were classified as low-intensity events, while high-intensity contacts were rare. These findings suggest that although physical contacts are present, the risk for significant injury resulting from these contacts is low. This is may reflect players' skill in anticipating, controlling, or mitigating contact, particularly at higher levels of play, or may indicate that volleyball's structure inherently limits opportunities for high-intensity impact, especially compared to collision sports like hockey or rugby.

When considering non-contact suspected injuries, half occurred at moderate intensity, 33% at low intensity, and just 17% at high intensity. Although high-intensity contacts could theoretically be more dangerous (51,55), the distribution of injury events across intensities suggests that not all injuries stem from high-force impacts. This could reflect contextual vulnerabilities, for example, a player not anticipating a ball-to-head impact, even at moderate speed, may still be injured due to lack of preparation or defensive posture. The significant IRR for high-intensity non-contact suspected injuries should be interpreted with caution given the very small number of cases, which introduces instability into the model and limits the validity of the estimates. These findings align with previous research indicating that volleyball is a low-contact sport with infrequent high-risk collisions (21). This is especially relevant for coaches and governing bodies, as it suggests that injury prevention efforts should not solely focus on preventing high-impact collisions but also address player readiness, court awareness, and protective strategies for more routine, moderate-intensity events.

The subgroup analysis of suspected concussions highlights the rarity of serious outcomes following head contact. Only two suspected concussions were recorded, both in the club athlete group, and only one led to referee stoppage. This suggests potential under-recognition of injury signs during gameplay and highlights the need for enhanced sideline protocols or referee training for identifying and responding to suspected concussions, particularly in youth settings.

Finally, the lack of significant variation in contact rates by season phase (regular season or playoff) indicates that intensity of play remains consistent between regular season and playoff matches, countering assumptions that post-season games may be more aggressive or dangerous. This agrees with previous literature from Baugh et al., and supports the notion that contact intensity in volleyball is more influenced by play style and positional dynamics than by competitive stakes (26).

6.4. Sensitivity Analysis

Additional exposure metrics including player-rally hours, player-points played, and player-sets played, were included to better represent athlete risk. For most comparisons, the choice of denominator had minimal impact on the results. However, discrepancies emerged in specific subgroups, particularly among males when comparing body contact rates by league. These discrepancies underscore the importance of denominator selection in sports injury epidemiology.

Notably, in section 5.1, some incidence rates shifted when changing the denominator. When comparing body contacts by league in the male population only, the IRR changes from

0.74 (95% CI: 0.68-0.80, $p < 0.001$) to 1.61 (95% CI: 1.49-1.75, $p < 0.001$), when switching from player-match hours to player-rally hours. This change in the direction of the effect is also observed when using player-points played (IRR = 1.21; 95% CI: 1.12-1.31, $p < 0.001$) or player-sets played (IRR = 1.22; 95% CI: 1.13-1.33, $p < 0.001$). This change did not occur in the female population, suggesting that combining USPORTS males and females into a single category may lead to a misinterpretation of true risk. Specifically, USPORTS males showed lower risk when using player-match hours but higher risk using other denominators, whereas USPORTS females demonstrated consistently lower incidence rates across all categories. This indicates that sex-specific analyses are important to accurately assess contact risk in volleyball, as aggregating male and female athletes may obscure meaningful differences.

This change in IR interpretation also highlights the impact of denominator selection on injury risk estimation. Player-rally hours better isolate active play time by excluding periods of inactivity (e.g., timeouts, substitutions, delays), potentially offering a more precise measure of risk during actual volleyball action. In contrast, player-match hours include all stoppages, which may dilute the perceived risk, particularly in high-level environments that may be subject to commercial breaks, increased timeout usage, inter-set entertainment, or other delays that are uncommon in club volleyball.

This change may also be due to the different amount of time required to start and finish a point in male versus female volleyball as discussed in section 6.2. As stated, the mean time to complete a point in male club volleyball was 7.74 seconds (+/-0.72 seconds) followed by 7.85 (+/-0.42) for male USPORTS, 9.01 (+/-0.83) for female club, and 9.26 (+/-0.47) for female USPORTS. These differences in rally duration help explain the shifts in IRR estimates when using player-rally hours versus player-match hours as the exposure denominator (Supplementary Table 3). Shorter rallies in male volleyball mean that player-rally hours comprise a smaller proportion of total player-match hours, particularly in male USPORTS athletes, where stoppages account for over 80% of total match time. Therefore, USPORT male matches contained proportionally less active play time than all other groups. Player-rally hours comprised only 18.24% of total player-match hours for USPORT men, compared to 39.64% for club males. This means that over 80% of USPORT men's match time is inactive. Thus, when player-match hours are used as the exposure metric, the high frequency of stoppages in USPORT play results in a lower body contact rate, despite the same or higher number of total events. When player-rally hours are used instead, the resulting IR is higher and may provide a better estimate of risk per unit of play, as downtime is excluded and the calculation reflects the true risk of sport participation rather than including extended rest periods when injuries are unlikely to occur.

These findings suggest that player-match hours may obscure important risk differences in fast-paced, high-stoppage environments like USPORT men's volleyball. The significant increase in body contact IR when using player-rally hours supports the argument that denominator choice can meaningfully affect epidemiological conclusions, particularly in comparisons between groups with different game tempos, substitution patterns, and time-management strategies. Given that denominator choice changes the interpretation of body contact risk between leagues, greater weight in this context should be placed on player-rally hour-based rates in the future, as they more accurately represent risk during active volleyball play and are less influenced by stoppage time. While player-match hours were chosen to align with existing sport epidemiology research, this analysis emphasizes that this may not always reflect true sport-specific exposure (60). These findings underscore the need to tailor exposure metrics to sport-specific contexts. Using only time-based denominators may misrepresent risk, especially in stop-start sports. Future research should consider standardized, play-specific exposure definitions to ensure meaningful cross-group comparisons and risk estimation.

6.5. Strengths and Limitations

6.5.1. Strengths

As previously described, video analysis within the context of sport-related research has many strengths (50). Specific to the current study, one strength was the use of multiple reviewers who underwent thorough training to decrease misclassification bias within the current study. Four reviewers, including the author, collegiate volleyball athletes, and an athletic therapist participated in video analysis training prior to data collection to ensure reliability within their findings. This multi-reviewer approach enhances the credibility of event classification and minimizes individual coder bias. Video analysis allows for these reviewers to watch and rewatch events multiple times and multiple speeds to gain an accurate image or the injury or contact event to ensure the most accurate information in being coded at all areas of the court simultaneously.

Selection bias was also minimized through a randomization. For both club and USPORTS groups, games were randomly selected at multiple stages, independent of opponent or match outcome. This ensured that filmed matches were representative of typical play and not influenced by game importance, team strength, or researcher preference.

Another strength of the current study is that the methods and proposal were reviewed by key members of the volleyball community including the SHRed Concussions Youth Advisory Committee, collegiate-level players and coaches, and Volleyball Canada personnel. The current study contributes to novel data in understudied athlete populations and allows for meaningful comparisons to be made for the development of prevention strategies at multiple levels. This approach ensured the study was relevant to the population it aims to serve and addresses real-world concerns, while maintaining practical and meaningful methods. By capturing real-world gameplay across competitive youth and university settings, the findings of the current study offer actionable insights for sport governing bodies, coaches, and medical professionals. The integration of injury, contact, and contextual variables makes the results highly applicable for informing safety protocols, education efforts, and future research.

Finally, the current study's methodology was informed by a body of existing literature regarding video-based injury surveillance in other team sports such as basketball, rugby, and hockey (49,50,55). By adapting these validated frameworks to the volleyball context, the current study maintains methodological consistency with previous research which adds to the rigor and comparability of the findings.

6.5.2. Limitations

The current study also has several limitations. One of the primary limitations of the current study was the video footage quality and camera angle. This bias is likely non-differential, as video quality did not vary systematically between groups. As a result, any misclassification would most likely bias the estimates toward the null, potentially underestimating true associations between contact events and suspected injuries. The camera angle was consistent for club matches, but the fixed position made it impossible to capture player actions that occurred off screen. For example, if a player is involved in an action that requires them to chase a ball into the stands or benches, this was likely not caught on camera and any contacts made in this area would be missed. This likely led to an underestimation of contact events outside of the main court area. In contrast, USPORTS video was obtained from multiple venues across the Canada West division with varying camera angle set ups. At times, this made it challenging to view contacts as the side angles commonly used for the main livestream limited the coder's view of contacts occurring along the net which may have also resulted in an underestimation of contact events in these court locations. However, replay footage and other camera angles were used while coding to ensure rigour.

A second limitation of this study is the lack of granularity in coding specific actions, body parts, and play styles in the analysis. For example, the action category of "defense" includes digging and transition, two distinct movements in volleyball. Similarly, body parts were grouped (e.g., Lower Leg / Ankle / Foot) to facilitate consistent coding and inter-rater reliability. While these groupings improved feasibility, they limited the ability to capture fine details. Future studies would benefit from distinguishing specific defensive actions, such as diving, digging, sprawling, and transitioning, to better identify the movements most associated with injury risk. However, it is important to consider that stratifying the sample into increasingly specific categories will reduce the number of events in each group, potentially limiting statistical power and making it more challenging to detect significant associations. Researchers may need to balance the level of detail with sufficient sample size or consider combining similar actions to maintain analytic stability.

Another inherent limitation to video analysis is the limited ability to accurately identify all suspected injuries or the potential underreporting of suspected injuries and suspected concussions (50). For example, some injuries may be subtle or delayed and therefore can be missed by video reviewers if not visually apparent or if they occurred outside the frame which could result in under reporting or misclassification. Additionally, video footage does not allow for player-level data collection regarding injury history, fatigue levels, playing experience, or other variables that may influence injury risk and may result in incidence-prevalence bias.

High-intensity contacts, suspected injuries, and suspected concussions were rare in this sample, leaving some analyses underpowered. While this is a positive outcome for volleyball athletes, this may have contributed to the wide confidence intervals and the ability to detect significant associations in certain subgroups. It is also important to note that many volleyball injuries occur outside of formal gameplay, such as during practice or training sessions (32). As a result, this study likely underestimates the true risk of contacts and injuries associated with overall volleyball participation.

Additionally, given the number of comparisons made, there is an increased risk of Type I error due to multiple testing, which may have led to some statistically significant findings occurring by chance. One approach to address this could have been the use of Bonferroni correction; however, Bonferroni has also been criticized for being overly punitive in some circumstances (63). In the context of injury surveillance, it may be preferable to prioritize minimizing Type II error because accepting a higher risk of false positives to ensure that potential injury mechanisms and outcomes are not missed (63).

Finally, the video analysis method may have led to under- or over-estimation of suspected injuries, depending on the visibility of the contact and the ability to accurately interpret injury mechanisms from video. This limitation could affect the generalizability of the findings to other volleyball populations. Additionally, unmeasured confounding factors, such as differences in athlete maturity, experience, or prior injury history, may also influence observed associations (28).

6.6. Implications for Practice and Policy

Volleyball Canada has introduced a number of rule changes in recent years to promote player safety (48). The findings from the current study suggest additional practical and policy-related opportunities to further promote player safety in club and university volleyball. The results can help guide injury prevention strategies to enhance athlete safety and inform educational initiatives. These insights can support coaches, sporting organizations, community members, medical staff, and policymakers in making informed decisions about athlete safety without compromising gameplay.

High-intensity contacts and suspected injuries were infrequent, as such, the data do not support the need for widespread rule changes aimed at limiting physical contact. However, education around current rules and policies may be important. For example, only one of the two suspected concussion events resulted in a referee-initiated stoppage which suggests a need for improved concussion recognition protocols among officials or rule changes regarding the reaction to head contacts. Regular training for referees on identifying signs of potential concussion and mandating a stoppage in play following a head impact may help ensure athlete safety.

Some elite sports such as the NFL employ a concussion spotter (64). These spotters, typically trained healthcare professionals, are responsible for observing gameplay specifically to identify signs of potential concussion or head trauma, particularly those that may be missed by on-court officials or coaching staff. As the findings of the current study show that concussion risk in volleyball may be minimal, it is likely not feasible to employ concussion spotters and highlights the need for further education about concussion signs and symptoms. At the club level, where busy court schedules and a high volume of games in a single day often limit access to medical personnel, it may be helpful to designate a parent or team staff member as a concussion or injury spotter. This approach aligns with Ontario's Rowan's Law, which recommends that sport organizations have a spotter present at all games and practices (65). In situations where a healthcare professional is not available, this individual should be trained to recognize visible signs of concussion and ensure that appropriate steps are taken to protect the athlete (66). Additionally, given the effectiveness of video analysis in identifying contact types and injury mechanisms in the current study, volleyball organizations may consider integrating video review into their educational initiatives. With proper consent and de-identification, real-game footage of injury events could be used to train athletes, coaches, parents, and referees on how to recognize high-risk scenarios and respond appropriately.

Furthermore, there were some instances in which athletes pursued balls onto the opposing team's side of the court in situations where this action was not permitted. According to volleyball rules, a player is allowed to cross the center line and attempt to recover a ball on the opponent's side only if the ball traveled there out of bounds. However, several observed cases involved the ball crossing the net in bounds, yet players still attempted to play it. This behavior introduces a significant risk of collision, as both teams may simultaneously and erroneously attempt to play the ball. While this scenario was not specifically measured and reported in this study, these incidents highlight a critical educational gap, emphasizing the need for improved athlete awareness of the rules governing ball recovery across the net.

Although volleyball is widely perceived as a safe, non-contact sport, the findings from the current study suggest that the frequency of physical contact, particularly head contacts, may be underestimated. On average, there were 3.3 head contacts per match. While most of these contacts were low in intensity and rarely resulted in injury, their presence underscores the need to reframe volleyball not as a non-contact sport, but as a sport with meaningful physical interactions that carry some risk. Recent literature has emphasized that even low-intensity, repetitive contacts may contribute to cumulative sub-concussive exposure, reinforcing the need to consider potential long-term implications even in sports traditionally regarded to be low-risk. (67). The rationale for suggesting a reconsideration of volleyball's designation is not to discourage participation, but to promote informed decision-making. By acknowledging the presence of physical contact, parents, athletes, and coaches can implement evidence-based safety strategies, encourage appropriate protective behaviors, and ensure early recognition and management of injury. Transparent communication about risk helps maintain trust, supports athlete health, and may ultimately sustain participation by minimizing preventable injuries. Educating athletes, coaches, and parents about the nature and frequency of contact events can help ensure that participants are fully informed, better prepared to recognize injury mechanisms, and more proactive in adopting safe playing behaviors. This type of education could be integrated into coaching certification, athlete development programs, and concussion protocols across both youth and university levels.

6.7. Implications for Future Research

The methods, analyses, and results of the current study highlight many future research opportunities. Specifically related to video analysis research, future sports injury surveillance studies should prioritize the development and use of sport-specific denominators to measure exposure. As demonstrated in this study, relying solely on traditional time-based denominators such as match hours may mask meaningful differences in injury risk, particularly in sports like volleyball with frequent stoppages and variable pacing. Incorporating more accurate, play-specific exposure measures, such as rally time or points played, will enhance the validity of sex and league comparisons and ensure more precise risk estimation.

Additionally, the methodology of future volleyball video analysis studies can be improved. First, improved camera angles that capture the entire gymnasium would enhance the ability to analyze chase scenarios and assess the environmental risks they may pose. Expanding the field of view would also increase statistical power by allowing for the inclusion of events that previously occurred off-screen. Future studies should consider using a multi-angle recording setup to facilitate accurate event tagging and ensure comprehensive capture of all relevant events, thereby improving detection accuracy and strengthening the reliability of coded outcomes.

Second, incorporating a larger sample of matches would beneficial. As this was the first study in this population, sample size calculations were based on pilot data. Ultimately, the study was underpowered for rare outcomes, such as suspected injury and suspected concussion. These events were infrequent, and meaningful comparisons by sex or league may require a substantially larger dataset. While collecting additional matches would involve greater logistical effort and resources, it would provide a more robust dataset that enhances the ability to identify low-frequency events and examine contextual risk factors for both contact and non-contact injuries. Expanding the sample would allow future studies to move beyond descriptive incidence rates and support the identification of modifiable injury risk factors, which can directly inform prevention strategies. Building on these results, future video analysis research in volleyball should include larger sample sizes to ensure sufficient statistical power to detect significant differences of infrequent outcomes.

Third, future research should link video-based findings to objective injury surveillance data, such as self-reported injury logs, medical staff reports, or wearable sensor data. Combining video-coded events with verified injury records would allow researchers to confirm whether high-risk scenarios observed on video result in injuries, improving the validity of associations between specific gameplay situations and injury occurrence. This integrated approach would also enable the development of more targeted prevention strategies by identifying both the biomechanical and contextual factors most strongly linked to real injury outcomes.

Fourth, future studies should evaluate the effectiveness of coaching strategies in club volleyball, particularly as they relate to injury prevention. The clustering of contacts in specific court zones and positions highlights the importance of examining individual risk factors in more detail. The higher rate of body contacts among club athletes suggests a need to improve younger players' spatial awareness and technical skills. Tailored education, especially for defenders and backcourt players, may help promote safer play by emphasizing anticipation and strategies to avoid high-speed impacts. Further research should also explore how player roles, ready position, and tactical elements like defensive setup influence injury risk.

Fifth, continued investment in warm-up routines and training interventions should also be considered. Implementing targeted training modules (e.g., neuromuscular training) and development programs that focus on footwork, positioning, and communication could reduce unnecessary collisions and reduce body contacts (38,39). Investigating the impact of these programs and routines on reducing contact and injury rates using randomized controlled trials or other experimental designs could be beneficial to evaluate the effectiveness of these interventions and will help validate these prevention strategies within the context of volleyball.

Sixth, future research should explore the knowledge and understanding of Volleyball Canada coaches and referees regarding concussion-specific rules, such as the use of concussion timeouts and substitution protocols. Investigating their awareness and application of these safety measures could help determine whether current policies are effectively reducing head contact incidents and injury risk. Additionally, studies evaluating the quality and reach of existing education on head injury prevention would help clarify whether these initiatives are sufficient or require enhancement. This line of inquiry could include assessing the efficacy of current strategies before widespread implementation or suggesting the development of evidence-based interventions aimed at improving safety in the sport.

Seventh, while our study did not directly assess the effect of net height on head contacts, future research could explore whether increasing net height at elite levels might reduce head exposure during blocking and defensive play. Currently, the standard net height reaches its maximum once athletes enter the 17U age category, meaning that both older adolescent and USPORT-level athletes compete on the same net height. This uniformity does not account for the considerable differences in physical maturity, jump height, and ball velocity seen at higher levels of play. Investigating the potential impact of net height on head contacts could inform primary prevention strategies in this demographic.

Eighth, future research could examine the use of wearable sensors or other biomechanical analyses to further understand the forces present to better understand why some contacts lead to injury while others do not. Such research could inform the development or continued use of protective equipment or adoption of technique modifications in certain movements.

Finally, the use of artificial intelligence (AI) or automated video processing systems, paired with the use of wearables, may be beneficial in providing real-time feedback on player contacts and potential risk management, as well as speeding up the process of video analysis while adding more individual level data. AI is already being used in the volleyball environment through the use of video tools, such as Balltime (68). Balltime is an AI-powered volleyball performance analysis platform that uses video footage to automatically track player movement, ball trajectory, and key in-game statistics that are typically labor-intensive to obtain through manual coding (68). Given its ability to detect player positioning, movement patterns, and ball velocity, Balltime has potential for adaptation in injury surveillance. By integrating injury-related tagging, Balltime, or other AI video analysis software tools, could be leveraged to identify high-risk scenarios, monitor exposure to contact, and support data-driven injury prevention strategies. Specifically, these insights could allow coaches, medical staff, and sport scientists to pinpoint when and where risky situations occur most frequently, tailor training to mitigate these scenarios, and monitor whether implemented changes effectively reduce injury incidence over time. With further development, these platforms could serve as a valuable tool for both researchers and sport organizations aiming to enhance athlete safety through automated, scalable video analysis, allowing AI to streamline this process.

6.8. Integrated Knowledge Translation

The current thesis was developed in partnership with the SHRed Concussions Youth Advisory Committee and other members of the volleyball community in Canada including current and former athletes, coaches, organizers, and community leaders from youth club, university, and elite level age groups. The proposal for this master's thesis was also reviewed by members of Volleyball Canada to ensure the results of the current study would be relevant to community leaders and policy makers in volleyball.

To date, the preliminary results of the current study have been published in the Journal of Head Trauma and have been shared at the 5th Annual Meeting of the Canadian Concussion Network (CCN-RCC) (69). Results will also be shared with key community leaders in volleyball such as provincial and national sporting organizations. The results of this study may be most useful to program directors and coaches in youth or USPORTS volleyball as they seek to understand and manage injury risk. Based on these findings, coaches and organizers can structure practices to minimize high-risk plays and may place greater emphasis on developing athletes' spatial awareness, defensive and blocking technique, or on court communication.

7. Chapter 7: Conclusion

This study provides the first comprehensive analysis of contact-related events and video-suspected injuries in Canadian youth and university volleyball. Club athletes and male players experienced significantly higher rates of body contacts, with male club athletes also showing elevated head contact rates. Body contact event rates were significantly higher among male club-level athletes compared to the other three groups when using player-match hours as the denominator, with middle blockers and outside hitters exhibiting the highest incidence rate of body contacts and head contacts, particularly during blocking actions in front court zones. While head contacts were less frequent, they occurred most often to due ball contact and in front court zones. Suspected injuries and concussions were rare. University athletes exhibited lower rates of body contacts and missed calls, suggesting a safer competitive environment than club volleyball. Most contacts were low-intensity and did not result in injury in either league or sex. Notably, the choice of denominator was shown to have a substantial impact on outcome interpretation. These findings highlight important contextual and demographic risk factors and underscore the need for targeted prevention strategies tailored to player position, sex, and level of competition. While contact exposure varies by sex and league, volleyball is largely a safe sport with relatively low rates of serious injury. These results support continued participation and suggest that with appropriate education and injury prevention efforts, more children and youth should be encouraged to play volleyball and enjoy its many physical, social, and developmental benefits.

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9. Appendices

9.1. Appendix A: Tables, and Figures

Supplementary Table 1. Power Calculations

Event	*Expected Rate: USPORTS (per 100 player-match hours)	Detectable Rate: Club (per 100 player-match hours)	Power (%)
Head Contact	28.0	18.08	80%
		16.67	90%
Body Contact	138.3	66.85	80%
		57.45	90%
Non-Contact Suspected Injury	3.5	0.29	80%
		0.00	90%
Suspected Concussion	3.05	0.11	80%

*Rates based on pilot data (2 USPORTS matches); power calculated using α = 0.05 (2-sided).

Supplementary Table 2. Outcome Measures; Event, Category, and Keyword Descriptions

Event Type	Event	Descriptor
Event Type	Body Contact (event) Head Contact (event) Non-Contact Suspected Injury (event)	Definitions provided in sections 4.6.1.2, 4.6.1.3, 4.6.1.4
Category	**Keyword**	
Number Of Players Involved in Contact	1 2 3+	
Players 1/2/3 Position	Outside / Left side Opposite / Right side Setter Middle Blocker Libero	Definitions provided in section 4.6.1.1
Player 1/2/3 Action	Attacking Blocking Defense Serve Receive Serving Setting Free Ball	What action was the athlete of interest performing at the time of the head contact, body contact, or suspected injury?

	Jousting Chase Screening	
Player 1/2/3 Level	Level 1 Level 2 Level 3	Definitions provided in section 4.6.1.5.2
Player 1/2/3 HC Type	HC1 HC2	Definitions provided in section 4.6.1.3
Player 1/2/3 Suspected Concussion	Yes No	Definition provided in section 4.6.1.5.1
Player 1/2/3 Suspected Injury	Yes No	Definition provided in section 4.6.1.4
Player 1/2/3 Contact Type	Ball Contact Player Contact Environmental Contact Non-Contact Injury	Definition provided in section 4.6.1.5.3
Player 1/2/3 Court Location	Zone 1 Zone 2 Zone 3 Zone 4 Zone 5 Zone 6 Sideline Baseline Opponent Court Opponent Sideline Opponent Baseline	Court locations are further described in Figure 2. In scenarios where the event occurs on the edge of two zones, the zone that most of the contact occurs in was selected. If the coders are not able to determine a majority placement, the zone the players are moving into was selected.
Player 1/2/3 Contact or Injury Location	Head / Neck Shoulder / Arm Wrist / Hand Stomach / T Spine / Ribs L Spine / Pelvis Hip / Thigh Knee Lower Leg / Ankle / Foot	
Player 1/2/3 Removed from Play	Yes No	Was the player removed from play directly following the head contact, body contact, or non-contact suspected injury?
Player Who Instigated Contact	Player 1 Player 2 Player 3 Opposite Team	

Intentionality	Incidental Deliberate	Was the head contact, body contact, or non-contact suspected injury the result of a deliberate, intentional action (i.e., did the player stick their hand out to contact or push another player [deliberate/intentional contact] or was there a collision with avoiding action [incidental contact])?
Player 1/2/3 Risk Action	Low Risk Action High Risk Action	Definition provided in section 4.6.1.5.4
Are The Players Involved in the Event on the Same Team?	Yes No	
Number of Possession Changes in the Rally	0 1-3 3+	
Missed Call?	Yes No	Did the referee miss a call that could have directly or indirectly led to the head contact, body contact, or non-contact suspected injury?
Did the Referee stop the play?	Yes No	Did the referee stop the play directly following the head contact, body contact, or non-contact suspected injury?
Ball on court?	Yes No	Was there a ball present on the court that should not have been there (common in tournaments or open gym atmospheres)?

9.1.1.1. *Supplementary Tables*

Supplementary Table 3. Sensitivity Analysis: Rate Based Denominator Comparison

Group	Event	Denominator (per 100)	USPORTS IR	Club IR	IRR (95% CI)	p-value
Male	**Body Contact**	player-match hours	324.94 (303.16, 347.88)	438.67 (397.81, 482.59)	0.74 (0.68, 0.80)	<0.001
		player-rally hours	1781.62 (1662.22, 1907.38)	1106.49 (1003.43, 1217.27)	1.61 (1.48, 1.75)	<0.001
		player-sets played	172.08 (160.55, 184.23)	140.67 (127.56, 154.75)	1.22 (1.13, 1.33)	<0.001
		player-points played	3.88 (3.62, 4.15)	3.20 (2.90, 3.52)	1.21 (1.12, 1.31)	<0.001
Female	**Body Contact**	match hours	203.55 (184.89, 223.58)	274.90 (244.72, 307.78)	0.74 (0.67, 0.82)	<0.001
		rally hours	866.14 (786.74, 951.38)	1071.74 (954.07, 1199.91)	0.81 (0.73, 0.89)	<0.001
		sets played	98.20 (89.20, 107.86)	114.33 (101.78, 128.01)	0.86 (0.78, 0.95)	<0.01
		points played	2.24 (2.03, 2.46)	2.64 (2.35, 2.96)	0.85 (0.77, 0.94)	<0.01

Supplementary Table 4. Incidence rates per 100 Player-Match Hours and IRRs for Contextual Categories Surrounding Suspected Injuries

Category	Variable	Events (n)	IR (95%CI)
Contact Type	Player Contact	7	1.04 (0.42, 2.14)
	Ball Contact	5	0.74 (0.24, 1.73)
	Environmental Contact	2	0.30 (3.59e-02, 1.07)
	Noncontact Injury	4	0.59 (0.16, 1.52)
Court Location	Zone 1	0	0.00 (0.00, 0.55)
	Zone 2	6	0.89 (0.33, 1.94)
	Zone 3	1	0.15 (3.8e-09, 0.83)
	Zone 4	8	1.19 (0.51, 2.34)
	Zone 5	0	0.00 (0.0, 0.55)
	Zone 6	1	0.15 (3.8e-09, 0.83)

	Sideline	1	0.15 (3.8e-09, 0.83)
	Baseline	1	0.15 (3.8e-09, 0.83)
	Opp. Sideline	0	0.00 (0.0, 0.55)
	Opp. Baseline	0	0.00 (0.0, 0.55)
	Opp. Court	0	0.00 (0.0, 0.55)
Action	Blocking	9	1.33 (0.61, 2.53)
	Defense	2	0.30 (3.59e-02, 1.07)
	Serve Receive	0	0.00 (0.00, 0.55)
	Attacking	5	0.74 (0.2, 1.7)
	Chase	2	0.30 (3.59e-02, 1.07)
	Setting	0	0.00 (0.0, 0.55)
	Serving	0	0.00 (0.0, 0.55)
	Free Ball	0	0.00 (0.0, 0.55)
	Joust	0	0.00 (0.0, 0.55)
	Screening	0	0.00 (0.0, 0.55)
Position	Outside	4	0.59 (0.16, 1.52)
	Middle	4	0.59 (0.16, 1.52)
	Setter	4	0.59 (0.16, 1.52)
	Opposite	5	0.74 (0.24, 1.73)
	Libero	1	0.15 (3.8e-03, 0.83)
Body Part	Head/Neck	4	0.59 (0.16, 1.52)
	Shoulder/Arm	1	0.15 (3.8e-03, 0.83)
	Trunk/Stomach/TSpine/Ribs	0	0.00 (0.00, 0.55)
	Hand/Wrist	4	0.59 (0.16, 1.52)
	LSpine/Pelvis/Groin	0	0.00 (0.00, 0.55)
	Hips/Thighs	1	0.15 (3.8e-03, 0.83)
	Knee	0	0.00 (0.00, 0.55)
	LowerLeg/Ankle/Foot	8	1.19 (0.51, 2.34)

*α = 0.05 (two-sided) or 0.025 (one-sided for 0 events).

9.1.1.2. *Figures*

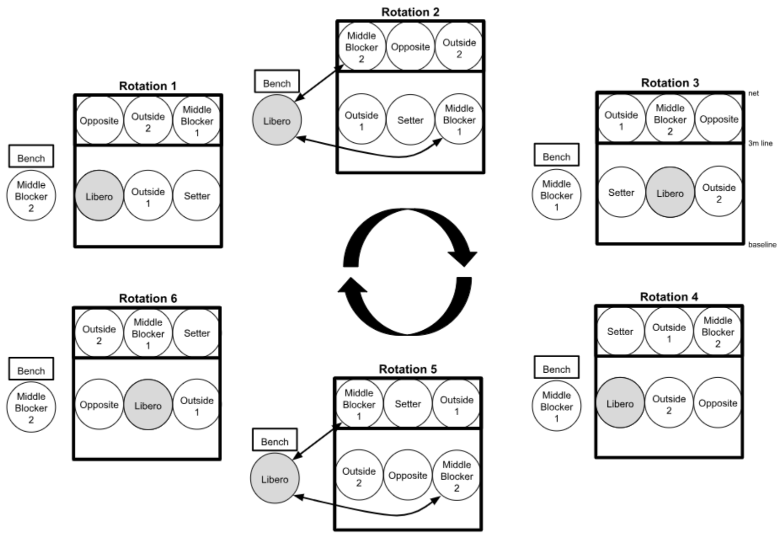

Figure 1. Court Rotations

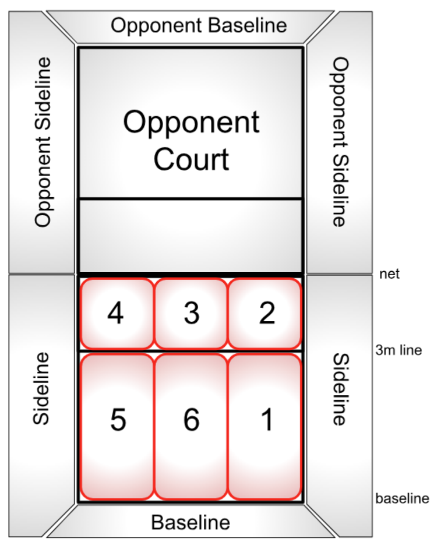

Figure 2. Court Positions

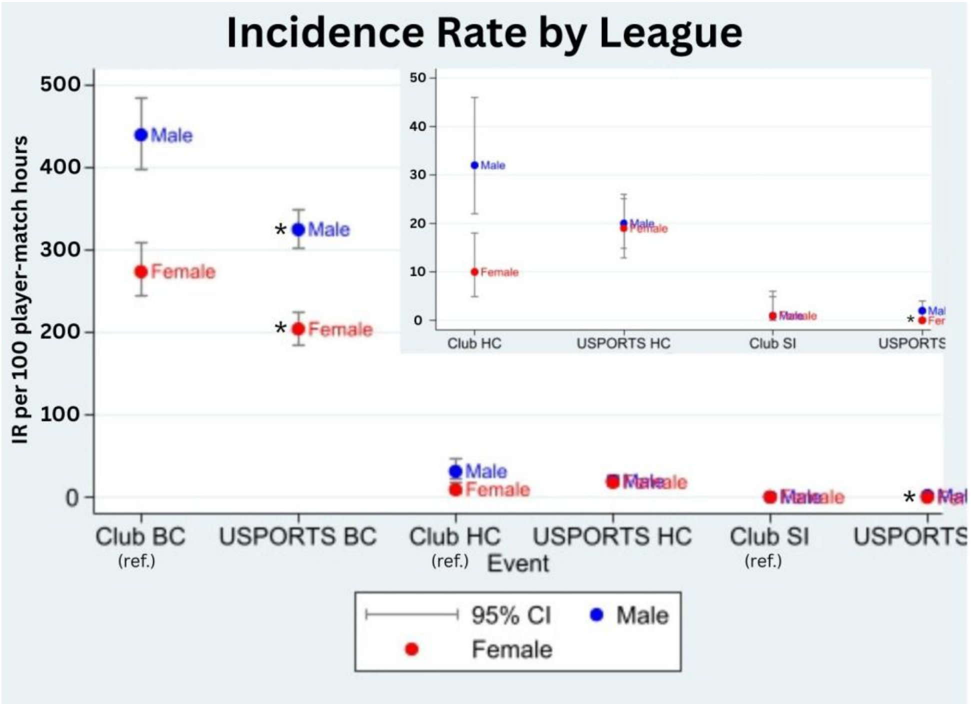

Figure 3. Incidence Rates for Body Contacts, Head Contacts, and Non-Contact Suspected Injuries by League

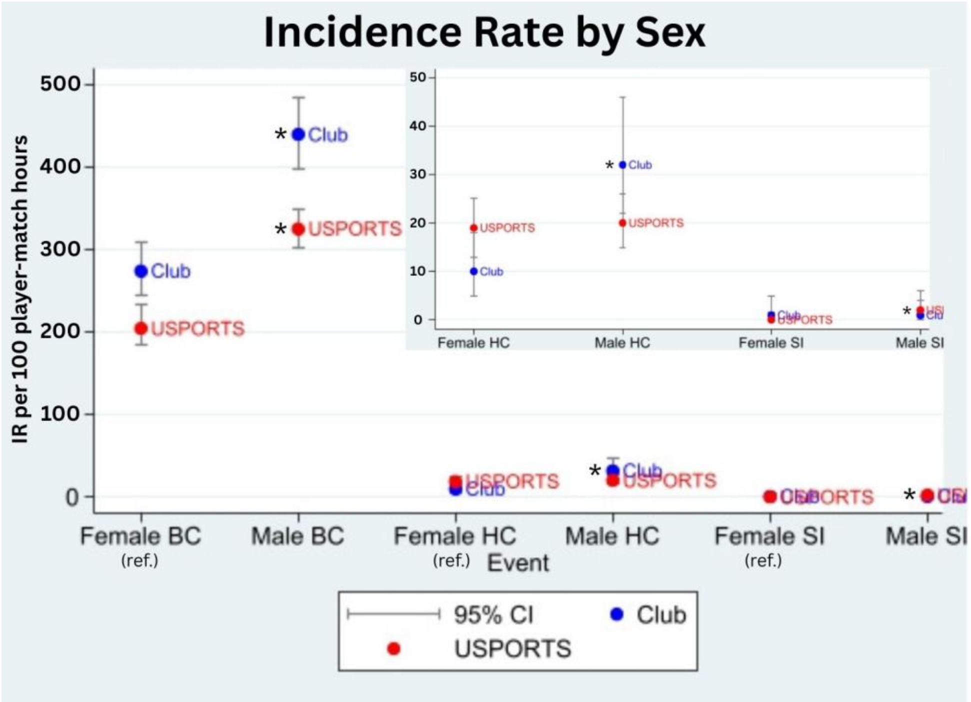

Figure 4. Incidence Rates for Body Contacts, Head Contacts, and Non-Contact Suspected Injuries by Sex

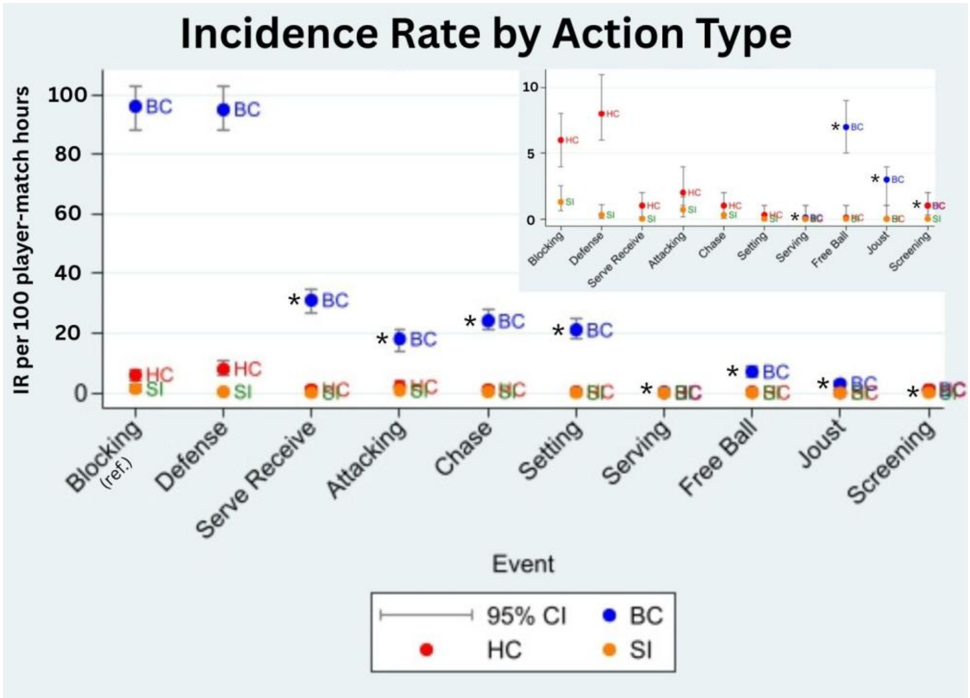

Figure 5. Incidence Rates of Body Contacts, Head Contacts, and Suspected Injuries by Action Type

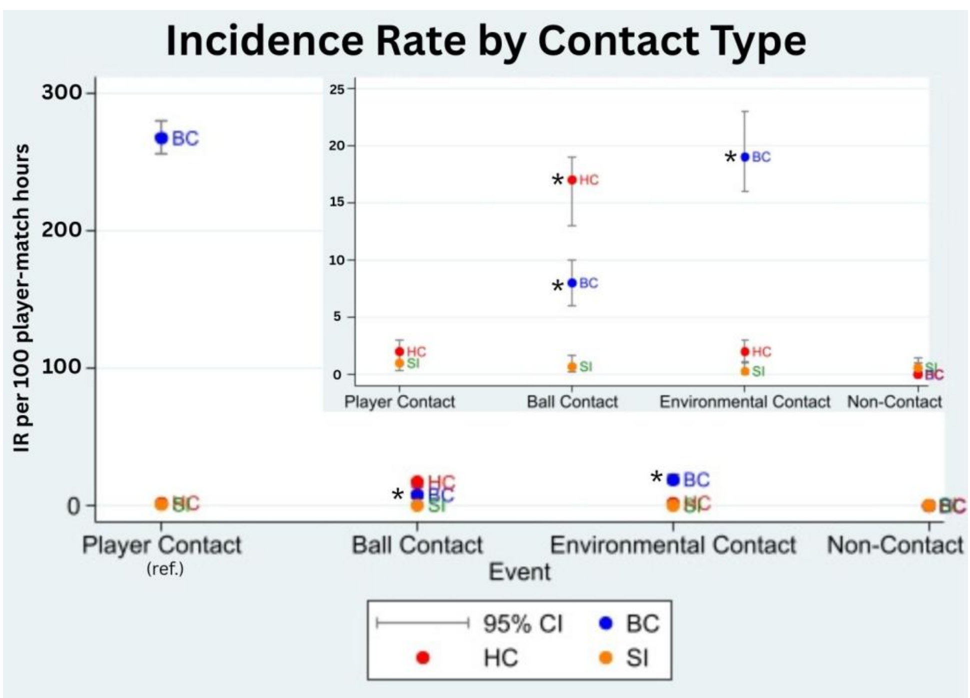

Figure 6. Incidence rates of Body Contacts, Head Contacts, and Suspected Injuries by Contact Type

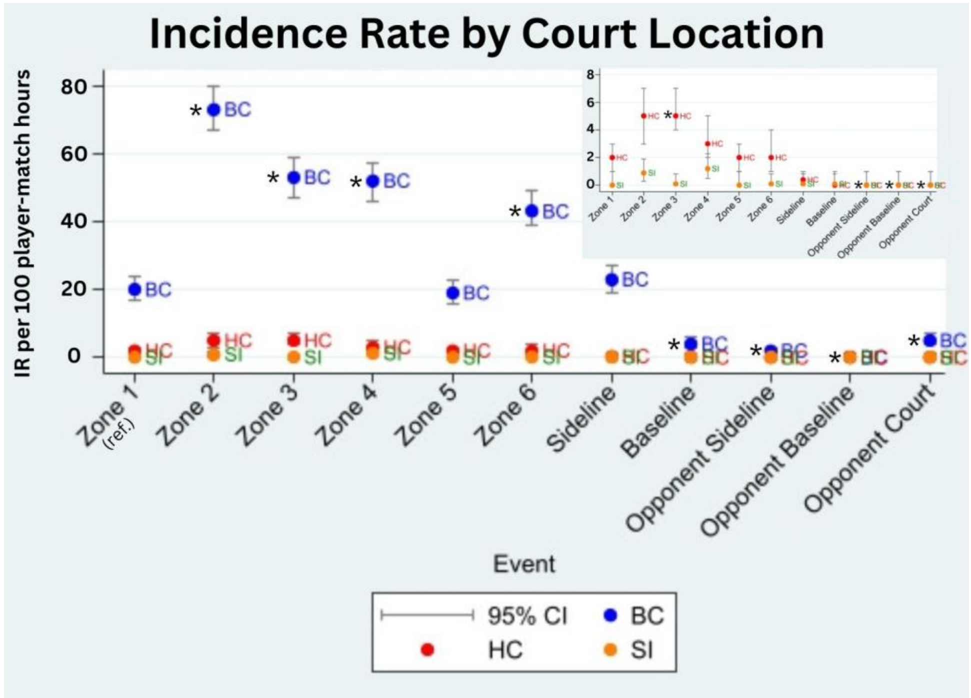

Figure 7. Incidence rates of Body Contacts, Head Contacts, and Suspected Injuries by Court Location

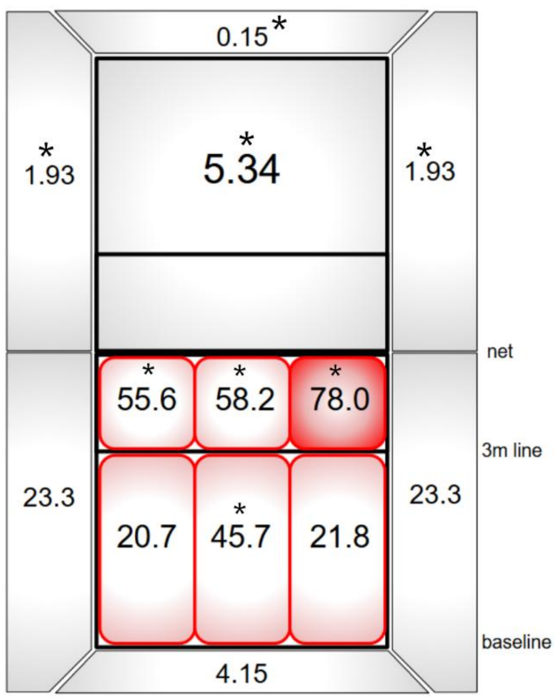

Figure 8. Indicence Rates of All Contacts by Court Location (visualized)

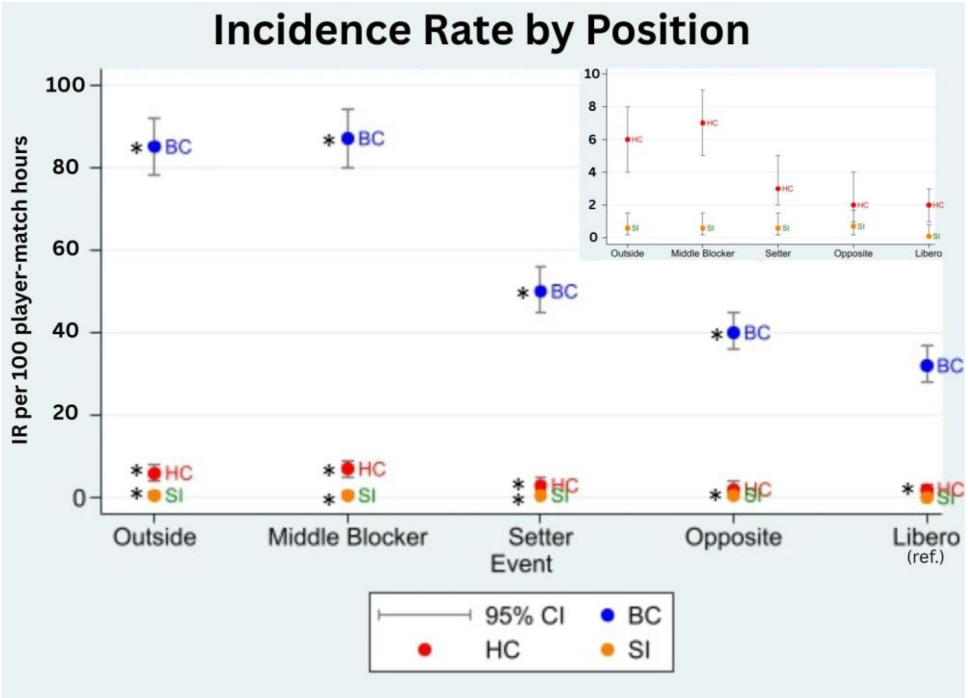

Figure 9. Incidence rates of Body Contacts, Head Contacts, and Suspected Injuries by Position

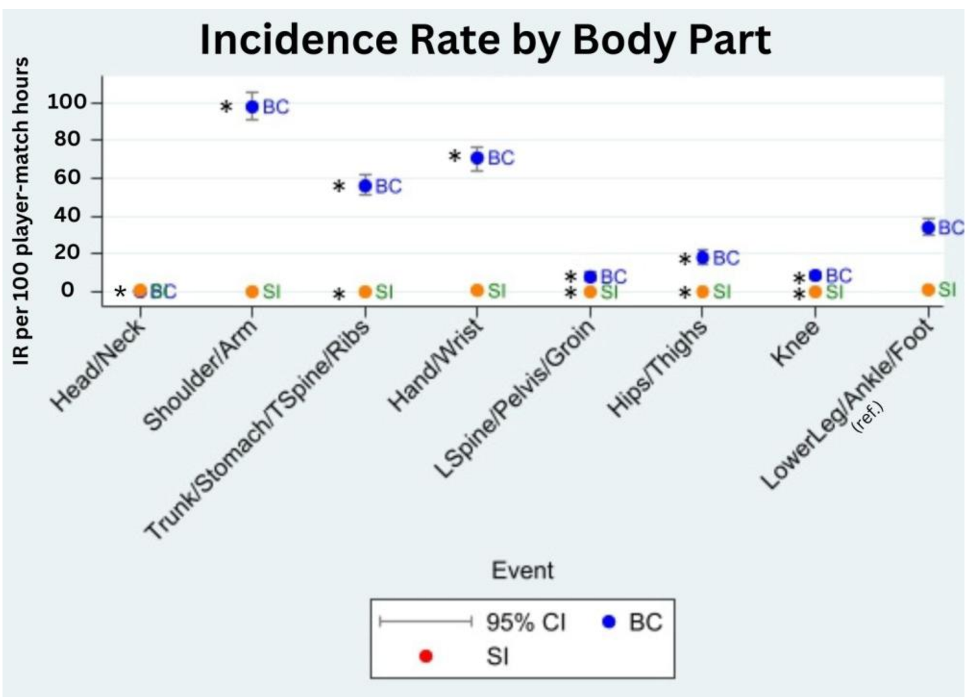

Figure 10. Incidence rates of Body Contacts, Head Contacts, and Suspected Injuries by Body Part

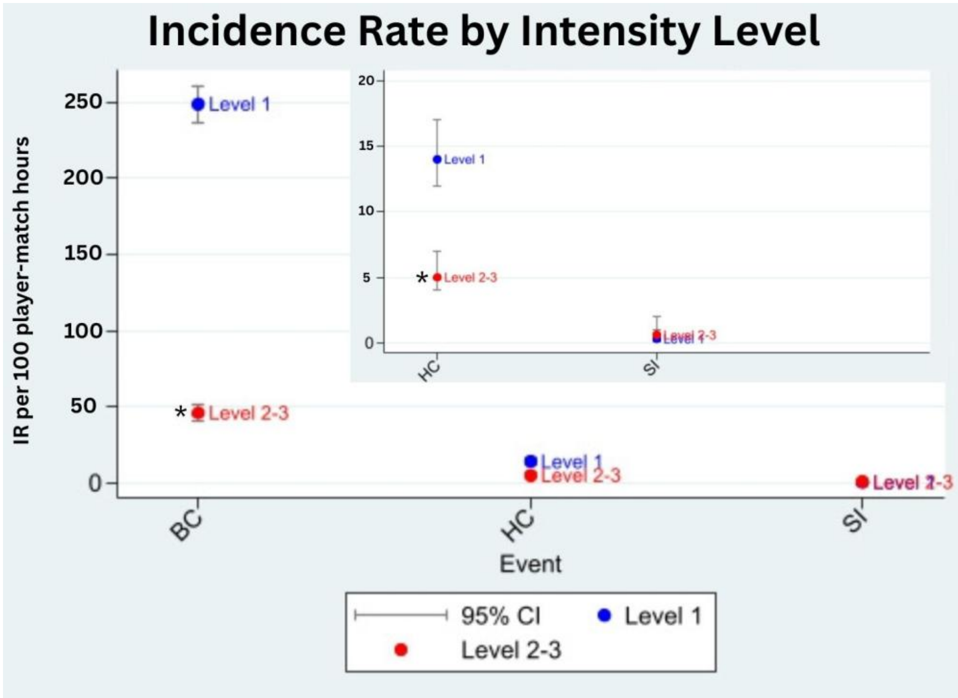

Figure 11. Incidence rates of Intensity Level for Body Contacts, Head Contacts, and Non-contact suspected injuries

9.2. Appendix B: Literature Review Methods

Using the keywords from the headings of each section, along with the keywords of the thesis provided on the title page, PubMed, and Google Scholar were used to find publications on each component of volleyball epidemiology. The search was performed in May of 2024. The specific search terms for each subject and number of results are displayed in Supplementary Table 5. Due to the large number of papers found in the search process, articles titles were screened for relevance. Additionally, the author reviewed the reference lists of included studies identified in the search output. Some articles were chosen that focused on populations outside of the specific target population of this study, (i.e., national level or professional athletes) because the studies are sentinel in this field and the topics may not be covered in the youth and collegiate populations. Although this information may not be generalizable to youth and university volleyball, it was often the best source of information on the sport when research on the target population was not available.

Supplementary Table 5. Search Terms and Results from May 2024 and June 2025

Search	May Results	June Results
volleyball AND injur*	983	1091
(volleyball AND injur*) kw	1	1
(volleyball AND injur*) tw	2	2
volleyball AND youth	911	1005
volleyball AND injur* AND youth	366	406
volleyball AND video analysis AND injur*	23	24
volleyball AND injur* AND video	37	39
volleyball AND concussion*	62	67
volleyball AND injur* AND incidence	300	321
volleyball AND injur* AND risk	415	473
volleyball AND injur* rates	97	111
volleyball AND injur* AND modality	32	34
volleyball AND injur* AND prevention	363	412
Total articles referenced in literature review	43	47

9.3. Appendix C: CanadaWest Video Agreement

RE: SHRed Concussions Study / Volleyball Research Opportunity
From: Rocky Olfert [redacted]
Sent: Thursday, January 4, 2024 2:40 PM
To: Jack Tyrrell [redacted]
Subject: RE: SHRed Concussions Study / Volleyball Research Opportunity
Hi Jack,
If you purchase an account, we can enable clipping and downloading.
There was research done a few years ago by Alberta and UBC on concussions and the game ball. (Specifically testing balls used for competition and impact on head contact)
Let me know if you need anything else.
[redacted]

From: Jack Tyrrell [redacted]
Sent: Thursday, January 4, 2024 9:50 AM
To: [redacted]
Cc: [redacted]
Subject: SHRed Concussions Study / Volleyball Research Opportunity
Hello
My name is Jack Tyrrell, I am a masters student at the University of Manitoba studying sports injuries. My supervisor is Dr Kelly Russell (CC'ed), one of the leading sports injury and concussion researchers in Canada. As a part of my masters, I am examining injury rates in both male and female volleyball. Using video analysis, we aim to compare injury rates at the club and collegiate level. Information from this study will allow us to develop injury prevention strategies to allow for safer sport participation and protect athlete health. This research is a part of the SHRed Concussions study which is a national study led by the University of Calgary and funded by the NFL's Scientific Advisory Board that aims to reduce concussions and the consequences of concussions in youth sports. You can find more information about it here:
https://www.ucalgary.ca/sport-injury-prevention-research-centre/research/studies/concussion/shred-concussions
I am emailing you as we are hoping to use video footage from Canada West's database in the study. This will allow us to access a large number of games and randomize the volleyball games selected in the study. Video analysis will allow us to count injuries, suspected injuries, body contacts, or head contacts. This type of research has never been done in volleyball. We would like to purchase a license to access the Canada West TV platform and download game footage to analyze. Video will be stored on a secure server and will never be shared. No identifying information available in the videos about the players/teams/schools/clubs will ever be released and no further information will ever be collected from players/teams/schools/clubs. We will not be naming the players/teams/schools/clubs or what games are part of the analysis. We will be presenting injury prevalence and rates. I have linked a paper that performed similar work on ringette injuries so you can get an idea of what information would be presented and how no one would ever know what teams were included. (Higher Rates of Head Contacts, Body Checking, and Suspected Injuries in Ringette Than Female Ice Hockey: Time to Ring in Opportunities for Prevention - PubMed (nih.gov))

I would love to discuss this opportunity with you further. Please let me know if there is an opportunity to meet via phone call or Zoom.
Thank you.
Jack Tyrrell

9.4. Appendix D: Consent Forms for Video Recording

Surveillance in High Schools to Reduce Concussions and Consequences of Concussions–SHRed Concussions

UNIVERSITY OF MANITOBA

RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM
Parent

Title of Study: "Surveillance in High Schools to Reduce Concussions and Consequences of Concussions–SHRed Concussions"

Principal Investigator: Dr Kelly Russell
Winnipeg, MB, 204-480-1312 email: krussell@chrim.ca

Co-Investigator: Dr Michael Ellis,
Winnipeg, MB, 204-927-2766

Sponsor: University of Manitoba

You are being asked to participate in a human research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. You may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words that you do not understand. Please ask the study staff to explain any words or information that you do not clearly understand. The study doctor institution is receiving professional fees and financial support to conduct this study.

When we say "you": in this consent form, we mean you or your child; "we" means the doctors and other staff.

Purpose of Study

This research study is being conducted to establish a national concussion surveillance program in schools, study concussion prevention strategy effectiveness, and develop concussion detection tools. We will compare athletes with a concussion to athletes with a musculoskeletal injury (injury to their upper or lower extremity).

A total of 600 Manitoba athletes will participate in this study over three years.

Study Procedures

This study will last three years. If you choose to participate, you will be asked to take part in annual baseline testing before the start of your sports season begins. This testing will include parent and child surveys designed to measure your mental and physical health as well as child physical testing (including balance and grip testing, a shuttle run). If you join the study while injured, we will focus on your recovery. You will do the baseline testing the next year.

PAGE 1 OF 5 Consent 9 – December 22, 2022 **PARTICIPANT INITIALS_____**

If during the course of the three years you sustain a sports-related concussion, you will undergo the same treatment that you otherwise would have received and will repeat the same type of testing initially done at baseline until you have healed completely. You may also be asked to wear something called an actigraph – a small device that measures your activity levels for a week at a time after you sign up or while you recover from a concussion.

Communications and reminders will be sent via email, phone call, or text to the email addresses and cell phone numbers provided by you on the consent and assent forms.

Enrollment and some testing procedures may be conducted virtually, either over the phone or via an encrypted video chat. These will be conducted on a secure platform, and in a private location to ensure your privacy. All information stored is on secure servers only accessible by study staff. Parental consent may be done via telephone or email.

If during the course of the study it becomes apparent that you are suffering from severe depression or have expressed a desire to self-harm, a referral will be made to psychiatric services.

A study staff member will ask if you have read and understood this consent document, and if you have any questions about the study or about participating.

You can stop participating at any time. However, if you decide to stop participating in the study, please talk to the study staff first. There will be no consequences if you suddenly withdraw from the study.

The study results will not automatically be provided to you. However, if you would like a copy of the results, please let us know at the time you agree to participate and we will mail you a copy of the results. Results are expected to be available in the summer of 2024. You will only be receiving aggregate results.

Risks and Discomforts

Beyond the risk that you may injure yourself when doing the baseline physical testing there are no risks to you for participating in this study. Every effort will be made by study staff to ensure that you complete the exercises safely to avoid injury.

There is a slight increase in risk of loss of confidentiality in doing aspects of the study virtually. All information collected is stored securely, and every effort possible is made to ensure privacy and confidentially.

Benefits

By participating in this study, you will be providing information to the study staff that will help prevent concussions and help us understand outcomes and risk. There may or may not be direct medical benefit to you from participating in this study. We hope the information learned from this study will benefit other participants with sport-related concussions in the future.

Costs

There will be no cost for the study treatment that you will receive.

Payment for Participation

You will receive no payment for your participation in this study but parking charges of up to $15/session will be reimbursed.

To thank you for your participation, your child will receive a $20 gift card after they complete baseline testing.

Confidentiality

Information gathered in this research study may be published or presented in public forums; however, your name and other identifying information will not be used or revealed. All study related documents will bear only your assigned study number and/or initials. Despite efforts to keep you and your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law. All study documents related to you will bear only your assigned patient number.

The University of Manitoba Health Research Ethics Board may review records related to the study for quality assurance purposes.

All electronic records will be stored on secure servers and any paper records will be kept in a locked secure area and only those persons identified will have access to these records. If any of your research records need to be copied to any of the above, your name and all identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave the University of Manitoba.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate or withdraw from the study at any time. Your decision not to participate or to withdraw from the study will not affect your care at this site. If the study staff feels that it is in your best interest to withdraw you from the study, they will remove you without your consent. We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study. Although all parts are important, if there is a portion of the study you do not want to participate in, you can still join the study and not complete the parts you do not want to.

Questions

You are free to ask any questions that you may have about your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact the study doctor and the study staff:
Dr Kelly Russell, 204-480-1312 or krussell@chrim.ca.

For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at 204-789-3389.

Surveillance in High Schools to Reduce Concussions and Consequences of Concussions–SHRed Concussions

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Dr Kelly Russell or her study staff. I have had my questions answered by them in language I understand. The risks and benefits have been explained to me. I believe that I have not been unduly influenced by any study team member to participate in the research study by any statements or implied statements. Any relationship (such as employer, supervisor or family member) I may have with the study team has not affected my decision to participate. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this study is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.
I understand that information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed.

By signing this consent form, I have not waived any of the legal rights that I have as a participant in a research study.

I agree to be contacted for future follow-up in relation to this study,
Yes _ No _

I would like a copy of the study results mailed to me,
Yes _ No _

Parent/legal guardian's signature____________________Date ______________
(day/month/year)

Parent/legal guardian's printed name: ____________________

Parent Email Address: ________________________

Parent Cell Phone Number:________________________

(day/month/year)

Child's printed name: ________________________

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Printed Name: ____________________________________Date ________________
(day/month/year)

Signature: ________________________

Role in the study: ________________________
Relationship (if any) to study team members:____________________

Video Recording Addendum to the Consent form

Study Title: *Rates of head contacts, body contacts, suspected injuries, and mechanism of injury in high school club versus collegiate volleyball: A video analysis study*

Principal Investigator: Dr Kelly Russell
Winnipeg, MB, 204-480-1312 email: krussell@chrim.ca

Sponsor: University of Manitoba

What is the purpose of the video recording?
The researchers doing this study are interested in recording body contacts and suspected injuries in volleyball. Video analysis will evaluate the type, frequency, and intensity of player-to-player contacts, head contacts, and suspected injuries and will be used to describe mechanisms leading to injury and concussion to evaluate body contact and suspected injury rates in volleyball.

What are the study procedures?
If you agree to take part, recording will happen during participation in volleyball games during the 2024 club volleyball season. No identifying information will be collected, information will not be linked to your study profile.

What are the risks of participation?
There are no risks related to recording the participants activity. There is a slight increase in risk of loss of confidentiality because of video recording. All information collected is stored securely, and every effort possible is made to ensure privacy and confidentially. Videos and impact behaviours will not be linked to individual participants.

What are the benefits of participation?
You/your child will not benefit directly from taking part in this research study. Researchers may make discoveries that could benefit individuals participating in volleyball in the future.

How will the videos be viewed and stored?
Dartfish software will be used for the analysis of video footage which will be stored on the secure University of Manitoba server. Video will be opened in a Dartfish window for the purposes of analysis on password-protected University of Manitoba computers, however, no footage will be stored within the third party software itself.

Will personal information be linked to the video(s)?
Data from videos will be stored separately from identifiable data collected as part of the main study. Videos themselves will be stored securely at the University of Manitoba according to their guidelines.

Are there any costs or compensation paid to participants?
There are no costs. You will not be paid for taking part. No information will be sold.

Whom do participants contact for questions?
If you have questions about taking part in this study, you can contact Dr. Kelly Russell, krussell@chrim.ca or Heather Normand hnormand@chrim.ca

December 12, 2023

By signing this addendum I agree that:

- I voluntarily consent to allow video recordings of my/my child's sport activity for the research purposes explained above;
- I understand the information within this addendum;
- I do not give up my/my child's legal rights by signing this form.

Signature of Participant	Name of Participant	Date
Signature of Participant's Legal Guardian if under 18	Name of Participant's Legal Guardian if under 18	Date
Signature of Person Obtaining Consent	Name of Person Obtaining Consent	Date

December 12, 2023

9.5. Appendix E: Ethics Approval

University of Manitoba | Research Ethics and Compliance

Research Ethics Bannatyne
P126-770 Bannatyne Avenue
Winnipeg, MB R3E 0W3
T: 204 789 3255
F: 204 789 3414
bannreb@umanitoba.ca

HEALTH RESEARCH ETHICS BOARD (HREB)

CERTIFICATE OF FINAL APPROVAL FOR AMENDMENTS AND ADDENDUMS

PRINCIPAL INVESTIGATOR: Dr. Kelly Russell	**INSTITUTION/DEPARTMENT:** U of M and HSC/Community Health Sciences/Pediatrics and Child Health	**ETHICS #:** HS22581 (H2019:064)
HREB MEETING DATE (If applicable):	**APPROVAL DATE:** March 19, 2024	
STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable): NA		

PROTOCOL NUMBER: NA	**PROJECT OR PROTOCOL TITLE:** Surveillance in High Schools to Reduce Concussions and Consequences of Concussions – SHRed Concussions **Sub-Study:** Surveillance in High School to Reduce Concussions and Consequences of Concussions in Canadian Youth:
SPONSORING AGENCIES AND/OR COORDINATING GROUPS: National Football League Scientific Advisory Board	

REMINDER: THE CURRENT HREB APPROVAL FOR THIS STUDY EXPIRES: **February 25, 2025**

REVIEW CATEGORY OF AMENDMENT:	**Full Board Review** ☐	**Delegated Review** ☒
Submission Date of Investigator Documents: January 5, 2024 (Signed March 14, 2024)	**HREB receipt date of Documents:** March 15, 2024	

THE FOLLOWING AMENDMENT(S) and DOCUMENTS ARE APPROVED FOR USE:

Document Name	Version (If applicable)	Date
Protocol:		
Protocol		March 14, 2024
Consent and Assent Form(s):		
Other:		

CERTIFICATION
The University of Manitoba (UM) Health Research Board (HREB) has reviewed the amendment to the research study/project named on this ***Certificate of Approval*** as per the category of review listed above and was found to be acceptable on ethical grounds for research involving human participants. The amendment and documents listed above were granted final approval by the Chair or Acting Chair, UM HREB.

HREB ATTESTATION
The University of Manitoba (UM) Health Research Board (HREB) is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement 2, and the applicable laws and regulation of Manitoba. In respect to clinical trials, the HREB complies with the membership requirements for Research Ethics Boards defined in

A unit of the office of the Vice-President (Research and International)
https://umanitoba.ca/research/opportunities-support/ethics-compliance/ethics/bannatyne

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Division 5 of the Food and Drug Regulations of Canada and carries out its functions in a manner consistent with Good Clinical Practices.

QUALITY ASSURANCE
The University of Manitoba Research Quality Management Office may request to review research documentation from this research study/project to demonstrate compliance with this approved protocol and the University of Manitoba Policy on the Ethics of Research Involving Humans.

CONFLICT OF INTEREST
Any Principal or Co-Investigators of this study who are members of the UMHREB did not participate in the review or voting of this study.

CONDITIONS OF APPROVAL:

1. This amendment is acceptable on scientific and ethical grounds for the ethics of human use only. ***For logistics of performing the study, approval must be sought from the relevant institution(s).***
2. This research study/project is to be conducted by the local principal investigator listed on this certificate of approval.
3. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to the research study/project, and for ensuring that the authorized research is carried out according to governing law.
4. **This approval is valid until the expiry date noted on this certificate of approval.** **A Bannatyne Campus Annual Study Status Report** must be submitted to the HREB within 15-30 days of this expiry date.
5. Any changes of the protocol (including recruitment procedures, etc.), informed consent form(s) or documents must be reported to the HREB for consideration in advance of implementation of such changes on the **Bannatyne Campus Research Amendment Form.**
6. Adverse events and unanticipated problems must be reported to the HREB as per Bannatyne Campus Research Boards Standard Operating procedures.
7. The UM HREB must be notified regarding discontinuation or study/project closure on the **Bannatyne Campus Final Study Status Report.**

Sincerely,

[redacted]

John Arnett, PhD. C. Psych.
Chair, Health Research Ethics Board
Bannatyne Campus

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Please quote the above Human Ethics Number on all correspondence.
Inquiries should be directed to the REB Secretary **Telephone:** (204) 789-3255/ **Fax:** (204) 789-3414

9.6. Supervisory Committee Members

Dr. Kelly Russell; Pediatrics and Child Health, University of Manitoba (advisor)
Dr. Tracie Afifi; Community Health Sciences, University of Manitoba (advisor)
Dr. Tamara Taillieu; Community Health Sciences, University of Manitoba
Dr. Carolyn Emery; Kinesiology, University of Calgary
Dr. Stephen West; Kinesiology, University of Calgary