Christopher Skazalski // Understanding volleyball injuries

DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
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The etiology and burden associated with the sport's most common injuries

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The improvement of ***understanding*** *is for two ends: first, our own increase of knowledge;*

secondly, to enable us to deliver that knowledge to others.

John Locke

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Christopher Skazalski

Doha/Oslo, September 2022

List of papers

This dissertation is based on the following original research papers, which are referred to in the text by their Roman numerals:

I. Skazalski C, Kruczynski J, Bahr MA, Bere T, Whiteley R, Bahr R. Landing-related ankle injuries do not occur in plantarflexion as once thought: a systematic video analysis of ankle injuries in world-class volleyball. Br J Sports Med. 2018;52:74-82. doi: 10.1136/bjsports-2016-097155

II. Skazalski C, Whiteley R, Hansen C, Bahr R. A valid and reliable method to measure jump-specific training and competition load in elite volleyball players. Scand J Med Sci Sports. 2018;28:1578-1585. doi: 10.1111/sms.13052

III. Skazalski C, Whiteley R, Bahr R. High jump demands in professional volleyball – large variability exists between players and player positions. Scand J Med Sci Sports. 2018;28:2293-2298. doi: 10.1111/sms.13255

IV. Skazalski C, Bahr R, Whiteley R. Shoulder complaints more likely in volleyball players with a thickened bursa or supraspinatus tendon neovessels. Scand J Med Sci Sports. 2021;31:480-488. doi: 10.1111/sms.13831

V. Skazalski C, Whiteley R, Sattler T, Kozamernik T, Bahr R. Playing with pain: knee, low back, and shoulder problems rampant among university and professional volleyball players. (Manuscript in submission. 2022)

Abbreviations

AEs	Athlete-exposures
CI	Confidence interval
ER	External rotation
FIVB	Fédération Internationale de Volleyball
GEE	Generalized estimating equation
ICC	Intraclass correlation coefficient
IQR	Interquartile range
IR	Internal rotation
ISS	Injury surveillance system
IMU	Inertial measurement unit
MDC	Minimal detectable change
NCAA	National Collegiate Athletic Association
OR	Odds ratio
OSTRC	Oslo Sports Trauma Research Center
OSTRC-H	OSTRC questionnaire on health problems
OSTRC-O	OSTRC overuse injury questionnaire
ROC	Receiver operating characteristic
ROM	Range of motion
SAB	Subacromial bursa
SD	Standard deviation
SMS	Short message service (i.e., text messaging)
US	Ultrasound

Summary

Volleyball is a fast-paced, hard-hitting sport that requires its athletes to perform a large volume of jumps and overhead attacks. As a result, most injuries in volleyball involve the ankle, knee, back, hand/fingers, and shoulder – comprising about 70% of all injuries within the sport. Injury risk management approaches may want to focus on these common injury locations to achieve maximum results.

Ankle sprains are the most common type of acute volleyball injury. To best understand the sport-specific factors involved with ankle sprains, it is recommended to perform a detailed video analysis of actual injury situations, since there is limited validity of questionnaire data from players and witnesses to provide this important contextual information. The repetitive nature of jumping within the sport has long been believed to be associated with knee problems (i.e., jumper's knee). A commercially available device to measure jump load has garnered significant adoption within the sport, but still needs to be validated in this population of professional players. Additionally, position and individual jump variability among professional players has not been investigated and individual jump demands are unknown. Despite the prevalence of shoulder problems in volleyball, prospective studies examining associated risk factors are almost non-existent. Finally, the knee, low back, and shoulder account for most overuse injuries in volleyball; unfortunately, previous studies utilized methodology that failed to examine the extent of their injury burden and impact on performance. Research using appropriate methods to capture the true prevalence of overuse complaints among elite players is needed; how these complaints change throughout the season is also unknown.

The overall aim of this thesis was to provide valuable insights into the etiology of volleyball injuries, which lays the foundation for managing injury risk within the highest levels of the sport. We focused on injury burden, risk factors, and mechanisms leading to common injuries and complaints among elite volleyball players.

Paper I. The aim was to describe the injury situations and mechanisms of ankle injuries in world-class volleyball based on systematic video analysis of injuries reported through the Fédération Internationale de Volleyball (FIVB) Injury Surveillance System. Videos of 24 injuries from major FIVB tournaments were included for analysis. The majority of injuries occurred while blocking, often landing on an opponent. The attacking player was overwhelmingly to blame for injuries at the net secondary to crossing the center line. Injuries while attacking often resulted from a back-row player landing on a front-row teammate. Landing-related injuries mostly resulted from rapid inversion with the absence of plantarflexion.

Paper II. In this study we evaluated the validity and reliability of a commercially available wearable device, the Vert, to count jumps and measure jump height in professional volleyball players. Jump count accuracy was determined by comparing jumps recorded by the device to jumps observed through systematic video analysis of three practice sessions and two league matches performed by a men's professional volleyball team. Jump height validity of the device was examined against reference standards as participants performed countermovement jumps on a force plate and volleyball-specific jumps with a Vertec. The Vert device demonstrated excellent accuracy counting volleyball-specific jumps during training and competition. It also provided an acceptable measure of on-court jump height that can be used to monitor athlete jump load. Some limitations exist as it is not recommended for measuring maximal jumping ability when precision is needed.

Paper III. We examined position-specific jump demands required for training and competition during a professional volleyball season and investigated the individual variability associated with jump load. Jumps performed by 14 professional players during one season of training and competition were timestamped, individually assigned, and recorded for jump height (n = 129,173 jumps; 142 team-sessions). Setters performed the greatest volume of jumps (121 jumps/training session) while opposites performed more high-intensity jumps than their teammates. Jump demands are high in professional volleyball – performance programs should be tailored to the match and training demands required at each position. Jump loads are highly variable as substantial week-to-week increases were observed for both the team and individual players. As a result, monitoring individual jump load seems necessary.

Paper IV. The aim was to examine the role of subacromial bursa thickness, neovascularization of the supraspinatus tendon, shoulder strength and range of motion, player position, and age in the development of shoulder complaints in professional volleyball players. Players underwent preseason baseline testing (n = 86) and reported shoulder complaints during the subsequent 12-week period. A substantial thickening of the subacromial bursa and presence of neovessels in the dominant arm were each associated with increased risk of shoulder complaints. Position matters as outside hitters and opposites were much more likely to develop shoulder problems while greater shoulder external rotation range of motion also increased risk. Players with current complaints at baseline presented with greater internal:external rotation (IR:ER) strength ratios; however, neither strength nor internal rotation range of motion at baseline was associated with an increased risk of developing future shoulder complaints.

Paper V. The aim of this study was to develop a more accurate and complete understanding regarding the weekly prevalence and burden of knee, low back, and shoulder problems within the highest levels of men's volleyball – including the role that preseason complaints, match

participation, player position, team, and age have on complaints. Seventy-five male volleyball players, representing four teams playing in their country's respective premier league participated over a 3-season period. Players completed weekly questionnaires reporting pain related to their sport and the extent to which knee, low back, and shoulder problems affected participation, training volume, and performance. Nearly all elite men's volleyball players experienced knee, low back, or shoulder problems during a given season – and the majority had at least one bout that substantially reduced training participation or sports performance. Almost half of the players were playing through some combination of knee, low back, and shoulder complaints each week. Notably, players who experienced preseason knee, low back, and shoulder problems continued to have more problems during the competitive season than their teammates; and position and match participation also had significant impact on these complaints. These findings suggest that knee, low back, and shoulder problems have a greater injury burden than previously reported.

Introduction

Volleyball – the sport

The sport of volleyball has demonstrated tremendous growth since its humble origins in a YMCA gymnasium in 1895. William G. Morgan invented the recreational game in Massachusetts, USA, where it could be played by people of all ages. It was designed to be less intense and less physically demanding than the other newly invented sport, basketball, which had been invented just 4 years earlier in Massachusetts. Discussing the origin of the game, Morgan noted:

> *In search of an appropriate game, tennis occurred to me, but this required rackets, balls, a net and other equipment, so it was eliminated – but the idea of a net seemed a good one. We raised it to a height of about 6 feet 6 inches from the ground, just above the head of an average man. We needed a ball; and among those we tried was a basketball bladder but this was too light and too slow. We therefore tried the basketball itself which was too big and too heavy.*[64]

Morgan eventually had A.G. Spalding & Bros. make a ball for this new game. Rules were tweaked and the game spread worldwide in the decades that followed. The game took on local rules as it spread to Asia – Philippines, China, Japan, and India, as well as into Europe, South America, and Africa. The international governing body, Fédération Internationale de Volleyball (FIVB), was then established in 1947. The first World Championships took place soon after in 1949 and 1952 for men and women, respectively. Volleyball has since become a mainstay in the Olympic Games, beginning in 1964 and followed by the inclusion of beach volleyball in 1996. The fast paced and technical sport that elite volleyball has become would likely leave Morgan speechless. However, he would be proud to know that the leisure activity he created over 125 years ago is now being played by more than 800 million people of all ages and ability levels worldwide.[67]

At the highest levels, international players represent their national teams and compete in the top professional leagues around the world. Many countries have club programs that develop top youth volleyball players until they are ready to compete at a university or professional level. In the United States, the highest level of competition is experienced during university competition through the National Collegiate Athletic Association (NCAA), which also sees participation from many international players during their university years. However, with no professional league in the United States, top players then go overseas to play professionally. University and professional leagues from around the world typically run during the fall, winter, and spring seasons for those living in the Northern Hemisphere. This leaves the summer months for national team training and competition. For the top players in the world, there is often little to no offseason between club and national team participation.

Game characteristics

Volleyball is a sport played by two teams on opposing halves of a court. The object of the game is to hit the ball over the net and onto the floor of the opponent's court. Play begins with a serve – one team hitting the ball to the other. Each team is allowed 3 contacts to return the ball to the other side. Play continues until one team scores a point by hitting the ball onto the floor of the opponent's court or when the opponent makes an error trying to return the ball. There are different versions of volleyball that can be played indoors or outdoors and modifications that allow all ages and ability levels to participate. For the purpose of this manuscript, 'volleyball' will refer to the internationally recognized version of indoor volleyball as outlined by the FIVB.[43]

The official court dimensions are 9 m by 18 m, with a net dividing the court into equal 9 m by 9 m sides. The height of the net is 2.43 m for men and 2.24 m for women. Six players are on the court for each team and must rotate clockwise around the six positions. At any given time, the three front-row players are the only ones who can jump and block at the net, while the three back-row players can only jump and attack the ball if they jump from behind the 3-meter line, which runs parallel to the net. Once the ball is put into play through the service to start each rally, players can move around the court. As a result, players specialize at certain positions on the court:

1. Setter – typically makes the 2nd of the 3 allowed contacts and they use their hands to 'set' the ball to one of the hitters.
2. Middle blocker – plays in the front-row in the middle position. Emphasis is on blocking the opposing hitters, but also hits (predominantly from the middle of the court).
3. Outside hitter – attacks and blocks the ball from the left-side. An all-around player who also has a large role defensively and during service reception.
4. Opposite – attacks and blocks the ball from the right-side. In men's professional volleyball, this player is often the go-to and strongest attacker.
5. Libero – this is a defensive specialist who only plays in the back-row, normally replacing the middle blocker.

The match is won when one team wins 3 sets. Each set is played to 25 points, but if the game becomes tied at 24-24, it continues until one team wins by 2 points. If the teams are tied at 2 sets a piece, the deciding 5th set is played to 15 points with the winner being required to win by 2 points again.

Player characteristics and physical demands

High-level volleyball, like many sports, requires large physiological demands and superior technical skill. The external constraints requiring athletes to hit over a net make it advantageous for players to be taller and jump higher. Volleyball players participating in the 2008 Beijing Olympic Games were tall – 1.97 m (males, SD=0.07) and 1.83 m (females, SD=0.08) on average – and with strong jumping abilities.[107] Male Olympians had an average attack jump reach of 3.44 m, meaning they can reach their hand an average of 1 meter above the net.[107] Female Olympians also had strong jumping abilities with an average attack jump reach of 3.04 m, reaching 0.80 m above the net.[107]

Differences are also observed between position groups. Among professional men's players, middle blockers and opposites are taller and heavier while liberos are the shortest and lightest.[82, 104, 106] Outside hitters and opposites are the best attack jumpers when taking a 2 to 4 step approach.[104, 106] Differences in jumping ability are also seen at different ages and levels of play as senior male national team players have been shown to jump nearly 12 cm higher on average than younger players participating on U-21 and U-19 national teams.[106] Similar to male players, females participating at higher levels are taller and have higher vertical jump values compared to lower-level players.[17, 46, 76, 81] Additionally, similar height patterns are observed across position groups among women, with middles and opposites being the tallest and liberos being the shortest.[81]

Jump biomechanics and game particulars

Jump technique is unique to the sport with various jump types used depending on the game situation. Typical volleyball jump techniques are performed when a player is spiking, blocking, setting, or serving. The spike jump utilizes unique footwork and technique, allowing the greatest jump height to be achieved and is integral to the success of the attack (Figure 1). Large emphasis is placed on using proper footwork and trunk and arm movements to generate high jumps and strong spikes. The number of steps used is sometimes adjusted to allow for a shorter or longer approach. A similar jump technique is used when performing a top-spin jump serve, while a jump float serve will often be performed with fewer steps and without maximum jump height.

Figure 1. *Typical 2- to 3-step spike approach. Source: USA Volleyball. Reproduced with permission from USA Volleyball.*

A strong block is another critical part of the game with 1, 2, and sometimes 3 players jumping together to create a wall of hands that is difficult for the opposing team to penetrate. Blocking often results in players performing maximal effort jumps, however, smaller effort jumps are sometimes used when trying to jump quickly or when late to block. Jump sets are the final jump-type commonly performed. Jump sets are often performed with submaximal effort – similar to jump float serves – and primarily consist of a setter jumping straight up and down while setting the ball to an attacking player.

The different jumping actions in volleyball result in unique match demands for each position group. For men's national team players, middle blockers perform the most block jumps (11.00 jumps/set compared to 6.25 to 6.50 jumps/set for setters and outside hitters).[106] As may be expected, middles (7.75 jumps/set) and outsides (5.75 jumps/set) also perform significantly more attack jumps compared to setters (0.38 jumps/set).[106] Additionally, style of play differences have been observed between men's and women's teams at the international level. Men's national team players have been found to primarily use a power jump serve while women perform fewer power jump serves and utilize a greater mix of jump float and standing serves.[93]

With this understanding, it is suspected that the jumps and landings performed during near-maximal effort spikes, blocks, and jump serves are of most interest in relation to knee complaints among volleyball players.

Spike and serve biomechanics

Similarities exist between the upper-body kinematics during a volleyball spike compared to the motion in other overhead sports (e.g., tennis serve, team-handball throw, baseball pitch).[98, 118] Wagner et al.[118] noted that similar proximal-to-distal sequencing (pelvic rotation – trunk rotation – trunk flexion – elbow extension – shoulder internal rotation – shoulder flexion) and similar angles during the acceleration phase for a volleyball spike, tennis serve, and team-handball throw suggest there is a general motor pattern that is used during overhead movements. Despite these similarities, unique biomechanical differences remain between the volleyball attack compared with other overhead sport skills, as well as between the various types of serves and spikes that are commonly used within volleyball. Reeser et al.[98] examined the upper limb biomechanics during a volleyball cross-body spike, straight-ahead spike, roll shot, jump serve, and float serve. Compared to a baseball pitch (fastball) and tennis serve, volleyball spikes were performed with a greater degree of shoulder abduction and horizontal adduction at the point of ball contact or release (shoulder abduction: volleyball – 130°, baseball – 89°, tennis – 101°; horizontal adduction: volleyball – 29°, baseball – 9°, tennis – 5°).[98, 99] Among the different types of volleyball attacks and serves, shoulder and elbow kinetics are greatest during spikes and jump serves; suggesting management of shoulder complaints may want to consider the number of hard spikes and jump serves performed during training.[98]

One nuance to the attack in volleyball is that it is ideally performed following a large jump, allowing the athlete to contact the ball at the highest point and providing the best angle to hit the ball down and into the opponent's court (Figure 1). This results in players having to transfer power from their lower extremities and trunk to their shoulder while in the air and no longer in contact with the ground. Additionally, players are required to adjust their position during their jump approach and while in the air to make contact with the ball, especially when the ball is poorly set and requires the attacker to reach for it.

Background and theoretical framework

Injuries in sport

Sports injury prevention – complexity modeled

Before we ascertain what previous studies have reported regarding injury incidence and mechanisms, it is important to acknowledge that a wide array of study designs and methodologies have been employed, making it difficult to compare study results. It has been over 25 years since the 4-step injury prevention research model was introduced by van Mechelen et al.,[111, 112] to combat the adverse effects of sports injuries resulting from sports participation. This fundamental model proposes four steps:

1. Identify the extent of the problem (incidence/severity)
2. Identify the risk factors and mechanisms associated with sports injuries
3. Introduce preventative measures
4. Test the effectiveness of the preventative measures by repeating step 1.

Shortly after, Meeuwisse[84] proposed a multifactorial model that accounted for the interaction of intrinsic and extrinsic risk factors prior to the inciting event. Meeuwisse et al.[85] would eventually modify this model to factor in the implications of repeated participation and exposure; noting that injury etiology is not a linear set of events, rather a recurring loop with ever-changing risk. Bahr and Krosshaug[14] expanded on these models with their comprehensive model for injury causation, which highlighted the importance of understanding both the risk factors and specific mechanisms leading to injury. They emphasized that a precise description of the inciting event is crucial in order to direct injury prevention efforts.[14] If this step is poorly executed, then any preventative efforts built on these findings are bound to underperform or ultimately fail.

Each of these models highlights the complex nature of sports injuries. The injury risk associated with sports participation is unique to each player and always changing with repeated or prolonged exposure. Bittencourt et al.[25] expanded on previous models by noting that the majority of human health conditions are complex and that the reductionist view in sports injury research – simplifying a phenomenon into the sum of its parts and viewing causality in a linear and unidirectional way – has for the most part failed to consistently identify sports injury risk factors. They encourage taking a complex systems approach, moving away from trying to find isolated risk factors and moving to risk pattern recognition which looks to uncover the complex pattern of interactions among a web of determinants – a group of variables with varying degrees of weak and strong interactions.[25]

Injury surveillance - methodology

Since identifying the extent of the problem is the foundation and first step in sports injury prevention, an effective injury surveillance system is a central part of any study that examines the etiology, mechanisms, and risk factors associated with sport-related injuries. The methods used to collect data will have considerable implications on study findings,[30, 112] and are often the reason why comparison of results between studies is difficult.[45] A researcher or clinician in the field should strive to utilize methodology that allows the collected data to reflect as accurately as possible the 'true' real-world results within their cohort. Valid and high-quality injury surveillance systems will allow for more accurate monitoring of sports injury trends and better informed injury prevention strategies.[42] A significant challenge to conducting a high-quality surveillance system is in balancing one's limited available resources, so as to not over-burden those collecting the data or those providing the data, which could introduce bias and skew results. While there is no single solution for all use cases, it is important to match one's chosen methods to the desired outcomes.

What constitutes an injury

How one defines an injury, or 'recordable event', may be the primary methodologic factor that impacts results from injury and illness surveillance systems.[30] Some surveillance systems use a narrow injury definition while others utilize a broad definition designed to capture a greater number of complaints (Figure 2). The majority of studies utilize a narrow injury definition, either a time-loss or medical-attention definition.[30] The use of either definition is likely to provide reliable and relatively easy to collect results as only the most severe injuries will be recorded, thus minimizing the demand on personnel recording the data. Unfortunately, use of narrow injury definitions fails to provide the full picture concerning the burden of injury and illness in sports. A broad 'all complaints' definition has been widely recommended in sport-specific consensus statements.[30, 51] Recording of all complaints provides insight into problems that may alter performance and training participation but do not require the athlete to seek medical attention or withdraw fully from participation. This is especially relevant for *overuse* complaints that result in frequent exacerbations and may be managed with minor/moderate adjustments to training participation and performance.

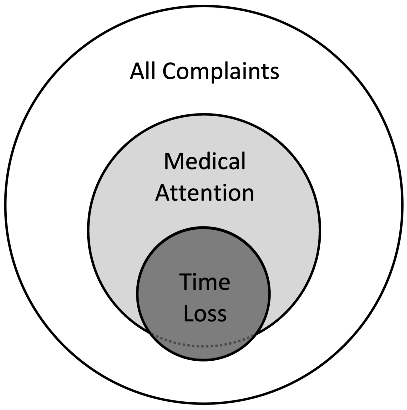

Figure 2. *Representation of the relative number of incidents registered using broad versus narrow injury definitions. Use of an 'all complaints' definition is designed to capture more complaints and likely provides a more accurate and complete understanding of the injury burden associated with these complaints. Adapted from Clarsen & Bahr, 2014.*[30]

Development of an overuse injury questionnaire, the Oslo Sports Trauma Research Center Overuse Injury Questionnaire (OSTRC-O), has enabled use of an 'all complaints' injury definition that is both valid and requires little time to complete.[33] The OSTRC-O utilizes 4 questions in which players report any pain related to their sport and the extent to which problems affect participation, training volume, and performance. This questionnaire can be used to collect data for any anatomical area that may be relevant for a particular sport (e.g., knee, low back, and shoulder, which were the three areas chosen as part of the original validation process for the questionnaire).[33] Regular administration of this questionnaire (e.g., weekly; secondary to its 7 day look back period), allows for active monitoring and insights into how these complaints change over time, specifically over the course of a full season.[32] Following the initial conception of this questionnaire, it has since been expanded to allow recording of all health problems (OSTRC Questionnaire on Health Problems; OSTRC-H), giving athletes the opportunity to provide additional information regarding the location and type of problem involved.[34] Finally, successful adoption of these questionnaires by researchers and sports organizations alike has resulted in minor revisions to these questionnaires to improve response adherence and the quality of data collection.[32]

How injuries are recorded

Once what constitutes a 'recordable event' within a specific injury surveillance system has been decided, it is important to determine *how* these problems will be recorded. The use of time-loss or medical-attention definitions lend themselves well to being completed by coaches and medical personnel. Time-loss injuries can be recorded by keeping a log of participants at each training or competition session and noting reasons for absences. Similarly, incidents requiring medical attention require the medical personnel to log each athlete encounter and provides the possible added value of having additional medical information included for each injury. While the medical-attention definition may work well in elite sporting environments with full-time medical personnel, it may not be feasible in many sporting environments that do not have the same financial and personnel support. Additionally, even in elite sport settings there are likely to be large differences in how recorders interpret what constitutes medical attention.[30] This has been highlighted through injury data collected from a youth football academy where a research-invested team physiotherapist recorded more than 8 times greater incidence of non-time-loss injuries compared to data collected by others without research interests.[123] Interesting to note was that the incidence of *time-loss* injuries was not different based on who was collecting the data in this study, leading to a recommendation for the use of time-loss definitions when comparing results between teams and seasons.[123]

Recording all complaints allows athletes to register their own complaints, likely through use of a questionnaire. The subjective nature of this presents its own strengths and limitations compared to the use of narrow injury definitions. While individual athletes will have different thresholds for how they interpret a problem, allowing athletes to record their own complaints eliminates the middle man and reduces the possible risk of systematic bias that comes with someone else's interpretation of what constitutes a recordable event.[30] Some have utilized paper questionnaires while many have incorporated these questionnaires into tech-friendly versions that can be completed online, through mobile apps, or with SMS text messaging.[30] With any form of implementation, it is important to take steps that will increase athlete adherence and motivation to avoid missing data or athletes failing to report complaints. Barboza et al.[16] investigated end-user perceptions of an online version of the OSTRC-H in which poor adherence was observed, with overall response rates of 50% across three sporting groups (judo, swimming, volleyball). Of interest was that response rates were roughly 80-100% the first few questionnaires of the season before progressively dropping to well under 50% after 10 to 11 questionnaires. To increase adherence from athletes when completing these questionnaires, the review panel that updated the OSTRC questionnaires recommends: (1) providing feedback to athletes, (2) timely follow-up by clinicians when responding to reported health problems, and (3) personal interaction that motivates athlete participation.[32]

Recording overuse problems in sports – the case of *beach* volleyball

While time-loss and medical-attention injury definitions may be appropriate in some sporting environments, Bahr[9] raises the question of "how appropriate this methodology is if it is applied to sports with few acute, traumatic injuries but a preponderance of overuse injuries." Bahr's study examined injuries among FIVB beach volleyball players by comparing time-loss injuries reported through a 'traditional' injury surveillance system with a survey reporting past and present knee, low back, and shoulder problems. Use of the time-loss injury definition resulted in a conclusion of very low injury risk, while survey data reported a high prevalence of knee, low back, and shoulder pain both during the present week (64%) as well as the prior two months (83%).[9] There are important differences between these two methods. Use of the pain survey allowed reporting of all symptoms, rather than specific injuries; this likely presents a more accurate view of the burden from these knee, low back, and shoulder problems, but limits further understanding related to specific injuries.[9] Since this paper by Bahr – discussing the methodology for recording overuse injuries in sports – was published in 2009, we have seen the creation and adoption of the OSTRC questionnaires. However, we are still lacking studies in volleyball that provide the true and accurate picture of injury burden as it pertains to common overuse injuries to the knee, low back, and shoulder. To provide framework for future investigations, Bahr made the following recommendations: (1) future studies should be prospective, with continuous measurement of symptoms; (2) valid instruments are needed to measure pain and relevant symptoms; (3) injury risk should be reported as *prevalence* and not incidence; (4) injury severity should be a measure of functional level and not just time loss from sports.[9]

Incidence versus prevalence

In order to compare injuries or health problems between teams, seasons, or studies, clinicians and researchers often discuss findings in terms of incidence or prevalence. Incidence reports the rate that *new* injuries/illnesses occur in a population during a given time.[12] To enable relevant comparisons across populations, it is advised to present this in relation to exposure (e.g., per 1000 h of player participation), rather than reporting per season or per year where differences exist between populations and make comparisons difficult.[112] Reporting incidence works well for acute, sudden-onset conditions (e.g., ankle sprains, finger sprains) but is not a good measure for chronic, gradual-onset conditions that have periods of remission and exacerbation.[12] For these overuse-type conditions, prevalence provides a better measure. Prevalence denotes the proportion of individuals that have an existing condition at any given time within a population.[12] In the case of volleyball, this could be the percentage of players that are suffering with patellar tendinopathy at a specific point in time (point prevalence). When measured regularly this can provide information about how the prevalence of this condition changes over the course of a season.[12]

Volleyball injuries – incidence, severity, location, type, and mechanism

To summarize the existing epidemiological literature and to see where knowledge gaps exist regarding injuries in elite volleyball, a systematic literature review was conducted (search strategy outlined in Table 1). Results from epidemiological studies, risk factor studies, and intervention studies were gathered to describe the incidence, characteristics, mechanisms, and risk factors for common volleyball injuries and are presented in the sections that follow.

Table 1*. Search strategy for the literature review on injury incidence in elite volleyball.*

Inclusion criteria	**Exclusion criteria**
Volleyball players (indoor)	Beach volleyball, sitting volleyball
Population: adults, 18 years and older	Children and adolescents
High-level, elite, university and professional players	High school or recreational players
Minimum duration of 1 season/year	Duration of < 1 season/year
Overall injury outcome with injury incidence or burden	Studies on specific injury types
Full article available in peer-reviewed journal	Abstract, conference paper, review, editorial, letter, or chapter
English language	Non-English language
Domain (combined with AND)	**Keywords (combined with OR within each domain)**
Sport	volleyball
Outcome	injur*
Analysis	incidence, burden, surveillance
Initial search results (PubMed, March 2022): 265	
Studies considered (after screening titles/abstracts): 20	
Studies included (after screening full text and reference lists): 14	

Studies examining volleyball injury epidemiology have primarily reported the incidence of injuries using one of three available methods (Table 2, Table 3, Table 4) – depending on the amount of exposure data: (1) injuries per 1000 h of participation; (2) injuries per 1000 athlete-exposures; and (3) injuries per player-season. Additionally, the injury definition (e.g., time loss, medical attention) greatly impacts the injury incidence presented across these studies.

***Table 2**. Injury incidence (per 1000 h) in volleyball.*[a]

Reference Design Country and period	Sex	Players / Level of play	Injuries	Injury definition	Incidence (per 1000 h)		
					Training	Match	Overall
Medical attention							
Juhan et al. (2021)[66] Prospective registration USA, 2003-2020	Female	108 players NCAA division I	804	An injury resulting from participation in an organized practice or competition, which required attention from an athletic trainer or physician; **medical attention**.	-	-	5.3 (F)
Bere et al. (2015)[21] Prospective registration International, 2010 to 2014	Male/ Female	32 FIVB NT events Senior NTs, Junior NTs (U-18, -19, -20, -21, -23)	440	Any musculoskeletal complaint newly incurred during match play and/or training during the event that received **medical attention**, regardless of time loss.	-	11.7 (M, senior) 10.5 (M, junior) 12.2 (F, senior) 7.8 (F, junior)	-
Pastor et al. (2015)[94] Prospective cohort Germany, 2007-08 to 2012-13	Male	72 player-seasons 1 pro team	186	Injury included if the team doctor consulted; **medical attention** (author note: 'blocking of the spine' included as an injury if treated by manual therapy).	-	-	4.38 (M, total) 3.30 (M, acute) 1.08 (M, overuse)
Aagaard & Jørgensen (1996)[1] Retrospective questionnaire Denmark, 1993-94 season	Male/ Female	137 players (67 M, 70 F) 16 teams (8 M, 8 F) 1st/2nd elite divisions	177	Injuries which handicap the player during play and/or require treatment (bandaging or **medical attention**) in order to continue playing, or completely prevent the player from playing (**time loss**).	3.5 (M) 3.9 (F)	5.8 (M) 2.9 (F)	3.8 (M) 3.8 (F)
				Medical attention (M/F)†	***3.7***	***9.2***	***4.1***
Time loss							
Bere et al. (2015)[21*] Prospective registration International, 2010 to 2014	Male/ Female	32 FIVB NT events Senior NTs, Junior NTs (U-18, -19, -20, -21, -23)	440	Any musculoskeletal complaint newly incurred during match play and/or training during the event that received medical attention; also reported **time loss**.	-	5.1 (M, senior) 2.1 (M, junior) 4.5 (F, senior) 2.6 (F, junior)	-
Verhagen et al. (2004)[114] Prospective cohort Netherlands, 2001-02 season	Male/ Female	486 players 50 teams (20 M, 30 F) 2nd/3rd divisions	100	Injury resulting from volleyball and causing the subject to stop activity, or resulted in subject not participating fully in the next planned sports activity; **time loss**.	1.8 (M/F) 2.3 (M) 1.5 (F)	4.1 (M/F) 3.8 (M) 4.2 (F)	2.6 (M/F) 3.0 (M) 2.4 (F)
Bahr & Bahr (1997)[11] Prospective cohort Norway, 1992-93 season	Male/ Female	273 players 26 teams (13 M, 13 F) 1st/2nd divisions	89	All acute injuries that resulted from a sudden event during organized training or competition, leading to **time loss** ≥ 1 day.	1.5 (M/F) 1.5 (M) 1.6 (F)	3.5 (M/F) 3.9 (M) 3.0 (F)	1.7 (M/F) 1.7 (M) 1.7 (F)
				Time loss (M/F)†	***1.6***	***3.9***	***2.1***
Male (MA, 3 studies)†					**3.5**	**10.5**	**4.1**
Male (TL, 3 studies)†					**1.9**	**3.9**	**2.4**
Female (MA, 3 studies)†					**3.9**	**7.8**	**4.6**
Female (TL, 3 studies)†					**1.6**	**3.6**	**2.1**

NT, national team; MA, medical attention; TL, time loss. †Median incidence reported.
[a]If a study included athletes that fell outside the criteria of the literature review (e.g., high school players or beach volleyball participants), only data from those meeting inclusion criteria are reported.
[*]Bere et al. (2015) included under time loss category, in addition to medical attention, as incidence data was presented for both definitions.

***Table 3**. Injury rate (per 1000 athlete-exposures) in volleyball – all these studies report data from the NCAA injury surveillance system.*

Reference Design Country and period	Sex	Players / Level of play	Injuries	Injury definition	Injury rate (per 1000 athlete-exposures)		
					Training	**Match**	**Overall**
Medical attention							
Chandran et al. (2021)[28] Prospective cohort USA, 2014-15 to 2018-19	Female	247 teams NCAA div I-III	2347	Injury that occurred from participation in an organized practice or competition and required **medical attention** by a team AT or physician, regardless of time loss.	6.79	6.58	6.73
Baugh et al. (2018)[18] Prospective cohort USA, 2013-14 to 2014-15	Male/ Female	64 team-seasons (9 M, 55 F) NCAA	593	Injury that occurred from participation in an organized practice or competition and required **medical attention** by a team AT or physician, regardless of time loss.	4.16 (M) 6.91 (F)	7.28 (M) 7.48 (F)	4.69 (M) 7.07 (F)
				***Medical attention (M/F)*†**	***6.8***	***7.3***	***6.7***
Time loss							
Kerr et al. (2018)[68] Prospective cohort USA, 2004-05 to 2013-14	Female	~50 teams/year NCAA div I-III	2149	Injury that occurred from participation in an organized practice or competition, required **medical attention** by a team AT or physician, and resulted in **time loss** ≥ 1 day.	3.80	3.83	3.81
Baugh et al. (2018)[18*] Prospective cohort USA, 2013-14 to 2014-15	Male/ Female	64 team-seasons (9 M, 55 F) NCAA	593	Injury that occurred from participation in an organized practice or competition, required **medical attention** by a team AT or physician, and resulted in **time loss** ≥ 1 day.	1.43 (M) 2.41 (F)	3.31 (M) 3.16 (F)	1.75 (M) 2.62 (F)
Reeser et al. (2015)[100] Prospective cohort USA, 2005-06 to 2008-09	Female	339,753 AE NCAA div I-III	1380	Any condition resulting in **time loss** ≥ 1 day.	4.12	3.93	4.06
Agel et al. (2007)[3] Prospective cohort USA, 1988-89 to 2003-04	Female	~109 teams/year NCAA div I-III	6941	Injury that occurred from participation in an organized practice or competition, required **medical attention** by a team AT or physician, and resulted in **time loss** ≥ 1 day.	4.10	4.58	-
				***Time loss (M/F)*†**	***3.8***	***3.8***	***3.2***
Male (MA, 1 study)					**4.2**	**7.3**	**4.7**
Male (TL, 1 study)					**1.4**	**3.3**	**1.8**
Female (MA, 2 studies)†					**6.9**	**7.0**	**6.9**
Female (TL, 4 studies)†					**4.0**	**3.9**	**3.8**

AE, athlete-exposures; AT, athletic trainer; MA, medical attention; TL, time loss.
†Median injury rates reported
*Baugh et al. (2018) included under time loss category, in addition to medical attention, as incidence data was presented for both definitions.

Table 4. *Injuries per player-season in volleyball.*

Reference Design Country and period	Sex	Players / Level of play	Injuries	Injury definition	Incidence (injuries per player-season)		
					Training	Match	Overall
Medical attention							
-	-	-	-	-	-	-	-
Time loss							
Cunado-Gonzalez et al. (2019)[39] Retrospective questionnaire Spain, 2012-13 season	Male/ Female	490 players (182 M, 308 F) 3 National leagues	463	Any mishap occurring during scheduled games or practices that cause an athlete to miss a subsequent game or practice session; **time loss**.	-	-	0.94 (M/F) 0.93 (M) 0.95 (F)
Augustsson et al. (2006)[5] Retrospective questionnaire Sweden, 2002-2003 season	Male/ Female	158 players (75 M, 83 F) Elite division	121	A volleyball injury, forcing the player to leave the court for the rest of the session and/or leads to reduction in level of training and/or matches; **time loss**.	-	-	0.77 (M/F) 0.68 (M) 0.86 (F)
Time loss ≥ 3 days							
Watkins & Green (1992)[121] Retrospective questionnaire Scotland, 1989-90 season	Male	86 players 1st division	46	Volleyball injury in which the degree of damage prevented the player, due to pain or other symptoms, from participation for ≥ 3 days; **time loss (≥ 3 days)**.	-	-	0.53 (M)

Overall incidence

An overview of studies reporting injury incidence in elite volleyball are presented in Table 2, Table 3, and Table 4 (subcategorized by injury definition and participant demographics). The majority of these studies utilized a prospective registration of injuries (10 of 14). Of the four studies[1, 5, 39, 121] utilizing retrospective questionnaires, three[5, 39, 121] did not have exposure data and were limited to reporting the number of injuries per player-season (Table 4). These studies, utilizing a traditional time-loss definition (≥ 1 day), reported 0.77 to 0.94 time-loss injuries per player-season among male and female volleyball players.[5, 39] Watkins & Green[121] utilized a more conservative time-loss definition (≥ 3 days) and, unsurprisingly, reported fewer injuries per player-season (0.53/player-season). These studies suggest that an average of one time-loss injury per season can be expected for most volleyball players and half of these time-loss injuries will result in at least 3 days of time lost.

A collection of five studies have reported data from the NCAA injury surveillance system between the 1988-89 and 2018-19 seasons (Table 3). The injury rate per 1000 athlete-exposures (AEs) has been reported for this data. Use of a time-loss injury definition reveals a median injury rate of 3.2 time-loss injuries per 1000 AEs compared to 6.7 medical-attention injuries per 1000 AEs. One study by Baugh et al.[18] presents the injury rate for both time-loss and medical-attention injuries. A 2.7-fold increase in the overall injury rate was reported when using a medical-attention injury definition compared with a time-loss definition (men: 4.69 versus 1.75 injuries per 1000 AEs; women: 7.07 versus 2.62 injuries per 1000 AEs), highlighting the importance and sensitivity of study findings based on this one methodologic factor alone.

Studies reporting injury incidence with full access to exposure data (Table 2) show an overall median injury incidence of 2.1 time-loss injuries per 1000 h and 4.1 medical-attention injuries per 1000 h. When it comes to the injury incidence in men's versus women's volleyball, the literature is mixed with some studies finding more injuries in men's volleyball and others observing more in women's volleyball. Generally, there does not appear to be any substantial difference in the overall injury incidence between men's and women's volleyball players.

Incidence of match versus training injuries and limitations in the literature

The overall body of literature reveals a higher injury incidence during match play compared to training (median: 3.9 versus 1.6 time-loss injuries per 1000 h and 9.2 versus 3.7 medical-attention injuries per 1000 h; Table 2). Differences in study methodology and populations reveals large variability – Aagaard & Jørgensen[1] utilized a retrospective questionnaire and reported as few as 2.9

medical-attention injuries per 1000 h among female players compared with Bere et al.,[21] who reported 12.2 medical-attention injuries per 1000 h using prospective registration from international women's competitions. Additionally, current studies likely under-report the real injury rates, as none of these studies have utilized an all-complaints injury definition. Overuse injuries are believed to be prevalent within the sport due to the repetitive nature of jumping and spiking, but none of these studies have utilized definitions to accurately detect the full magnitude of these problems. Bere et al.[21] examined injuries from the highest levels of competition during international team play and while concluding that time-loss injury risk was low, they suspected that the 20% of injuries that were considered overuse in their study was likely "a gross underestimate of the true magnitude of overuse problems in this elite player population." We have previously observed in the case of beach volleyball where traditional injury reporting failed to detect the high prevalence of overuse knee, low back, and shoulder problems;[9] and now it is becoming increasingly clear that we are lacking knowledge in this area when it comes to indoor volleyball.

This gap in the literature lays the foundation for Paper V in which we aim to develop a more accurate and complete understanding regarding the prevalence and burden of common overuse problems within the highest levels of men's volleyball.

Injury severity – days lost from participation

The mean time lost for all injuries was presented by two studies: Verhagen et al.[114] reported a mean of 4.3 weeks using a time-loss injury definition and Aagaard & Jørgensen[1] reported a mean time loss of 10-13 days using a medical-attention definition – unsurprising as use of a medical-attention definition includes injuries with no time lost from participation. Despite the mean time loss of only 10-13 days, players reported continued symptoms for a mean of 59 days,[1] hinting at the true burden of many of these injuries where players resume training and competition but continue to suffer from the symptoms associated with the injury.

Time-loss definition

Injury severity can be reported according to the consensus recommendation by Fuller et al.,[51] originally established for football injuries but widely adopted for other sports: slight (0 days), minimal (1-3 days), mild (4-7 days), moderate (8-28 days), or severe (> 28 days). Unfortunately, the injury epidemiology studies in this cohort of elite volleyball players utilized numerous variations in the specific cut-off points. To best compare the existing literature we will use a modified version of the Fuller et al.[51] recommendation and one that aligns with the latest International Olympic Committee consensus statement on reporting sports injury epidemiology data:[12] minor (≤ 7 days), moderate (8-28 days), or severe (> 28 days).

Most time-loss injuries were minor (≤ 7 days) with 57% of injuries (median; range: 42-62) being classified as such across the studies.[5, 11, 39, 68] Two additional studies reported 73-81% of injuries with time loss < 10 days.[3, 100] Moderate injuries followed with 31% of injuries (median; range: 21-38) resulting in time loss of 8-28 days and severe injuries (> 28 days) were the least common, comprising 20% of all injuries (median; range: 17-27).[5, 11, 39] These data suggest that coaches and staff could anticipate about half of all time-loss injuries to allow a player to return to participation within the week, while about 1 in 5 injuries would keep the player out for at least 4 weeks.

Medical-attention definition

Use of a medical-attention definition allows capture of many additional injuries that do not lead to time loss. This is evident as two studies reported 47-48% of all injuries resulted in no time loss.[21, 28] Three studies reported 72-78% of all injuries were minor (≤ 7 days) while only 2-7% of injuries are severe with > 28 days of time loss.[1, 21, 94]

Injury location

With a general knowledge of the overall incidence and severity of volleyball injuries, it is important to understand the specific joints and body regions that are most involved so targeted injury risk management approaches can be applied. Despite large variability between studies due to assorted study methodology and populations, most injuries in volleyball involve the ankle, knee, back, hand/fingers, and shoulder – 70% of all injuries involve these five locations (Table 5). Minor differences were observed between injuries from competition versus training. Notably, injuries involving the ankle made up a greater percentage of competition injuries compared to training (26% versus 17% of all injuries; Table 5). Injury risk management approaches may want to focus on these common injury locations to maximize the return on time and effort. Note that locations that regularly experience overuse problems may be underrepresented in these data as there is likely no sudden onset of symptoms and players often do not experience time loss. This is evident in a study by Bahr & Bahr[11] which only included acute injuries resulting from a sudden event. This resulted in knee injuries only accounting for 8% of all injuries, the lowest proportion of knee injuries observed compared to more than 10 other study populations (range: 11-30%; Table 5). Studies that included gradual onset and symptoms from overuse knee and patellar tendon problems reported a greater proportion of knee injuries.

***Table 5**. Proportion (%) of all reported injuries based on **body region** in elite volleyball – two most common regions from each study highlighted with boxes, with the most common in bold text and shaded.*

1st author (year)	Head-face	Shoulder	Arm-elbow	Hand-fingers	Back-trunk	Hip-thigh	Knee	Lower leg	Ankle	Foot
Overall										
Chandran (2021)[28]	9	10	3	10	11	10	**15**	9	14	6
Juhan (2021)[66]	8	11	3	7	**20**	10	17	8	11	7
Cunado-Gonzalez (2019)[39]	1	15	2	9	6	6	18	5	**37**	
Baugh (2018)[18]										
Men	11	15	0	16	12	6	**18**	7	13	1
Women	8	8	3	8	12	12	**16**	8	14	8
Bere (2015)[21]										
Senior men	4	3	3	11	15	8	16	6	**29**	3
Junior men	7	10	1	**18**	9	7	14	11	17	8
Senior women	8	1	0	12	18	5	18	4	**27**	2
Junior women	6	8	3	17	8	8	11	6	**30**	2
Pastor (2015)[94]	1	8	3	11	**24**	6	23	6	11	4
Augustsson (2006)[5]	2	12	1	8	16	2	17	11	**23**	8
Verhagen (2004)[114]†	-	9	-	-	10	-	12	-	**41**	-
Bahr (1997)[11]δ	-	8	-	7	11	4	8	-	**54**	-
Aagaard (1996)[1]										
Men	-	13	3	**22**	11	-	17	-	16	7
Women	-	**22**	2	**22**	6	-	20	-	16	4
Watkins (1992)[121]	-	2	-	22	17	-	**30**	-	26	9
Practice										
Chandran (2021)[28]	8	12	2	9	12	10	**14**	11	12	6
Kerr (2018)[68]	6	10	2	8	13	13	14	6	**17**	5
Bere (2015)[21]	-	-	-	-	12*	-	13	-	**17**	-
Competition										
Chandran (2021)[28]	12	7	3	11	8	10	16	7	**19**	5
Kerr (2018)[68]	10	8	3	10	11	6	16	5	**26**	3
Bere (2015)[21]	-	-	-	10**	-	-	16	-	**31**	-
Overall (median)	**7**	**10**	**3**	**11**	**12**	**7**	**17**	**7**	**20**	**6**
Men	6	9	3	17	14	7	18	7	17	6
Women	8	9	3	11	12	10	17	8	15	5
Practice	**7**	**11**	**2**	**9**	**13**	**12**	**14**	**9**	**17**	**6**
Competition	**11**	**8**	**3**	**11**	**10**	**8**	**16**	**6**	**26**	**4**

† 'Other lower extremity injuries' is 21% and 'Other upper extremity injuries' is 7%

δNumbers estimated from figures presented in manuscript

*Proportion of lower back injuries is 12%, all trunk/back injuries may be higher

**Proportion of fingers/thumb injuries is 10%, all hand injuries may be higher

Injury type and diagnosis

The most common injury types in volleyball are joint/ligament sprains (range: 23-36% of all injuries),[18, 21, 28, 39] followed by tendinopathies (range: 15-19%)[18, 28, 39] and muscle strains (range: 14-21%).[18, 21, 28, 39] The recent awareness and focus on concussions within the sports medicine community has provided current data in which concussions make up 6-7% of injuries.[18, 28] Other types of injuries such as abrasions/lacerations (0%),[28] contusions (typically 1-6%, but 13% during international competitions),[18, 21, 28, 39] dislocations/subluxations (1-4%),[18, 28, 39] fractures (2-6%),[18, 28, 39] illness/infections (1-3%),[18, 28] and muscle spasms (2-4%)[18, 28] are each responsible for a smaller proportion of injuries.

Injury mechanisms

How these injuries normally occur

Overall, roughly 25% of volleyball injuries are overuse (range: 24-26%)[18, 28] and an additional 25% are noncontact (23-27%).[18, 28] The remaining 50% of injuries are the result of contact with another player (12-14%),[18, 28] contact with the ground (12-14%),[18, 28] contact with the ball (12-13%),[18, 28] contact with another apparatus (0-1%),[18, 28] out of bounds contact (1%),[28] and other/unknown mechanisms (range: 10-11%).[18, 28] Volleyball is not traditionally thought of as a contact sport, but the sport demands of jumping and diving for balls results in its fair share of contact-related injuries. This is noticeable during match play where a greater proportion of match injuries result from contact with another player (17-30%) compared to training injuries (9-15%).[3, 28, 68]

Sport-specific activity

The majority of volleyball injuries are related to two sport-specific activities: (1) blocking (median: 28%; range: 14-41%)[1, 28, 39, 100, 121] and (2) spiking (23%; 11-32%).[1, 28, 39, 100, 121] Blocking and spiking both involve repetitive jumping during training and competition (e.g., result in possible overuse injuries) and bring multiple players into a confined space, increasing the risk of collisions and precarious landings involving others. The remaining known injuries collectively occur during general play (27-34%),[28, 68] with some from defensive dig attempts (11%, 0-16%)[1, 28, 39, 100, 121] and very few from serving (2%, 1-3%)[1, 28, 39] and setting (2%, 2-4%).[1, 28, 39, 121]

Injuries – positional differences

A player's position dictates his role on the team and will greatly impact what type of injuries he is at risk of sustaining. Table 6 reveals the distribution of all volleyball injuries based on playing position. A quick glance appears to show that outside hitters and middle blockers experience the greatest number of injuries. And while this may be true, it is important to remember that the starting lineup in volleyball includes two outsides and two middles, with only one setter, opposite, and libero. Therefore, teams usually carry more outsides and middles on their roster compared to other positions, resulting in a greater proportion of injuries experienced by these two groups. Unfortunately, only one study controlled for exposure and provided position-specific injury rates. Bere et al.[21] found middle blockers (17 injuries per 1000 match hours) to have the highest injury incidence during international match play. Outsides and opposites (11 and 10 injuries per 1000 match hours, respectively) were next with setters and liberos (7 injuries per 1000 match hours each) experiencing the fewest match-related injuries. Middle blockers play in the center of the front row and are substituted off the court in favor of liberos/defensive specialists in the back row. This results in middles, with nearly all their exposure in the front row, blocking and spiking almost exclusively, which is where the majority of volleyball injuries occur. Liberos, in comparison, are back row players with relatively low injury risk – but they do experience the highest proportion of finger and thumb injuries (~21% of all libero injuries), likely due to defensive overhand dig actions.[21]

Front row or back row

The majority of injuries happen in the three front-row positions (67-73%).[3, 5] Furthermore, 89% of all known acute injuries reportedly occur at the net.[11] This is where the greatest congestion occurs as multiple players from both teams move to position themselves accordingly and jump simultaneously with hopes of successful attacks and blocks.

Table 6*. Distribution (%) of all reported injuries based on* **playing position** *in elite volleyball.*

Reference	Libero	Middle blocker	Outside hitter	Opposite	Setter	Other/ unknown
Overall						
Chandran et al. (2021)	16	22	**27**	10	14	10
Pastor et al. (2015)	5	31	**42**	12	9	-
Practice						
Chandran et al. (2021)	15	23	**27**	11	13	11
Competition						
Chandran et al. (2021)	18	20	**29**	9	16	8
Reeser et al. (2015)	12	28	**37**	8	12	3

A conventional injury presentation

At this point, the picture of what common volleyball injuries look like is taking shape. Putting everything together we could argue that many volleyball injuries tend to: (1) take place during matches; (2) involve relatively little time-loss but with symptoms nagging for months; (3) involve the ankle, knee, back, hand/fingers, or shoulder (and the associated ligaments, tendons, and muscles); (4) result from contact with another player, the ground, or the ball – or present as overuse with gradual-onset (likely still resulting from *repetitive* contact with the ground or ball); and (5) be associated with blocking or spiking while playing in the front row.

Injury attention and treatments

We have discussed the use of time-loss injury definitions and the consequences from these injuries, time loss from sport. But rarely are the additional sequelae from these injuries discussed. Cunado-Gonzalez et al.[39] reported that 95% of time-loss injuries among elite Spanish players received some type of treatment. Nearly all of these injuries received physical therapy (97% of treated injuries), with many receiving medication (64%), orthoses/splints (14%), surgery (6%), and injections (4%).[39] The type of treatments offered and the individual rates that each intervention is used will be highly variable across leagues and teams as it will depend largely on access to local medical support services. The important note here is that these injuries are more than numbers on a page or in a study, many players will have complex paths to recovery prior to full return to sport and performance – reminding us of the value that an effective injury risk management approach can have.

Acute volleyball injuries - mechanisms and risk factors

We have highlighted that injuries primarily involve one of five locations: (1) ankle; (2) knee; (3) back; (4) hand/fingers; and (5) shoulder. In these next two sections, we will examine the injury mechanisms and risk factors associated with the most prevalent acute and overuse injuries. Gaps in the literature will also be highlighted, noting where the papers that form this thesis can add to our understanding and assist with managing injury risk.

Acute versus overuse

Not all injuries are created equal. Aagaard & Jørgensen[1] reported that ankle and finger injuries were primarily acute injuries (86% and 97%, respectively) while knee and shoulder injuries were overwhelmingly reported as overuse (88% and 90%). This dichotomy is of interest as there are clearly unique injury mechanisms between these distinct injury types.

Ankle sprains

Ankle sprains are the most common acute volleyball injury, accounting for 20-54% of all time-loss injuries.[3, 5, 11, 18, 100, 114] They are more likely to result during competition than training (relative risk: 1.6 to 3.9).[3, 11, 13, 100] Data from the FIVB Injury Surveillance System reveals that ankle sprains account for 26% of all injuries during international competition (match play: 31%, training: 17%).[21] Meanwhile, in NCAA women's volleyball, ankle sprains accounted for 44% of all match injuries and 29% of all training injuries.[3] And with 31% of ankle sprains in NCAA women's volleyball resulting in time-loss of 10$^+$ days and an average time-loss of 4.5 weeks among Dutch players, ankle sprains are not inconsequential.[100, 114]

Risk factors

A history of prior ankle sprain is the leading known risk factor for a future sprain. Studies have reported 67-79% of players who experienced an ankle sprain had a previous injury to the involved ankle.[2, 11, 13, 114] Moreover, there appears to be a time-sensitive relationship where the players at greatest risk are those with a recent history of an ankle sprain – 9.8-fold increased risk following a sprain within the preceding six months and 5.6-fold increased risk following a sprain 6-12 months prior.[11] Implementation of an ankle injury prevention program that included education, proprioceptive training, and volleyball-specific technical drills found a 47% reduction in the incidence of ankle sprains post-intervention; suggesting that the risk of injury is modifiable.[15]

Injury mechanisms

Ankle sprains in elite men's volleyball are believed to take place primarily at the net with as many as 86% of sprains occurring in the front row.[13] Contact with another player accounts for 47-87% of ankle sprains.[5, 11, 21, 114] The majority of ankle sprains are reported to take place as a result of landing on the foot of an opponent (68%) or on the foot of a teammate (19%).[11] This is traditionally observed when an attacking player jumps and reaches for a ball that is set too low, fast, or tight to the net – causing the attacker to come close to the net and land on or partially beyond the centerline.[11] The FIVB rules allow for a player's foot to land on the centerline, directly underneath the net, and even land beyond the centerline into the opponent's court as long as part of the player's foot remains in contact with the line or directly above the line.[43] This creates a 'conflict zone' where blockers and attackers from both teams are allowed to land in the same space under the net, supposedly leading to the high number of ankle sprains within the sport. Data from elite domestic leagues suggest that ankle sprains are often the result of player contact while blocking (40-63%)[1, 5, 13, 39, 100] and spiking (21-28%).[1, 13, 39, 100] Blockers are at greater risk than spikers, likely a result of a tactical advantage where blockers jump slightly after an attacking player, and as a result, are at risk of landing on the foot of an already landed attacker in the 'conflict zone' under the net.[13] Additionally, it is common for two or three blockers to jump next to each other when trying to stop an attacking player; any lateral movement from one or more blockers can cause a player to drift and result in one blocker landing on the foot of another.

The relationship between ankle sprains and the sport-specific actions of blocking and spiking were observed in studies consisting of national elite-level players – competing domestically in Denmark, Norway, Spain, Sweden, and the United States – and primarily using retrospective questionnaires;[1, 5, 13, 39] with only one including prospective registration of data.[100] No data are available from the highest level of play at the international level. Findings from the FIVB Injury Surveillance System reveal that the most common injuries in both men's and women's senior- and junior-level players involve the ankle.[21] Therefore, investigation of the actual sport-specific injury situations and mechanisms that lead to ankle injuries among world-class players is of interest (Paper I).

Precise description of the inciting event

We previously discussed the 4-step injury prevention research model introduced by van Mechelen et al.,[112] in which the second step is to identify the risk factors and mechanisms associated with sports injuries. Bahr & Krosshaug[14] expanded on this step by stressing the importance of a precise description of the inciting event, including not just the biomechanical description but also the sport-specific playing situation. Unfortunately, there is limited reliability of questionnaire data from players and witnesses to provide this important information as injuries happen quickly and often involve other players.[14, 70] To best understand the sport-specific factors involved with ankle sprains, it is recommended to perform a detailed video analysis of actual injury situations.[14, 70] A systematic video analysis has previously examined ankle injuries in football,[4] but never in sports with predominantly landing-related injuries.

Furthermore, lateral ankle sprains have traditionally been thought to result from rapid inversion in a *plantarflexed* position. Case studies examining the kinematics associated with ankle sprains have contrasted this. Through use of model-based image-matching of recorded injuries[48, 49, 88] and marker-based motion analysis from actual injuries while running and cutting,[49, 69] researchers have described the injury, in this limited number of cases, as occurring in a neutral or dorsiflexed position, not plantarflexion. Further assessment of the specific injury kinematics from a larger number of cases is of interest, including landing-related injuries which have not been examined. This question was investigated in Paper I.

Hand/finger injuries

Injuries to the hands and fingers account for 11% (median; range: 7-22%) of all injuries across a wide range of studies and methodologies (Table 5). Two studies reported as many as 22% of all injuries sustained to the hands and fingers.[1, 121] Aagaard & Jørgensen[1] used a medical-attention injury definition that specifically referenced use of bandaging to continue playing, while Watkins & Green[121] used a time-loss definition of at least 3 days lost. Use of these particular definitions may be why a greater proportion of hand and finger injuries were observed in these studies. Injuries to the hand and wrist primarily involve the fingers. Bere et al.[21] reported 11% of all injuries involved the fingers and thumb while just 3% were to the hand and 1% to the wrist. Aagaard & Jørgensen[1] reported finger injuries resulted in minimal days of absence from sport (mean: female – 6 days; male – 3 days) but symptoms remained for an average of 49 to 60 days (females and males, respectively). These findings are consistent with the notion that finger injuries are prevalent and typically require minimal time loss from sport, despite players continuing to play with symptoms for weeks and months.

In an atypical dataset examining the most severe hand injuries (those presenting to a trauma department), 39% of hand injuries were sprains and strains, 25% were fractures, and 16% were contusions.[22] At a 5-year follow-up, 28% of patients reported stiff and crooked fingers with limitations and tenderness in certain movements.[22] While many acute finger injuries are minor and can be managed with minimal or no time loss from sport, more substantial injuries are not entirely unusual.

Injury mechanisms

Finger injuries are mainly caused by contact with the ball (77%);[21] specifically, the majority of known finger injuries occur while blocking (66-81%).[1, 39] This is evident as players frequently make contact with the ball through their hands and fingers while blocking, either immediately following a hard struck ball by an opposing player or sometimes even contacting the ball at the same time. Perhaps not as obvious is that backrow players, liberos in particular, are susceptible to finger injuries due to defensive overhead digs of hard-driven balls.[21]

Overuse volleyball injuries - mechanisms and risk factors

There is no question about the substantial impact acute injuries have within volleyball and their potentially lasting effect on individual players. For years, however, overuse injuries have been overlooked and underreported by sports medicine researchers. Traditional injury reporting methods using time-loss or medical-attention definitions are not sufficient to detect most overuse problems in which athletes continue to train and compete without missing team events. Despite using less-than-optimal methodology, early studies revealed three distinct areas where these overuse injuries are most commonly observed: knees (20-33%), shoulders (20-32%), and backs (18-32%).[5, 114]

Use of an overuse injury questionnaire (OSTRC-O) within high school volleyball found a high average weekly prevalence of knee problems (36%), followed by shoulder (16%) and low back problems (14%) during a 13-week study window.[31] Studies examining the weekly prevalence of knee, low back, and shoulder complaints among professional players are needed and the extent to which these complaints change over the course of a full season is unknown. Paper V examines this with the goal of presenting a more accurate and complete picture of the real injury burden and impact on performance from knee, low back, and shoulder problems.

Knee injuries

Patellar tendinopathy

Knee injuries in volleyball are primarily overuse (88%), with patellar tendon problems being the primary culprit.[1] Patellar tendinopathy, commonly referred to as jumper's knee, is an overuse injury that affects a large number of athletes participating in sports that require a lot of jumping – and, as a result, landing. Other sports, such as basketball and athletics, are afflicted by jumper's knee, but volleyball players have the greatest prevalence with as many as 45-51% reporting complaints at any time (basketball: 32%, 2nd highest).[74, 75] Lian et al.[74] found players with symptoms had a mean age at onset of 18.8 years (range: 13.5-25.9) with the average duration of current symptoms lasting 3.5 years.

Clinical presentation

This condition expresses itself as pain in the front of the knee that is directly related to sport. Diagnosis is primarily made based on history of localized pain to the inferior patellar pole or at the insertion of the quadriceps tendon (sometimes referred to as quadriceps tendinopathy) that is associated with athletic activity.[74, 75, 103] Among elite junior-level players to develop jumper's knee symptoms, 25 out of 28 (89%) developed symptoms at the proximal patellar tendon with the remaining 3 developing symptoms at the quadriceps insertion.[115] Pain on palpation can be used to confirm and clarify an athlete's history.[96] Clinical diagnosis has historically also been performed in conjunction with imaging; however, it is important to note that a disconnect exists between pathology observed on imaging and pain.[73, 103] Cook et al.[36] demonstrated that *pathologic* tendons are frequently observed in the imaging of asymptomatic athletes with pain-free function while Lian et al.[73] reported similar observations in volleyball players. In a prospective study with junior-level players, Visnes et al.[117] reported baseline ultrasound changes (hypoechoic areas, odds ratio [OR] 3.3; neovascularization, OR: 2.7) were associated with increased risk of developing jumper's knee complaints, although they noted a lack of a one-to-one relationship between pain and these structural changes. A detailed history should be the primary means for making an accurate diagnosis of current or previous jumper's knee symptoms; other clinical tests (e.g., tendon pain during single leg squat, ultrasound, and Victorian Institute of Sport Assessment) can be used as needed for further confirmation.

Risk factors

Among younger players (elite high school), boys are three to four times more likely to develop jumper's knee symptoms compared to girls.[116] Position also appears to play a role, as Lian et al.[74] observed jumper's knee to be most prevalent among outside hitters (67%) and middle blockers (64%), followed by setters (22%) and liberos/defensive specialists (17%). Malliaras et al.[80] examined associations between tendinopathy and a variety of measures (ankle dorsiflexion range, sit and reach flexibility, ankle plantarflexion strength, jump height, volleyball experience, and off-season activity levels). The only significant finding was that players with tendinopathy had decreased ankle dorsiflexion range of motion.[80] Unfortunately, this relationship is merely a correlation and we do not know if decreased dorsiflexion range is a possible cause or consequence of patellar tendinopathy. Few studies have examined the biomechanics of jumping and landing in relation to patellar tendinopathy. There appear to be group differences in ankle and knee moments and altered jump/landing strategies between those with and without symptoms; similarly these findings are limited as they are also correlations.[23, 24] Of interest, players with recent patellar tendinopathy used an altered landing mechanism to avoid tendon loading while players with a history of past patellar tendinopathy used a stiffer landing strategy.[23] While only an observed relationship, landing strategies likely need to be considered either proactively or during the management of athletes with jumper's knee symptoms.

Jumper's knee paradox

The jumping ability of volleyball players has been an area with some of the most interesting findings regarding risk factors for jumper's knee. A 5-year prospective study with elite junior-level players discovered that the players who went on to develop patellar tendinopathy during their subsequent three years in the program had significantly better baseline counter-movement jump tests upon entering the program compared to those who did not develop symptoms (OR: 2.1 per centimeter difference).[115] This has led to the concept of the *jumper's knee paradox* – where the most talented jumpers are at increased risk for jumper's knee and jumping ability itself is a risk factor for developing symptoms.[115] Additional studies have compared the jumping ability of players with current symptoms compared to players without symptoms and found that players with jumper's knee continued to perform better in jump tests, particularly in ballistic tests that require large eccentric loads.[72, 74]

Training load

Weekly training and match exposure have both been identified as important risk factors for developing jumper's knee at the elite junior level.[10, 116] The strongest predictor was match exposure with an odds ratio of 3.9 for every extra set played per week while volleyball-specific training had an odds ratio of 1.7 for every additional hour of training per week.[116] In this particular study, those who developed symptoms performed, on average, nearly 3 additional hours of volleyball training each week compared with asymptomatic athletes, both while attending the volleyball academy (14.9 versus 12 h/week) as well as prior to attending the academy (10.5 versus 7.6 h/week).[116] Ferretti et al.[44] interviewed 407 players from various divisions in Italy and observed an apparent dose-response relationship where the more days of training and matches per week, the greater prevalence of jumper's knee (2 sessions/week: 3%; 3x/week: 15%; 4x/week: 29%; >4x/week: 42%).

These studies highlight a clear relationship between training volume and jumper's knee complaints in volleyball. However, Bahr & Bahr[7] have since noted that time trained may not be a valid measure of jump load as substantial between-player variability in jump count has been observed within junior-level players. They observed jump frequency ranging from 6 to 128 jumps/h among boys and 3 to 22 jumps/h among girls, denoting that an hour of training for one athlete is not the same as an hour for another.[7] These findings suggest that jump volume, rather than training volume (number of hours or sessions/week), may be a more valid risk factor for jumper's knee.[7]

Jump load

Historically, manual counting of jumps through direct observation or video analysis was the only method available to obtain a measure of jump load, a very time-consuming method.[7] This would provide the total number of jumps performed, but would lack a measure of jump intensity or jump height. With advancements in technology, we may be able to use an inertial measurement unit (IMU) to measure not only jump count, but also jump height. Two relatively small studies have reported acceptable validity of a commercially available IMU with adolescent volleyball players.[29, 78] Use of this device has grown rapidly among university, professional, and national teams, yet this device has not been validated with professional volleyball players.

Therefore, the aim of the second study forming this thesis was to assess the validity and reliability of this method to count jumps and measure jump height in male professional volleyball players (Paper II).

Use of a valid and reliable device to measure volleyball-specific jump counts and jump heights opens opportunities for coaches and support staff to monitor training and competition jump load in real time. While this is a relatively novel approach in volleyball, other sports such as baseball and its organizations have monitored pitching loads and implemented strict rules regarding pitch counts for adolescent players and guidelines for professional pitchers in an effort to limit overuse injuries to the shoulder and elbow.[35, 47, 77, 92] As a starting point, the jump demands required for each position during a full season of professional volleyball is unknown. Players and coaches are unable to effectively prepare for a full season of volleyball's intense jump demands and are unable to truly tailor training programs for specific position groups. Additionally, players rehabilitating from injury have limited frame of reference for the specific jump demands expected of them upon full return to training and competition. Furthermore, while Bahr & Bahr[7] observed large interindividual jump variability among junior-level players, individual jump variability among professional players has not been investigated.

Therefore, the aim of the third study forming this thesis was to examine position-specific jump demands required for training and competition during a professional volleyball season and to investigate the individual variability associated with jump load (Paper III).

Playing surface

An additional factor related to training and jump load is the surface that players train and compete on. In 1984, in one of the first studies to examine jumper's knee in volleyball, Ferretti et al.[44] noted that symptoms occurred most often among athletes playing on hard surfaces, such as cement or linoleum, rather than hardwood. The playing surface may not be a significant factor for many high-level athletes playing on hardwood courts in developed countries. However, as the sport of volleyball has benefited recently from rapid growth, less-than-ideal playing surfaces may be a significant contributing factor for those playing in developing nations, younger age groups, or anyone playing where limited financial support is available to cover the associated expenses for high-level hardwood courts and gymnasiums.

Shoulder injuries

The high ball velocities seen in elite volleyball result in large loads transferred through the athlete's shoulder. The point prevalence of players with current shoulder complaints has been reported in elite junior-level players (16%, Norway)[31] and in university players (22%, Iran).[87] Reeser et al.[101] reported a season-prevalence of 43% and a lifetime-prevalence of 58% among collegiate club-level players – with 46% of those athletes noting decreased sport performance as a result of their shoulder problems. In a study examining competitive amateur players with shoulder pain, players reported onset of symptoms of more than 3 years (mean: 40 months, range: 2-180 months) with 60% of players having to take time off from volleyball due to shoulder pain (mean: 96 days, range: 7-365 days).[65] Additionally, 77% of players reported that pain limits how hard they can spike and 60% noted pain with hitting to all locations of the court.[65]

Knowledge gap at the highest levels

The evidence is clear, shoulder problems are common in volleyball and afflict players from all skill levels. However, research examining the prevalence and consequences of shoulder complaints has only been performed with junior and amateur players, leaving little known about the most elite players. Paper V attempts to fill this knowledge gap as it aims to provide a more accurate and complete understanding regarding the weekly prevalence and burden of shoulder problems – in addition to knee and low back problems – within the highest levels of men's volleyball, including the role that preseason complaints, match participation, player position, team, and age have on complaints.

Risk factors

Prospective studies examining risk factors for shoulder complaints in volleyball are almost non-existent.[50, 120] Instead, nearly all of the studies that focus on the shoulders of volleyball players have reported either normative data or examined group differences between players with current shoulder complaints compared to those without. Nevertheless, based on what we do know, the strongest risk factor appears to be a history of past shoulder pain (OR: 9.3).[50] This finding is consistent with the overall body of sports injury research in that previous injury puts you at an increased risk for future injury.[52] Player position also plays a role as attackers (outside hitters, opposites, and middle blockers) experience a greater proportion of shoulder injuries compared to setters and liberos.[21, 101] One retrospective study assessed service style and found athletes who utilized a float serve were less likely to have experienced shoulder problems compared to those using a jump serve or top-spin serve; it is unknown if attackers tend to self-select and also perform jump or top-spin serves more often or if serve type does in fact impact one's injury risk.[101]

Muscle strength

One prospective study by Forthomme et al.[50] reported that players who went on to develop shoulder pain during the season were weaker in both eccentric internal rotation (IR) and eccentric external rotation (ER) strength during a preseason isokinetic assessment. Although not statistically significant, there was also a noteworthy trend that players who went on to develop shoulder pain were weaker in both IR and ER concentric strength during preseason testing.[50] One additional prospective study with a small sample size (7 of the 16 players developed shoulder problems) reported injured players had a muscle strength imbalance with relative eccentric ER weakness compared to concentric IR strength during a preseason isokinetic assessment.[120] Based on very limited evidence, there appears to be some relationship between shoulder strength deficits and players who go on to develop shoulder problems, but further studies are needed to fully understand this relationship. While not always the case, it is worth noting that athletes with current or previous shoulder problems have been shown to have continued shoulder strength imbalances, with decreased ER strength relative to IR strength often observed.[50, 101, 108]

Other possible risk factors

A few additional items have been observed in players who present with shoulder complaints compared to those without. With limited studies examining risk factors for shoulder complaints in volleyball, we are left to speculate if these additional items are either: (1) adaptations resulting from athletes continuing to play through shoulder pain, or (2) actual risk factors that precede shoulder complaints. One study found poor single-leg squat control, coracoid and pec tightness, altered scapula positioning, and restriction of flexion range of motion more prevalent in those with current shoulder complaints.[101] Meanwhile, a study comparing the upper arm kinematics during a volleyball spike between players with and without a history of shoulder injury found no differences between the two groups.[86] Mohseni-Bandpei et al.[87] examined shoulder pain within a variety of sports, including volleyball, and found a higher body mass index, more than 5 years of practice, playing more than 4 days per week, and playing at the national level were all associated with having a history of shoulder pain. These findings are limited, but in principle, appear consistent with earlier discussions in which the most talented volleyball players have the greatest risk of injury (e.g., players that developed jumper's knee jumped the highest, trained the most, and competed at the highest levels).

Sport-specific adaptations

Volleyball players have been shown to have a number of sport-specific adaptations around their shoulders which result in differences between their dominant and non-dominant sides. These are considered normal adaptations to sport, as they are commonly observed and do not appear to contribute to shoulder complaints or injury risk. Bony changes are natural in the dominant arm of overhead athletes – as seen with humeral torsion – and lead to a perceived increase in ER ROM and decrease in IR ROM relative to the non-dominant arm.[59, 105] This is also observed in volleyball where decreased IR ROM is regularly reported – often with concomitant ER gain, but sometimes without.[27, 50, 101, 119, 120] Associated particularly with volleyball, infraspinatus muscle atrophy is prevalent in as many as 33% of volleyball players.[62] Sometimes diagnosed as suprascapular neuropathy, an observed wasting of the infraspinatus muscle is seen in both symptomatic and asymptomatic athletes and often goes undetected for years. This is typically an incidental finding that has no apparent relationship to common shoulder complaints, but an athlete presenting with loss of ER strength should be managed as any other player with decreased strength.

Ultrasound

In addition to these traditional musculoskeletal risk factors, ultrasound examination of the shoulder's subacromial bursa (SAB) and neovascularity of the supraspinatus tendon may be of interest (Paper IV). The role of the SAB is to protect the rotator cuff from wear; thickening of the SAB may result from chronic irritation of the bursa or may be a protective physiologic response during overhead sports and certain occupational work.[6] Thickening of the SAB has been associated with shoulder pain and injuries in overhead athletes. Galluccio et al.[55] observed subacromial bursitis on ultrasound in 63% of waterpolo players with pain compared to roughly 24% without pain. Additionally, SAB thickness was associated with pain in open-water endurance swimmers after completion of the event.[37] This study with endurance swimmers was interesting as they assessed swimmers 4 months prior to the race, 2 weeks prior, and within 1 week following. Not only was SAB thickness associated with pain following the event, but SAB thickness increased with increased training volume (kilometers).[37] These findings suggest that some amount of SAB thickening is a pain-free normal adaptation to swimming load, while some circumstances of SAB thickening are associated with pain. SAB thickness has not been investigated in volleyball players or other overhead athletes, and its relationship with the development of shoulder complaints is unknown.

Research examining patellar and Achilles tendons has reported neovascularization and tendon abnormalities to represent risk factors for future development of symptoms.[60, 83] A systematic review and meta-analysis noted that tendon abnormalities on ultrasound were associated with a 5-fold risk of future symptoms in lower extremity tendinopathies.[83] And a large prospective study found a 6.9-fold increased risk of developing Achilles tendinopathy during the subsequent 12 months in asymptomatic runners with neovascularization, a stronger relationship than prior history of Achilles tendon complaints (OR: 3.8).[60] It is unknown whether similar findings can be expected in the upper extremity as the presence of neovessels in overhead athletes and their relationship with complaints still needs to be explored.

Prospective studies examining traditional risk factors for shoulder complaints in elite volleyball are needed, and the inclusion of shoulder tendon and bursa characteristics is of interest. Therefore, the aim of the fourth study forming this thesis was to examine the role of subacromial bursa thickness, neovascularization of the supraspinatus tendon, shoulder strength and range of motion, player position, and age in the development of shoulder-related complaints in professional volleyball players (Paper IV).

Low back injuries

Low back injuries are more common in volleyball than most other sports. Hassebrock et al.[57] examined lumbar spine injuries in NCAA athletes from 25 sports, over a 5-season period. Women's volleyball (4.9 injuries per 10,000 athlete exposures) had the 3rd highest injury rate, trailing only women's gymnastics (8.0 per 10,000 athlete exposures) and women's tennis (5.7 per 10,000 athlete exposures).[57] This rate of lumbar injuries in volleyball is substantially higher than both the combined women's sports (2.9 per 10,000 athlete exposures) and men's sports injury rates (2.6 per 10,000 athlete exposures).[57] Unfortunately, men's volleyball was not included in the study. Additionally, 88% of the injuries in women's volleyball were characterized as overuse or non-contact.[57] Noormohammadpour et al.[89] examined low back pain prevalence among female university athletes in Iran and reported a 20% point prevalence and 40% 1-year prevalence of low back pain among women's volleyball players.

Low back pain has been classified as a chronic condition with recurrent periods of symptom exacerbation – meaning one can expect most episodes to have reasonably short-term symptom resolution, often followed by another episode within a year.[41] This not only makes managing low back complaints challenging, but also makes studying and reporting the prevalence difficult as symptoms come and go throughout the season. Studies are needed to examine the prevalence of low back complaints over the course of a full season, especially in men's volleyball where information on low back complaints is particularly lacking. Paper V examines this with the goal of presenting a more accurate and complete picture of the real injury burden and impact on performance from knee, low back, and shoulder problems in men's volleyball.

Aims of the thesis

The overall aim of this project was to provide valuable insights into the etiology of volleyball injuries, which lays the foundation for managing injury risk within the highest levels of the sport. We focused on injury burden, risk factors, and mechanisms leading to common injuries and complaints among elite volleyball players.

One study examined mechanisms leading to ankle injuries (Paper I), two studies explored principles of jump load and its relevance to knee injuries in volleyball (Papers II and III), one investigated risk factors for shoulder complaints (Paper IV), and the final paper investigated the prevalence and burden of knee, low back, and shoulder complaints (Paper V).

The specific aims addressed in the five papers were:

1. To describe the injury situations and mechanisms of ankle injuries in world-class volleyball based on systematic video analysis of injuries reported through the Fédération Internationale de Volleyball (FIVB) Injury Surveillance System (Paper I).

2. To evaluate the validity and reliability of a commercially available wearable device, the Vert, to count jumps and measure jump height in professional volleyball players (Paper II).

3. To examine position-specific jump demands required for training and competition during a professional volleyball season and to investigate the individual variability associated with jump load (Paper III).

4. To examine the role of subacromial bursa thickness, neovascularization of the supraspinatus tendon, shoulder strength and range of motion, player position, and age in the development of shoulder complaints in professional volleyball players (Paper IV).

5. To develop a more accurate and complete understanding regarding the weekly prevalence and burden of knee, low back, and shoulder problems within the highest levels of men's volleyball – including the role that preseason complaints, match participation, player position, team, and age have on complaints (Paper V).

Methods

This thesis is based on five studies, with each study resulting in a corresponding original research paper. Paper I is a systematic video analysis that examined the volleyball-specific injury situations and mechanisms of ankle injuries reported through the FIVB Injury Surveillance System. Paper II is a validation and reliability study that examined the Vert device, a commercially available wearable device, and its ability to accurately and reliably count jumps and measure jump height. Upon successful validation of the Vert device, Paper III investigated an entire season of jump load for a men's professional team that wore Vert devices daily during training and competition – position-specific jump demands and individual variability associated with jump load were examined. Paper IV investigated risk factors for shoulder complaints in professional volleyball players, including traditional musculoskeletal measures and more novel measures of the subacromial bursa and tendon neovascularization. The final paper (Paper V) investigated the prevalence and burden of knee, low back, and shoulder complaints in men's volleyball.

Study design and population

Video analysis of ankle injuries (Paper I)

Injury and video recordings

We analyzed video recordings of injuries to the ankle that were reported through the FIVB Injury Surveillance System from all major men's and women's senior-level tournaments (World Championships, World Cup, World Grand Prix, World League, and Olympic Games) from September 2010 through November 2014. There were 34 major FIVB tournaments during this time and the Injury Surveillance System protocol was followed in 23 of these. The FIVB Injury Surveillance System is based on prospective registration of injuries, where the medical staff of participating teams are requested to provide daily reports on all newly incurred injuries.[21] We requested video footage from the FIVB archives of all ankle injuries with subsequent time loss (n = 32); of these, 27 were available on video. Video review revealed that the injury situation was not visible in two cases and unclear in one case, resulting in 24 acute ankle injuries available for analysis. These 24 injuries included 3 injuries captured from one camera angle, 8 from two camera angles, 9 from three angles, 3 from four angles, and 1 from six camera angles.

Video analysis

Five experts in the field of volleyball and sports medicine participated in the video analysis, following similar protocols to previous video analysis studies.[19, 20] First, three of the experts reviewed the videos and came to a consensus on the injury index frame – the first frame in which an abnormally large movement occurred outside the expected normal range of physiological motion. Next, all five analysts independently reviewed the videos and completed an assessment form for each case that included a combination of open and closed questions evaluating playing situation, center line infringement and the mechanism of injury. Finally, the individual results were collated, and any discrepancies were discussed by the same three experts reviewing the remaining cases until consensus was determined.

Validation of Vert device: jump counts and jump height (Paper II)

This study was conducted in two stages. The first stage examined the validity of the commercially available inertial measurement unit (IMU), Vert Classic, to accurately count jumps in men's volleyball. The second stage assessed the validity of the device to measure jump height.

Jump count

Fourteen male professional volleyball players from an elite club in Qatar wore Vert devices during three practice sessions (3.4 h in total) and two league matches (nine sets, 3.7 h). All practice and match sessions were recorded and analyzed by two volleyball experts. Each jump was individually coded with the time, jump type, and player identity. Jumps recorded by the device were compared against visual observation to observe the number of true positives (jumps recorded by the Vert device and observed on video), false negatives (jumps not recorded by the device but observed on video), and false positives (jumps recorded by the device but not observed on video).

Jump height

The second stage of this study examined the Vert device for jump height validity and reliability through a series of volleyball-specific jumps and countermovement jumps. Ten male professional volleyball players and 12 male recreational athletes participated, providing a large distribution of jump heights. Participants wore two devices around their waist – as recommended by the manufacturer – to examine interdevice reliability, and a third and fourth device around their chest and lower leg to assess real-world use cases by some athletes. Individuals first performed a series of easy (50%), medium (75%), and maximal effort countermovement jumps on a force plate. Next, participants performed a series of submaximal and maximal effort vertical jumps using a Vertec: (1) 1-hand reach; (2) 2-hand reach; and (3) spike approach jump which included a two- or three-step approach. The Vertec is a commonly used apparatus for measuring vertical jump ability in volleyball players and is comprised of a vertical post containing horizontal vanes that can be pushed out of the way to measure the jump height and reach of athletes.

Jump demands in professional volleyball (Paper III)

Jump data were collected for an entire season from 14 players playing on an elite, professional men's volleyball team in Qatar. Players wore Vert devices for all training and competitions and were provided devices at the start of each session, prior to any jumping. Jump data were matched against attendance records and any missing jump data were imputed to most accurately reflect true jump load and demands. Jump counts were used to describe the jump demands in professional volleyball, as well as the individual player and position variability. Individual and team jump count averages were calculated for training sessions, match sessions, weekly jump totals, and jump frequency (jumps/hour) during training and matches. Positional jump demands for 3-, 4-, and 5-set volleyball matches and average jump height used during match play were presented. Finally, the distribution of jump height used during training compared to match play was determined for each position group.

Risk factors for shoulder complaints in professional volleyball (Paper IV)

Volleyball players from three professional men's club teams in Qatar participated during the 2016-2017 club season and national team players competing during at least one of three consecutive national team seasons (2015-2017) were included. Players received preseason musculoskeletal assessments and reported shoulder problems throughout the 12-week follow-up period, resulting in a total of 56 unique players completing 86 player-seasons.

Baseline testing

Trained physical therapists and strength and conditioning coaches with experience in volleyball and musculoskeletal screening of athletes conducted the tests. A sports physical therapist with >10 years of musculoskeletal ultrasound experience performed all humeral torsion, subacromial bursa thickness, and neovascularization assessments, blinded to the results of the baseline questionnaire.

Shoulder strength

Shoulder external rotation (ER) and internal rotation (IR) strength were measured with a handheld dynamometer and by taking the maximum score from 3 trials using an eccentric "break test," previously shown to have excellent intra- and inter-tester reliability.[61, 95] Scores were converted to percent body weight and calculations made to determine each player's IR:ER strength ratio.

Range of motion and humeral torsion

Bilateral glenohumeral passive ER and IR range of motion were measured in supine with stabilization of the scapula, similar to methods previously described.[124, 125] Humeral torsion was measured for both arms using a diagnostic ultrasound device and a method previously described with excellent inter-tester reliability and a minimal detectable change of 2.9° ± 2.6°.[122] An adjusted measure of dominant arm ER and IR range of motion that accounts for this side-to-side difference in humeral torsion was created so that glenohumeral range of motion could be adequately compared with the non-dominant arm.

Subacromial bursa thickness and neovascularity

A standardized examination was performed to evaluate the supraspinatus tendon and with color Doppler activated, the presence or absence of vessels within the supraspinatus tendon was recorded. Finally, with the Doppler disengaged, the subacromial bursa was examined for the point where it was seen to be thickest.[40, 91, 110]

Monitoring of shoulder problems

Shoulder problems were reported by players at baseline and throughout the 12-week follow-up period by completing the OSTRC overuse injury questionnaire (OSTRC-O). Shoulder problems were defined as "pain, aching, stiffness, looseness, or other complaints."[33]

Injury burden in volleyball: knees, low back, and shoulders (Paper V)

Four elite men's volleyball teams, playing in the premier league in Japan, Qatar, Turkey, and the United States, participated in this study over a 3-season period (2017-18 through 2019-20). This resulted in 75 players participating during eight team seasons (3 seasons – one team, 2 seasons – two teams, 1 season – one team) with a mean season length of 6.9 ± 0.9 months. Eight (10.7%) players participated over three seasons, 29 (38.7%) players over two seasons, and 38 (50.7%) players over one season; totaling 120 player-seasons. Liberos fulfill a unique roll on the team that requires little to no jumping or overhead attacks. As a result, the weekly prevalence of complaints for liberos was reported for comparison between position groups, but they were not included in further analyses – resulting in 102 player-seasons completed by outside hitters (n=42), middle blockers (n=28), setters (n=18), and opposites (n=14).

Reporting of knee, low back, and shoulder problems

Knee, low back, and shoulder complaints were reported weekly by players completing paper versions of the OSTRC-O and for the entire season.

Ethical considerations

The rights of participants were protected throughout each study and participants provided informed consent. All five studies were approved by the relevant ethics committees and institutions. The Regional Ethics Committee Midt-Norge provided approval for the first study (Paper I) while the Anti-Doping Lab Qatar Institutional Review Board provided three separate approvals for the remaining studies (Papers II-V).

Data and statistical analysis

Video analysis of ankle injuries (Paper I)

After each analyst independently reviewed the videos and completed their assessment forms, the results were collated for each question. If four or all five of the reviewers came to the same conclusion, agreement was said to have been reached. In the case of three reviewers having the same conclusion and no other options were chosen by more than one reviewer, agreement was again deemed to have been reached. In the remaining cases where agreement was not reached from the completed forms, three of the experts met to review the videos and discuss each case in detail. Each video was viewed as many times as needed. If all three experts agreed after reviewing the video together, agreement was said to have been reached. If no agreement was reached, the result was deemed 'unclear'.

Validation of Vert device: jump counts and jump height (Paper II)

During the jump count validation stage of this study, a jump was defined using the same definition as Charlton et al.[29] – "any occasion where both feet of the athlete were visually inspected to leave the ground at approximately the same time." The Vert device, however, uses a minimum threshold of 15 cm before recording a jump. To account for this, all jumps that were observed on video and not recorded by the device were reassessed by both examiners and jumps estimated to be <15 cm were categorized as "small" and not included for analysis. Additionally, any jumps that occurred out of view of the camera were not included.

During jump height validation, a Vert device would intermittently not detect a jump resulting in no height being reported from that particular device. This occurred most frequently with devices placed in the participant's sock. All jump heights measured by devices were included in this analysis. Vert device data were analyzed against force plate and Vertec measurements across a range of test conditions to determine the device bias (mean difference, 95% CI) and minimal detectable change

(MDC). Data were also assessed using intraclass correlation coefficients (ICC, two-way mixed, consistency). Analyses were conducted using SPSS version 21 (IBM Corporation, New York, NY, USA).

Jump demands in professional volleyball (Paper III)

Occasionally, a player performed full training with the team but recorded no jumps – either from not wearing a device or because of a technical error where the jumps were not successfully registered. To impute this missing data, a session-specific jump count was calculated for each player. This was based on player-specific average jump counts and a team-weighted jump count for that particular session. To determine the jump demands required during match play, only jumps performed during actual competition were included. Jumps performed during the pre-match warm-up or between sets were not included in this match total; however, they were still included in the weekly and season jump totals. Similarly, jump frequency during matches was calculated from the cumulative set times and did not include pre-match warm-ups or rest times between sets. Additionally, an adjusted jump frequency during matches was calculated for middles. This reflected the jump frequency by middles during the 7/12^{ths} of the serve and serve receive rotations they completed on the court during match play – as they were substituted off the court in favor of a libero in the back row.

Match jump counts were presented with 95% CI. Individual jump count average during match play was calculated from matches the player participated in, irrespective of their status as a starter or substitute. Each player's average weekly jump count was presented alongside the interquartile range (IQR). Jump heights were expressed as a percentage of maximum jump height for each player.

Risk factors for shoulder complaints in professional volleyball (Paper IV)

Data collection resulted in a total of 86 player-seasons to be analyzed. On five occasions, the player tested was not included in the final analysis. This was secondary to missing a baseline questionnaire (n = 4) or incomplete follow-up questionnaires as a result of changing clubs (n = 1). Baseline test results were reported for the remaining 81 player-seasons, but only those without baseline shoulder complaints were included in the *prospective risk factor* analysis.

Preliminary inferential statistical analyses were performed to determine which baseline variables were significantly different ($P \leq .05$) between: (1) players without shoulder complaints; and (2) players who developed shoulder complaints during the 12-week follow-up. These variables were then assessed and considered for inclusion into the final model. Subacromial bursa side-to-side difference was further evaluated by examining the area under the curve of a receiver operating characteristic (ROC) curve to determine an appropriate cutoff value for players with and without substantially thicker bursas between the dominant and non-dominant arms. Generalized estimating equations (GEEs) were used to model for probabilities of shoulder complaints after adjusting for all factors (position, subacromial bursa side-to-side difference, neovessel presence, shoulder external rotation ROM, age) and repeated variables (team, participant) using unstructured working correlations. Analyses were conducted using SPSS version 21 (IBM Corporation, New York, NY, USA).

Injury burden in volleyball: knees, low back, and shoulders (Paper V)

Questionnaire response rate was calculated based on the number of players who did not complete a team's weekly questionnaire; weeks in which the team did not train and therefore no questionnaires were provided were not considered missing, nor if a player was not training with the team (e.g., an international player late to join team). To best compare results across teams, the questionnaire from the first week of each regular season was defined as week 0; resulting in preseason questionnaires defined as week -1, -2, -3, etc. The weekly prevalence of all problems and substantial problems were determined for all players and examined based on the individual player's preseason complaints status, match participation, position, team, and age. Each player was classified as either a substantial match contributor (start or play the majority of at least 25% of the team's matches) or as having limited/no match participation and verified against match reports, attendance logs, and match video. A total of 52 player-seasons were classified as substantial match contributors (six team-seasons with 6 substantial match contributors; two team-seasons with 8 substantial contributors). Data are reported as mean values with 95% CI unless otherwise noted.

Results and discussion

Systematic video analysis of ankle injuries in world-class volleyball (Paper I)

This is the first study to describe injury situations and injury mechanisms for acute ankle injuries sustained among world-class volleyball players. A total of 24 injury cases were included in the video analysis, including 14 from men's volleyball and 10 from women's volleyball (Table 7). Through systematic video analysis of actual injury situations reported through the FIVB Injury Surveillance System, the main findings of this study were: (1) the majority of injuries occur while blocking – often landing on an opponent; (2) the attacking player is overwhelmingly to blame for injuries at the net secondary to crossing the center line and landing partially into the blocker's court; (3) injuries during the attacking phase are often from a back-row player landing on a front-row teammate and (4) landing-related injuries mostly result from rapid inversion without any substantial plantarflexion.

Landing on another individual is the most common inciting event

Landing-related injuries during traditional volleyball play – including blocking, attacking and setting – accounted for nearly all of the acute ankle injuries observed. Of these, the vast majority (90%) were the result of one individual landing on another. This is consistent with previous studies that used questionnaires, including examination of ankle sprains in Norwegian volleyball that found 87% occurred when landing on the foot of an opponent or teammate.[11, 13] Any interventions designed to prevent acute ankle sprains in the sport likely need to focus on minimizing the risk of players landing on one another through education on typical injury situations and technical training for take-offs and landings.[15]

Table 7. *Playing situation and injury information for 24 cases of ankle injuries in world-class volleyball.*

		Injury Information							Blocking	
Injury #	**Playing Situation**	**Sex**	**Player Position**	**Row**	**Offense/ Defense**	**Court Position**	**L/R Ankle**	**Ankle Bracing**	**Lands: 1 or 2 Feet**	**# Blockers**
Blocking - Lands on Opponent										
1	Blocking - Lands on opponent	Male	Opposite	Front	Defense	[2] Front Right	Right	No	1	2
2	Blocking - Lands on opponent	Male	Opposite	Front	Defense	[2] Front Right	Left	Yes	1	2
3	Blocking - Lands on opponent	Male	Opposite	Front	Defense	[2] Front Right	Left	No	2	2
4	Blocking - Lands on opponent	Female	Outside	Front	Defense	[4] Front Left	Right	Yes	1	2
5	Blocking - Lands on opponent	Male	Middle	Front	Defense	[3] Front Middle	Left	No	1	1
6	Blocking - Lands on opponent	Female	Middle	Front	Defense	[3] Front Middle	Right	Yes	1	1
7	Blocking - Lands on opponent	Female	Middle	Front	Defense	[3] Front Middle	Left	Yes	1	2
8	Blocking - Lands on opponent	Female	Outside	Front	Defense	[4] Front Left	Right	No	2	2
9	Blocking - Lands on opponent	Male	Outside	Front	Defense	[2] Front Right	Left	No	2	2
10	Blocking - Lands on opponent	Female	Opposite	Front	Defense	[2] Front Right	Right	No	1	1
11	Blocking - Lands on opponent	Female	Outside	Front	Defense	[4] Front Left	Right	Unclear	Unclear	2
Blocking - Lands on Teammate										
12	Blocking - Lands on teammate	Male	Outside	Front	Defense	[4] Front Left	Left	No	2	2
13	Blocking - Lands on teammate	Male	Middle	Front	Defense	[3] Front Middle	Right	No	1	2
14	Blocking - Lands on teammate	Male	Opposite	Front	Defense	[2] Front Right	Right	No	1	2
15	Blocking - Lands on teammate	Male	Middle	Front	Defense	[3] Front Middle	Left	No	1	2
Attacking - Back Row, Lands on Teammate										
16	Back Row - Lands on teammate	Male	Outside	Back	Offense	[6] Back Middle	Left	No	-	-
17	Back Row - Lands on teammate	Female	Outside	Back	Offense	[6] Back Middle	Right	Yes	-	-
18	Back Row - Lands on teammate	Female	Opposite	Back	Offense	[1] Back Right	Right	Unclear	-	-
Attacking - Back Row, Landed on by Teammate										
19	Back Row - Landed on by teammate	Male	Setter	Front	Offense	[2] Front Right	Left	Yes	-	-
Attacking - Front Row, Lands on Opponent										
20	Attacking - Lands on opponent	Female	Opposite	Front	Offense	[2] Front Right	Right	No	-	-
Other Injury Situations										
21	Jump Setting - Lands (non-contact)	Female	Setter	Front	Offense	[2] Front Right	Right	No	-	-
22	Back Row Attack - Lands (non-contact)	Male	Middle	Back	Offense	[6] Back Middle	Left	No	-	-
23	Collision/Contact with teammate	Male	Opposite	Front	Defense	[2] Front Right	Left	No	-	-
24	Celebration (non-contact)	Male	Middle	Front	Offense	[3] Front Middle	Right	No	-	-

Blocking injuries mostly involve landing on another player

The act of blocking puts players more at risk than other components of the game. Blockers sustained 62.5% of ankle sprains in this study, which is consistent with previous findings that 61% of ankle injuries transpired while blocking in the top Swedish division.[5] The 15 injuries to blockers in the current study were all related to the blocker landing on another player, either an opponent (n = 11) or teammate (n = 4). When blockers land on a teammate, the injury often happens because one or both blockers are moving laterally during an attempt to close the block and make it difficult on the hitter. This was observed in our study as the middle blocker was drifting laterally in all the incidents that resulted in injuries to middle blockers or their teammates.

Plays in which the blocker landed on an opponent mostly resulted from the attacking player landing under the net and partially into the blocker's side of the court (Figure 3). This mainly happens if the set is tight to the net and the attacker jumps and lands under the net, but can also result from an errant jump in which the attacker simply jumped and landed too tight despite a good set.

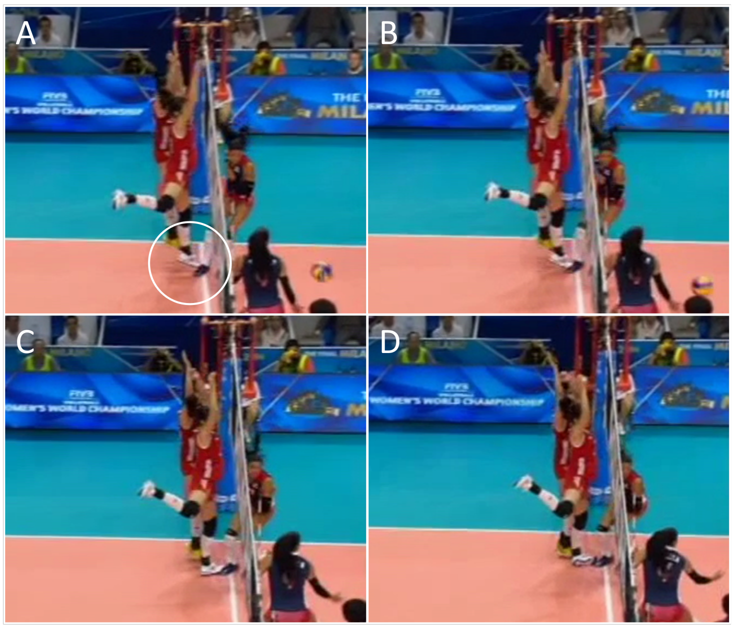

Figure 3*. Injury situation: middle blocker (in red) landing on the foot of an opposing attacker who has landed on the center line and partially into the injured player's court. (A) Left ankle of middle blocker in plantarflexion just prior to landing. (B) Initial contact with opponent's foot, ankle plantarflexed. (C) Left ankle in neutral 'foot flat' position. (D) Left ankle in inverted position following rapid inversion moment.*

No center line violations, but injuries under the net involve center line landings

All the injuries involving contact with the opposition were a result of players landing on the center line under the net. The attacking player landed on the center line in every situation (n = 12; Table 8) and landed partially into the opponent's court in all but one play. FIVB rules allow a player to land with a foot partially into the opponent's court as long as the penetrating foot maintains contact with the center line or is directly over the center line.[43]

No center line violations were incurred by any of the players; however, a player landing on the center line was a contributing factor in all of the situations examined. Injuries to blockers landing on opposing attackers continue to be the most common situation associated with ankle injuries at this level of the sport. One previous attempt to make the center line rule more strict during a preseason tournament in Norway resulted in substantial disruption to the game through a significant increase in center line violations and the rule being changed back prior to the start of the regular season.[8] If players were given more time to adjust to the strict center line rules, the number of violations may decrease. Additional consideration may be given for a rule change that makes center line violations strict for attacking players but lenient in other scenarios where there is no/less risk of ankle injury. While it is unclear exactly what effect changes to the center line rules would have on injury incidence, proposals to restrict contact with the center line or opponent's court within the conflict zone under the net should be considered.[97]

Table 8. *Landing position of the attacker and blocker relative to the center line and opponent's court.*

		On center line		Into opponent's court		Center line violation
Injury #	**Playing situation**	**Attacker**	**Blocker**	**Attacker**	**Blocker**	**Either player**
Blocking – lands on opponent						
1	Blocking – lands on opponent	Yes	Yes	No	No	No
2	Blocking – lands on opponent	Yes	No	Yes	No	No
3	Blocking – lands on opponent	Yes	No	Yes	No	No
4	Blocking – lands on opponent	Yes	No	Yes	No	No
5	Blocking – lands on opponent	Yes	Yes	Yes	No	No
6	Blocking – lands on opponent	Yes	No	Yes	No	No
7	Blocking – lands on opponent	Yes	No	Yes	No	No
8	Blocking – lands on opponent	Yes	Yes	Yes	Yes	No
9	Blocking – lands on opponent	Yes	Yes	Yes	Yes	No
10	Blocking – lands on opponent	Yes	Yes	Yes	No	No
11	Blocking – lands on opponent	Yes	Unclear	Yes	Unclear	No
Attacking – front row, lands on opponent						
20	Attacking – lands on opponent	Yes	Yes	Yes	No	No

Attacking injuries: most commonly resulting from back-row attacks

This study is the first to describe back-row attacks as a common injury situation. In fact, two-thirds of attacking injuries (4 out of 6) resulted from a back-row attacker landing on an inattentive front-row teammate. Each of these injuries was the result of offences operating out of system – in which the play during the rally takes the team away from running the preferred pass, set, and hit sequence.[67] Coaches and players need to recognize these potential at-risk situations and be certain that no front-row players move into the landing path of the back-row hitter, eager to cover potential block returns.

Injuries mostly occur through inversion, with the absence of plantarflexion

Of the 24 injuries observed, 21 were landing-related injuries (18 inversion, 1 eversion, 2 unclear) that involved the injured player landing from a traditional volleyball play – attacking, blocking, and setting. These landing-related injuries included 19 situations where the injured player landed on another player and 2 occasions where the injured player landed without any contact with another individual.

The typical injury involved the ankle dorsiflexing from a plantarflexed position at initial contact towards a foot flat position on the ground. In most injury cases, inversion did not occur until the ankle was in neutral flexion with the absence of any significant plantarflexion. This was evident in the 19 cases where a player landed on another player; the ankle first moved into a neutral dorsiflexed position prior to rapid inversion/eversion in 15 situations compared with one situation in which the ankle was not first in a neutral dorsiflexed position (three situations were unclear).

This confirms recent case studies of accidental ankle sprains during laboratory cutting maneuvers that found the ankle was in a dorsiflexed position at the moment of peak inversion.[49, 69] Injuries during high jumping and field hockey also reported the ankle not being plantarflexed at the moment where maximal inversion occurred,[88] and five cases from tennis found no significant plantarflexion component.[48] Rather, a combination of inversion and internal rotation was described as the primary mechanism.[48] The authors suggested that ankle sprains from jump landing in sports such as volleyball may still occur from an inversion plus plantarflexion mechanism. Our results, however, reveal that landing-related injuries in volleyball also mainly occur through inversion without any substantial plantarflexion.

Validation of Vert device: jump counts and jump height (Paper II)

This is the first study to examine validity of the Vert device in professional male volleyball players and with 3,637 jumps, individually matched to video analysis, it is the largest to explore jump count accuracy across any level of volleyball. The device demonstrated excellent accuracy in counting volleyball-specific jumps during both practice and match play. Our results also show that, while the device provides a good measure of on-court jump intensity at the group level, it should not be used to measure maximal jumping ability when precision is needed.

Jump count

A total of 3,637 jumps were observed on camera and included for analysis (Table 9). The number of jumps included in this study was substantially greater than two previous studies which examined jump count validity in junior-level players.[29, 78] Few false negatives (n = 25, 0.7%) and false positives (n = 12, 0.3%) were observed across all jumps – resulting in one false positive per 303 jumps or 5.17 h of training and match play. The false positives occurred when players stopped their spike approach (n = 4), dove for a ball (n = 2), attempted a defensive bump/dig (n = 1), or tossed the belt off-court (n = 1). The remaining four instances resulted from suspected device/syncing errors in which a jump was recorded for a player who made no distinct movements.

Table 9*. Jump count accuracy of the Vert device compared to video analysis – based on jump type and session type.*

	Video	True positives (n, %)		False negatives (n, %)		False positives (n, %)	
Jump type							
Block	1,266	1,259	(99.4%)	7	(0.6%)	0	(0.0%)
Attack	1,170	1,162	(99.3%)	8	(0.7%)	0	(0.0%)
Set	426	424	(99.5%)	2	(0.5%)	0	(0.0%)
Jump float	347	344	(99.1%)	3	(0.9%)	0	(0.0%)
Jump serve	308	305	(99.0%)	3	(1.0%)	0	(0.0%)
Defensive overhead	32	32	(100.0%)	0	(0.0%)	0	(0.0%)
Defensive bump	25	25	(100.0%)	0	(0.0%)	1	(3.8%)
Miscellaneous	63	61	(96.8%)	2	(3.2%)	11	(15.3%)
Session type							
Practice	2,521	2,503	(99.3%)	18	(0.7%)	7	(0.3%)
Match	1,116	1,109	(99.4%)	7	(0.6%)	5	(0.4%)
Total	**3,637**	**3,612**	**(99.3%)**	**25**	**(0.7%)**	**12**	**(0.3%)**

We observed a small prevalence of false positives (0.7%) compared to the study by Charlton et al. (12%).[29] The use of different definitions to classify and include jumps for analysis likely contributes to this apparent discrepancy. Charlton et al. included all jumps, regardless of jump height. In the current study, we did not include jumps that were perceived to be less than the device's 15 cm detection threshold. MacDonald et al.[78] also compensated for the device's minimum threshold by only counting jumps that subjectively were believed to be higher than this cutoff. MacDonald et al.[78] reported that the device overestimated the total number of jumps compared to those observed via visual observation by nearly 6% during match play. Because jumps were not individually matched in their study, they were left to speculate that the discrepancy was related to small jumps that were not counted through video review.

For the purpose of managing jump load, the Vert device does an excellent job at accurately counting jumps in professional players. The high level of accuracy allows coaches and staff to trust the daily, weekly, and season-long jump counts provided by the device when planning individual and team-wide training and recovery sessions.

Jump height

Information on Vert device bias, minimal detectable change (MDC), and reliability of the devices can be found in Table 10. The Vert device showed good correlation with the Vertec during volleyball-specific jumps, but consistently overestimated jump height by an average of 5.5 cm (12% of mean jump height). MDC was stable across all volleyball jump types and effort levels, ranging from 8.8 cm to 9.8 cm (18% to 24% of mean jump height). Figure 4 shows the correlation between the Vert device and force plate measurements during countermovement jumps (see also Table 10), as well as the relationship between the Vert device and Vertec measurements during three different volleyball jumps (Table 10).

The Vert device showed excellent interdevice reliability for two devices placed in the same pouch and worn around the waist during volleyball jumps ($r = .99$, 95% CI 0.98-0.99) with no bias between the devices (Table 10). However, placing the device at other locations on the body impacted jump height measures substantially. Devices placed on the waist and chest corresponded well, while placement of the device within a sock resulted in unacceptable recordings (Table 10).

***Table 10**. Bias, MDC, and reliability of the Vert device – based on jump type, effort level, athlete type, and device placement on the body.*

	Vert bias (cm)[1]		MDC (cm)	ICC[1]		# jumps
Volleyball jump type (Vert vs Vertec)						
All volleyball jumps	5.5	(4.5 to 6.5)	9.7	0.85	(0.80 to 0.89)	188
Spike approach	5.4	(3.8 to 7.1)	9.5	0.88	(0.81 to 0.92)	68
1-hand reach	3.2	(1.4 to 5.0)	9.8	0.78	(0.66 to 0.86)	60
2-hand reach	8.0	(6.4 to 9.6)	8.8	0.75	(0.61 to 0.84)	60
Effort level (Vert vs Vertec, volleyball jumps)						
Maximal effort	4.6	(3.2 to 6.0)	9.7	0.86	(0.80 to 0.90)	98
Submaximal effort	6.6	(5.2 to 8.0)	9.5	0.72	(0.60 to 0.80)	90
Athlete type (volleyball jumps)						
Professional volleyball player	2.2	(1.0 to 3.4)	11.6	0.82	(0.68 to 0.90)	41
Recreational athlete	6.5	(5.6 to 7.4)	8.7	0.79	(0.72 to 0.84)	147
Vert placement (volleyball jumps)						
Waist vs Vertec	5.5	(4.5 to 6.5)	9.7	0.85	(0.80 to 0.89)	188
Chest vs Vertec	6.6	(5.7 to 7.5)	8.1	0.90	(0.86 to 0.92)	170
Sock vs Vertec	1.2	(-1.5 to 4.0)	23.0	0.44	(0.30 to 0.57)	139
Inter-device reliability by Vert placement (volleyball jumps)						
Waist vs Waist	-0.3	(-0.6 to 0.0)	2.3	0.99	(0.98 to 0.99)	147
Chest vs Waist	0.9	(0.3 to 1.5)	5.9	0.94	(0.92 to 0.96)	170
Sock vs Waist	-4.6	(-7.4 to -1.7)	23.6	0.39	(0.24 to 0.52)	139
Countermovement jump (Vert vs force plate)						
Force plate	9.1	(8.1 to 10.0)	5.5	0.93	(0.89 to 0.96)	65

ICC, Intraclass correlation coefficient (two-way mixed, consistency); MDC, Minimal detectable change

[1] 95% Confidence intervals are shown in parenthesis

Jump height is slightly overestimated and limitations exist when measuring jumps of similar heights

The Vert device showed excellent interdevice reliability for two devices placed at the waist, consistent with previous research in junior-level athletes.[29] However, the large minimal detectable change during countermovement and volleyball jumps limits the use of the device for jump height testing. The device does not appear to represent a valid method to detect differences of <5 cm during jump testing and should not replace more accurate methods for measuring maximal jumping ability (e.g., force plates). The Vert device is not alone as the measurement error using other vertical jump testing methods, including jump and reach tests, contact mats, and belt mat systems, are also too large to detect small differences in jump height.[90]

Force plate testing has long been used as the gold standard for measuring jump height.[26, 58, 113] However, practical challenges and costs associated with using force plates have resulted in adoption of other reference standards for on-site testing apparatuses, such as that commonly used to measure jump and reach tests (i.e., the Vertec). The Vertec has been found to be a valid method of measuring jump height with high reliability.[71, 90] However, research examining validity and reliability of the Vertec is limited, uses different methodology,[26, 71, 79, 90] and leaves conflicting views about the validity of the Vertec and other on-site jump height methods (e.g., contact mats, accelerometers, and belt mats) to be able to detect small changes in jump height. In the present study, the Vert device demonstrated nearly a twofold larger minimal detectable change during volleyball jumps performed with the Vertec compared to countermovement jumps on the force plate. Previous studies have reported increased jump height variability by the Vertec compared to a criterion reference, including a force plate.[26, 71] However, use of the Vertec allowed testing of volleyball-specific jumps which have been recommended when testing volleyball players and have been shown to have high reliability, equal to that of squat and countermovement jumps.[104]

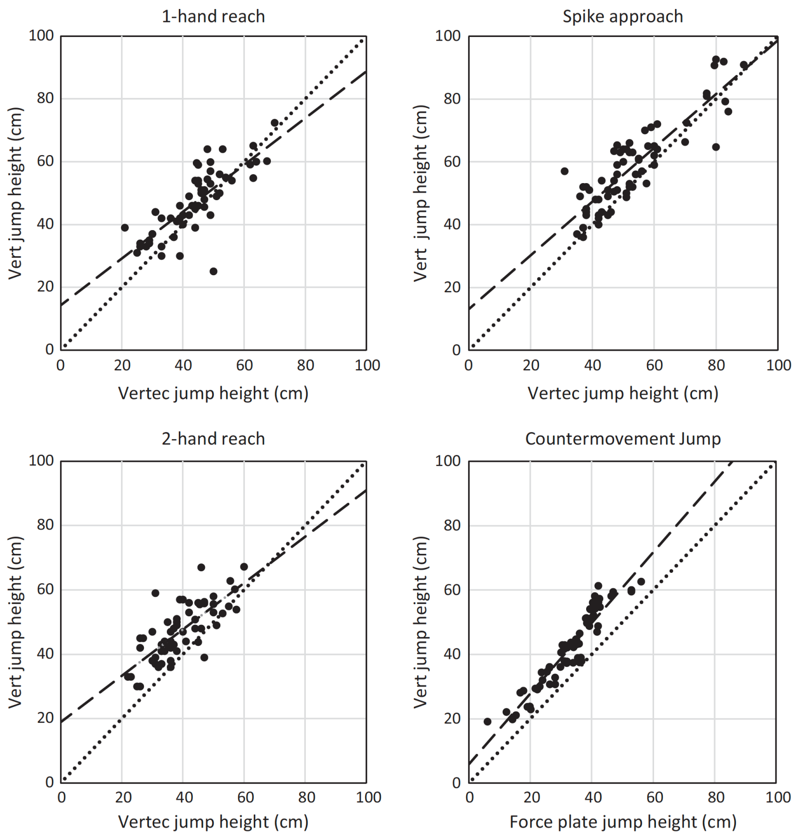

Figure 4*. Jump height during three different volleyball jumps (Vert vs Vertec) and a countermovement jump with force plate (Vert vs force plate). The dashed line represents the line of best fit, and the dotted line represents the line of equality (x = y).*

Acceptable measure of on-court jump intensity for use in load monitoring

Despite the relatively large minimal detectable change, which limits use of the Vert device for jump testing, the device does report jump height accurately enough to gauge general jump intensity and discriminate between jumps of different intensity levels. For example, we cannot confidently discriminate between two jumps similar in height (e.g., Vert recording of 72 cm and 75 cm) and identify which jump is higher; however, we can be highly confident that a recorded jump of 87 cm is in fact higher than a recorded jump of 72 cm as the 15 cm difference falls outside the bounds of the minimal detectable change observed across all volleyball jumps. This provides an opportunity to categorize jumps based on different height ranges and monitor jump loads not only by total jump count, but also by different intensities.

Jump demands in professional volleyball (Paper III)

This is the first study to examine the season demands and variability in jump load in elite, male professional volleyball players. Despite a relatively stable average weekly team jump load from the beginning to the end of the season, substantial week-to-week increases were observed both for the team and within individual players. Additionally, large positional differences were observed for jump counts and jump heights during training and competition.

Jump count

A total of 129,173 jumps were performed during training and competition over one professional volleyball season – resulting from 142 sessions (108 practices, 27 matches, 7 friendly matches).

Setters, followed by middle blockers, perform high volume and frequency of jumps

Setters (121 jumps/session) and middle blockers (92 jumps/session) performed the largest volume of jumps during training and had the highest weekly jump averages. Sheppard et al.[106] performed an analysis of spike jumps, block jumps, and jump serves during 16 international volleyball matches, providing additional insight on the specific jump types required during match play. They reported that middle blockers performed a greater number of block jumps while setters performed very few attack jumps.[106] While these studies cannot be compared directly, as not all jumps were analyzed in the former study and no data from trainings were included, insight can be gained on the type of jumps each of these positions must perform during competition.

One additional observation from the current study was that middle blockers performed a high frequency of jumps/h during match play, especially when adjusted for their limited match participation secondary to being substituted out of the back row in favor of a libero (middles – 98 jumps/h of on-court time; setters – 67 jumps/h; opposites – 53 jumps/h; outsides – 47 jumps/h). This unique aspect of match jump demands for middles (bouts of high jump frequency with periods of rest) should be considered when designing training programs.

The match demand for each position is presented in Table 11.

***Table 11**. Positional jump demands for 3-set, 4-set, and 5-set volleyball matches and average jump height used during match play over one professional men's volleyball season.*

	Jump count					**Jump height (%)**			
	All matches[1]		**3-set**	**4-set**	**5-set**	**All matches**[2]	**3-set**	**4-set**	**5-set**
Opposite	82	(72 to 92)	59	89	116	76%	73%	77%	77%
Outsides	68	(62 to 75)	55	74	88	62%	60%	64%	60%
Middles	85	(77 to 93)	67	89	115	64%	63%	65%	66%
Setter	100	(89 to 110)	76	110	128	56%	56%	56%	57%

[1] 95% confidence intervals are shown in parenthesis
[2] Jump height as a percentage of maximum jump height (median)

Substantial week-to-week jump load variability observed at both the team and individual level

Weekly average jump count per player fluctuated considerably throughout the season ranging from a 44% week-on-week decrease to a 2.4-fold week-on-week increase. Research in other sports has reported greater injury risk associated with large week-to-week changes in training load and has suggested that in order to minimize risk of injury, week-to-week changes should be limited to no more than a 10% increase in training load.[38, 53, 54, 102] During the observed season, there was an increased week-to-week team jump load of at least 10% in one-third of the weeks and an increased week-to-week team jump load of at least 30% in six of 27 weeks. Some jump load variation is expected over a long professional season and even the most well-intentioned coaches trying to minimize spikes in team loads will have high and low weeks of varying intensity levels.

One surprising finding during this study was that all 14 players had at least 1 week in which his weekly jump count increased twofold or greater. This happened to eight of the players during the transition from preseason to the first week of the regular season. Additionally, 18 of 28 weeks included at least one player with a twofold increase in weekly jump count (12 weeks) or at least one player returning to training after performing no jumps the previous week (11 weeks). While a coach may plan team training loads and adjust jump loads accordingly, one of the greatest challenges may be accounting for the at-risk *individual*, rather than the team as a whole. The present findings expand on those by Bahr and Bahr,[7] who observed substantial between-player differences in jump volume and frequency during 1 week of training among elite adolescent players. Substantial session, weekly, and within-player jump volume differences existed in the current study. This highlights the large individual jump load variability observed in professional volleyball players and infers a need to monitor individual player jump loads.

Jump height

Jump heights observed during the season varied based on player position and session type – distribution of jump heights from training and matches are displayed in Figure 5.

Opposites perform a large number of high-intensity jumps

Opposites performed more high-intensity jumps than other position groups. This was evident during training and even more pronounced during match play, when the majority of their jumps were greater than 70-80% of their maximum jump height. This is not surprising, as the opposite hitter is often the "go-to" attacker when a kill is needed and maximal jump height is required. This finding may be unique to the men's game, as younger levels and women's volleyball often place their best players and attackers in the outside positions.

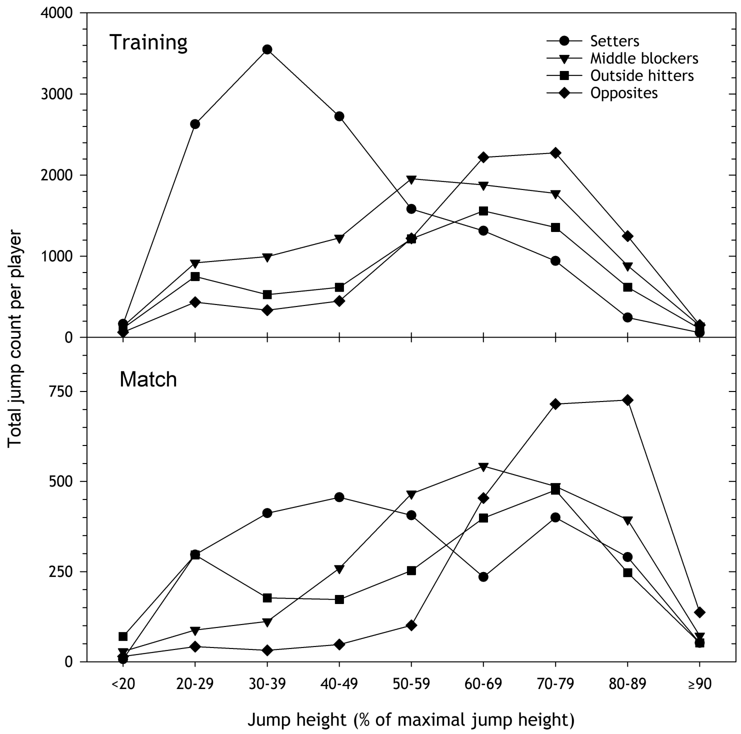

Figure 5. *Distribution of jump height from training (n = 108 sessions) and matches (n = 27) during one professional club volleyball season – based on player position.*

Risk factors for shoulder complaints in professional volleyball (Paper IV)

This is the largest prospective study to date exploring risk factors for shoulder complaints in volleyball players and the first prospective study to examine the relationship between subacromial bursa thickness and neovascularization in the development of shoulder complaints in overhead athletes.

A total of 81 player-seasons were analyzed, including baseline testing and 12-week questionnaire follow-up. In 22 (27.2%) cases, the player reported shoulder complaints at baseline while the remaining 59 (72.8%) reported no baseline complaints. Of these remaining 59 player-seasons, 16 (27.1%) developed complaints during the subsequent 12 weeks. Table 12 shows the relationship between these three subcategories of players – those who never reported shoulder complaints, those who prospectively developed complaints during the season, and those presenting with existing complaints at baseline testing.

Athletes with a substantially thicker subacromial bursa in their dominant shoulder and those with neovessels present were both much more likely to develop complaints. Younger players and players with greater shoulder external rotation ROM were also at increased risk. Finally, outside hitters and opposites were 12.2-fold more likely to develop shoulder complaints compared with their teammates.

Player position

Outside hitters (11 of 19) and opposites (2 of 4) developed substantially more shoulder complaints than other position groups (middles: 2 of 19, setters: 0 of 12, liberos: 1 of 5). This is consistent with previous findings in collegiate volleyball players – attackers (outside hitters, opposites, and middles) reported a greater prevalence of shoulder pain than setters and liberos.[101] A greater proportion of outside hitters than other players also reportedly experienced shoulder injuries during major FIVB tournaments.[21] In the current study, very few middles reported shoulder complaints. It is unclear from the literature whether middles typically have fewer shoulder complaints than other attackers or whether this is related to our limited sample size.

***Table 12**. Relationship between preseason musculoskeletal screening measures in: (1) players with existing baseline complaints; (2) players without baseline complaints that went on to develop complaints; and (3) players without complaints at any time.*

			Players without baseline complaints			
	Players with baseline complaints (n=22)		Developed season complaints (n=16)		No complaints (n=43)	
Category	**Mean (95% CI)**	**SD**	**Mean (95% CI)**	**SD**	**Mean (95% CI)**	**SD**
Player characteristics						
Age (y)	25.1 (23.7 - 26.5)	3.1	23.5 (21.4 - 25.6)**	3.9	26.5 (25.2 - 27.9)	4.3
Body weight (kg)	90.9 (87.1 - 94.7)	8.6	89.5 (86.7 - 92.2)	5.1	90.3 (87.8 - 92.8)	8.2
SAB thickness (mm)						
Dominant arm	0.89 (0.73 - 1.06)	0.37	0.87 (0.63 - 1.11)	0.44	0.75 (0.66 - 0.85)†	0.30
Non-dominant arm	0.56 (0.43 - 0.70)	0.30	0.44 (0.34 - 0.54)**	0.19	0.58 (0.49 - 0.67)†	0.30
Side-to-side difference (d-nd)	0.33 (0.12 - 0.54)	0.48	0.44 (0.22 - 0.65)**	0.41	0.17 (0.08 - 0.26)†	0.29
Range of motion - dominant shoulder (degrees)						
External rotation (measured)	128 (120 - 137)	19	136 (126 - 146)	18	126 (122 - 131)	15
Internal rotation (measured)	76 (68 - 83)	17	85 (77 - 94)	16	84 (78 - 90)	19
External rotation (adj.)‡	115 (107 - 124)	19	127 (118 - 137)**	18	115 (110 - 121)	17
Internal rotation (adj.)‡	89 (81 - 97)	18	94 (85 - 104)	18	95 (88 - 102)	22
Total range of motion	204 (191 - 218)	30	221 (213 - 229)**	15	210 (203 - 218)	24
Humeral torsion difference	13 (11 - 16)	6	9 (4 - 15)	10	11 (9 - 14)	8
Range of motion – non-dominant shoulder (degrees)						
External rotation (measured)	123 (116 - 130)	16	123 (115 - 130)	14	120 (117 - 124)	11
Internal rotation (measured)	83 (75 - 91)	18	93 (87 - 99)	11	88 (82 - 93)	17
Total range of motion	206 (194 - 219)	29	216 (208 - 224)	15	208 (202 - 214)	19
Strength - dominant shoulder (% body weight)						
External rotation	0.21 (0.19 - 0.24)	0.05	0.24 (0.22 - 0.26)	0.04	0.23 (0.21 - 0.24)	0.05
Internal rotation	0.32 (0.30 - 0.35)*	0.06	0.29 (0.28 - 0.31)	0.03	0.29 (0.28 - 0.31)	0.05
IR:ER ratio	1.63 (1.34 - 1.91)*	0.64	1.26 (1.15 - 1.37)	0.21	1.35 (1.26 - 1.44)	0.30

Abbreviations: SAB, subacromial bursa; d, dominant; nd, non-dominant; IR, internal rotation; ER, external rotation.
†One player did not have SAB thickness measurements performed (n=42).
‡An adjusted measure of external and internal rotation range of motion that accounts for the amount of humeral torsion in the dominant arm compared to the non-dominant arm.
*Players with baseline complaints significantly different from players without baseline complaints ($P \le .05$).
**Players who developed season complaints significantly different from group with no complaints ($P \le .05$).

Range of motion

A recent systematic review found volleyball players, on average, have more shoulder external rotation (ER) and less internal rotation (IR) range of motion in the dominant arm compared with the non-dominant arm.[27] This greater shoulder ER motion appears to be a natural adaptation to the sport, resulting from increased humeral torsion in the dominant arm. This was evident in the current study as substantial side-to-side differences were observed in the raw ER and IR measurements, but those differences dissipated after accounting for humeral torsion.

Additionally, the observation of apparent ER gain and concomitant glenohumeral IR deficit existed within our population and became problematic when ER gain led to greater total rotational ROM. Having greater shoulder ER ROM increased a player's risk of developing complaints by 8% for every additional degree (Table 13). Therefore, an increase of 12° of ER ROM, the group mean difference between those who developed complaints and those who did not, increased a player's risk by 96%.

***Table 13**. Generalized estimating equations displaying the likelihood of in-season shoulder complaints based on position, side-to-side difference in subacromial bursa thickness, neovessel presence, shoulder ER ROM, and age (n=58, players without baseline shoulder complaints).*

	B	SE	Wald	*df*	*P* value	Odds ratio (95% CI)	
Position (Out/Opp vs. MB/S/L)†	2.50	1.03	5.85	1	0.016	12.15	(1.60 to 92.07)
SAB difference (≥0.3mm, yes/no)	2.33	0.86	7.34	1	0.007	10.24	(1.90 to 55.16)
Neovessel presence (yes/no)	1.88	0.99	3.58	1	0.058	6.52	(0.94 to 45.50)
Shoulder ER ROM (°)	0.07	0.04	3.17	1	0.075	1.08‡	(0.99 to 1.17)
Age (y)	-0.23	0.10	5.88	1	0.015	0.79	(0.66 to 0.96)

Abbreviations: B, beta; SE, standard error; Wald, Wald Chi-Square; df, degrees of freedom; SAB, subacromial bursa; ER, external rotation; ROM, range of motion.
†Position grouped as outsides/opposites vs. middle blockers/setters/liberos.
‡For every 1° of change.

Shoulder strength

Previous cross-sectional studies have reported mixed findings on a possible relationship between shoulder strength imbalance and previous shoulder injury.[27, 50, 56, 101] One prospective study with 16 players suggests an association between muscle strength imbalance and the risk of shoulder problems.[120] In the current study, we found no relationship between the risk of shoulder complaints and shoulder rotation strength or IR:ER strength ratio.

However, it is of interest that players with current shoulder complaints at baseline presented with greater IR:ER strength ratios and (non-significantly) less IR ROM. These differences could be acute or long term in nature, and while we did not detect any relationship with subsequent complaints, it is unknown whether serial testing on a daily or weekly basis would allow for early detection of deficits prior to the onset of substantial complaints.

Subacromial bursa thickness and neovessel presence

Subacromial bursa (SAB) thickening in the dominant arm was a normal finding among professional volleyball players; 81% had increased SAB thickness in the dominant shoulder compared with the non-dominant side. However, a substantial side-to-side difference was associated with shoulder complaints (10.2-fold increased risk; Table 13). These findings are consistent with previous work in which increased SAB thickness was observed within the painful shoulders of endurance swimmers, waterpolo players, and non-athletes with unilateral shoulder pain during overhead activity.[37, 55, 110]

Those with neovessels present were 6.5 times more likely to develop shoulder complaints (Table 13). Additionally, combining the neovessel and SAB thickness results (Figure 6) provides additional insight. Players without neovessels and without increased SAB thickness were unlikely to develop shoulder complaints (4%). This is in stark contrast to players with neovessels and/or increased SAB thickness; as many as 48% developed complaints. The reasoning for this is unknown, but it is of clinical interest to determine how to properly load the shoulder of players with increased SAB thickness or neovascularization in a manner that minimizes future complaints.

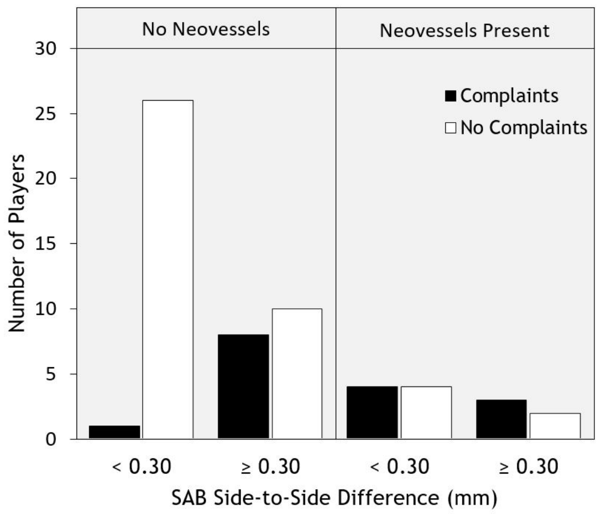

Figure 6. *Development of shoulder complaints in professional volleyball players based on preseason ultrasound findings: players without substantial increased side-to-side subacromial bursa (SAB) thickness (<0.3mm) and without neovessels present in the dominant arm rarely developed complaints (n=58, players without baseline shoulder complaints).*

Injury burden in volleyball: knees, low back, and shoulders (Paper V)

A total of 102 player-seasons were analyzed, comprising 2,867 weekly injury questionnaires. Nearly all elite men's volleyball players experienced knee, low back, or shoulder problems during a given season – and the majority had at least one bout that substantially reduced training participation or sports performance. While many knee, low back, and shoulder problems do not result in time-loss injuries, almost half of the players (46%) were playing through some combination of knee, low back, and shoulder complaints each week. Notably, players who experienced preseason knee, low back, and shoulder problems continued to have more problems during the competitive season than their teammates. This is pertinent information for those trying to best manage their athletes and hoping to minimize the risk of these complaints progressing into substantial problems over the course of the season.

Prevalence of knee, low back, and shoulder problems

The prevalence of knee, low back, and shoulder problems was high; nearly all players (93%) experienced complaints at some point during the season. The average weekly prevalence of knee, low back, and shoulder problems was 31% for the knee (95% CI 28-34%), 21% for the low back (95% CI 18-23%), and 19% for the shoulder (95% CI 18-21%). The collective impact of knee, low back, and shoulder problems resulted in an average weekly prevalence of 46%, with higher prevalence during the preseason that decreased throughout the season.

It is not unusual for players to experience knee, low back, or shoulder problems for a substantial portion of the season; 51% of players reported some combination of knee, low back, and shoulder problems for more than half the season. While a portion of these problems were minor with little burden to the athlete, 58% of players reported at least one bout of substantial knee, low back, or shoulder problems that led to a reduction in training volume or sports performance each season.

Preseason complaints

The prevalence of knee (38% vs. 29%) and low back problems (27% vs. 19%) was higher during the preseason than in-season. This is consistent with previous research that has reported a higher incidence of volleyball injuries during the preseason.[3, 109] It is unclear why this same finding was not observed for shoulder problems, where the average prevalence did not change from the preseason to the regular season (19% vs. 19%).

The most striking observation may be that players who experienced preseason knee, low back, or shoulder problems of any kind continued to have significantly more problems during the regular season as well (average weekly prevalence – knee: 42% vs. 13%, *P*<.001; low back: 34% vs. 8%, *P*<.001; shoulder: 38% vs. 12%, *P*<.001; Figure 7).

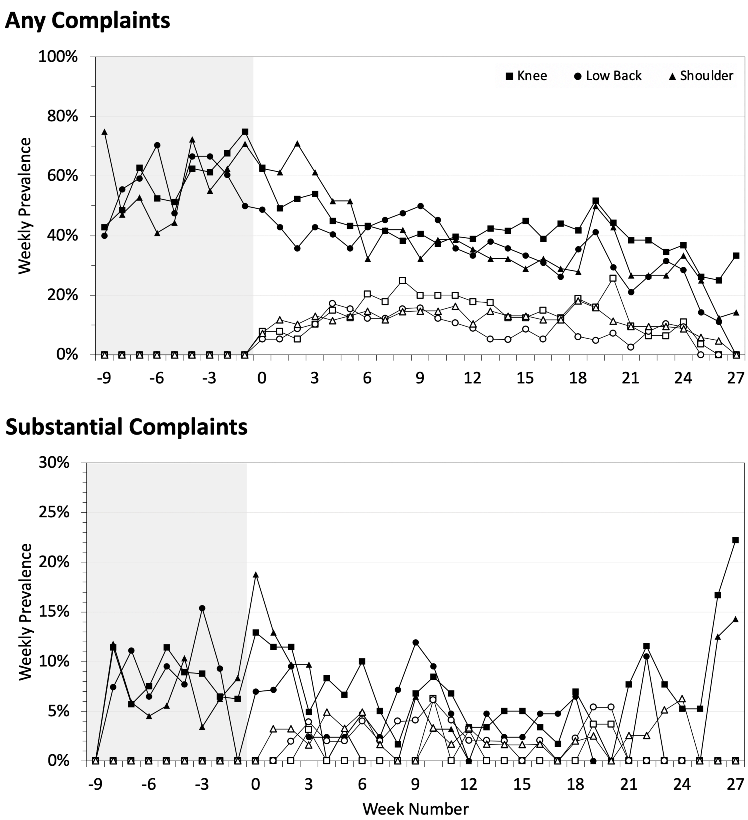

Figure 7. *Volleyball players with preseason knee, low back, and shoulder complaints continue to have a greater prevalence of complaints throughout the season compared to players without preseason complaints. More substantial complaints are also observed but with noticeably smaller prevalence (solid marker = players with preseason complaints, open marker = players without preseason complaints; week 0 indicates start of regular season).*

Furthermore, there appears to be a dose-response relationship, where players who experienced substantial knee problems in the preseason had an even higher prevalence of in-season complaints compared to both those without complaints and those with less severe preseason complaints (Table 14).

Table 14*. Average weekly prevalence of in-season knee, low back, and shoulder problems among elite men's volleyball players based on preseason complaints status – greater prevalence of problems among players with preseason complaints (n = 102 player-seasons).*[a]

	Knee	Low Back	Shoulder	Total Problems
All problems				
No preseason complaints	8 (5-10)	6 (5-8)	8 (7-10)	11 (9-14)
Preseason complaints (excluding substantial problems)	38 (36-41)	32 (27-36)	39 (34-44)	53 (48-58)
Preseason complaints - substantial problems	54 (46-61)	40 (33-48)	39 (31-47)	50 (43-57)
Substantial problems[b]				
No preseason complaints	1 (0-1)	2 (1-3)	2 (1-3)	2 (1-3)
Preseason complaints (excluding substantial problems)	5 (4-6)	2 (1-3)	3 (1-6)	8 (6-9)
Preseason complaints - substantial problems	16 (10-21)	11 (6-17)	5 (0-9)	16 (11-21)

[a]Data reported as mean values (%) with 95% CI in parentheses
[b]Substantial problems defined as moderate/severe reductions in training volume or sports performance, or complete inability to participate in training or competition.

Methodological considerations

Video analysis of ankle injuries (Paper I)

The inclusion of injuries registered prospectively during the FIVB Injury Surveillance System has minimized the risk of selection bias of included injuries and videos. Through the use of systematic video analysis, the description of injury situations and mechanisms has been reported with improved detail and accuracy over those previously described through questionnaires, which may contain recall bias from participants. While a systematic approach was used to uphold the highest levels of scientific rigor, there are several limitations which should be borne in mind when interpreting the results of this study.

One limitation is that the cases included are limited to only senior-level world-class competitions. Injury mechanisms within younger players and lower levels of adult competitors may differ. Second, injuries were only available from match play; there may be additional or other risks involved during training. Additionally, video analysis studies are dependent on the quality of the video and the number of camera views available. While most of the current videos had good quality with multiple views, there were a couple of cases in which the injury situation was easily observed but the motion of the ankle was obscured. We used a systematic approach to best determine the exact moment of injury and to ensure each reviewer evaluated the same time point, but although correspondence between reviewers was near perfect, we cannot be sure that this was when the ligament tear occurred. Also, the videos received were from television broadcasts – and while this provided high-quality views from different vantage points, in most cases the index frames analyzed were from slow motion replays at unknown speeds. This left us with unknown time gaps between frames and the inability to perform an accuracy calculation of the proposed index frame estimates prior to eventual consensus of the final index frames by all three reviewers, as performed by Bere et al.[20] Furthermore, the injury reporting form used within the Injury Surveillance System does not include information relating to the specific anatomical structures involved; we therefore cannot draw conclusions on the relationship between injury mechanisms and associated structural involvement. Finally, reports of hip and knee mechanics were limited as attempts to assess their positions in the frontal and transverse planes were inconsistent among reviewers.

Validation of Vert device – jump counts and jump height (Paper II)

As this study is the first to examine validity of the device in male professional volleyball players, extrapolation of the results to different levels of play or to female athletes may be limited. When examining device placement, every effort was made to simulate placement of the device as if it were tucked into the sports bra of a female player; however, use of a properly fitted sports bra may yield different results. Additionally, the accuracy of the Vertec during jump testing is dependent on accurate initial reach measurements, timing, and coordination of participants to hit the vanes at the apex of their jump and is limited in precision with the smallest incremental heights bound by the spacing between each horizontal vane.

It is important to note that, while performing the jump height validation with our professional players, there was an issue where not all the data recorded on the Vert devices synced properly with the iPad. As a result, some data were lost, limiting the total number of jumps available for analysis from our professional cohort. Detailed analysis revealed that the only substantial difference between the professional and recreational groups was an observation of greater jump heights in the professional group; the very reason for including both groups in the jump height validation.

Jump demands in professional volleyball (Paper III)

While this study includes over 120,000 jumps, extrapolation of the results to other national leagues, teams, and levels of competition may be limited. Different coaching styles and training regimens may also limit generalizability, but the take-home message remains: There is a need to monitor individual jump load. Every attempt was made to record all jumps performed during the season. However, missing data were imputed using player- and session-specific season averages. The imputed data were not used in the calculations of training and match jump count averages, jump frequencies, or jump height averages and should have minimal impact on the weekly jump counts, as they accounted for a small percentage of all player sessions.

Risk factors for shoulder complaints in professional volleyball (Paper IV)

Our findings may have implications for other overhead athletes, but as we only included professional volleyball players, extrapolation of these results to other sports and different levels should be done with caution. Direct comparison of the subacromial bursa (SAB) thickness and neovessel assessments to previous studies is difficult as different methods are often used. Similar to others, we measured the SAB thickness at its thickest point without including the peribursal fat; some have measured at set distances from nearby landmarks and/or included the peribursal tissue.[40, 63, 91, 110] Assessment of the SAB thickness and neovessels in different positions also limits direct comparison across studies. While the SAB side-to-side cutoff of 0.3 mm is reasonable based on previously reported MDC data for ultrasound assessment,[63, 91] it should be recalled that this was calculated post hoc; clinicians should be cautious in adopting this until confirmed in other athlete populations. As some players were included multiple times from different seasons, we assessed for group differences that may have biased the results. Subgroup analyses examining SAB thickness, neovessels presence, and shoulder complaints revealed only one player who presented twice with complaints and increased side-to-side SAB thickness (≥0.3 mm) and one player twice with complaints and neovessels. Additional subgroup analyses revealed no group differences in the questionnaire response rate or distribution of responses among players included over multiple seasons. Players were tested and followed systematically for 12 weeks through the use of structured questionnaires; however, other variables such as individual player load were not assessed and may also contribute to complaints.

Injury burden in volleyball – knee, low back, and shoulder complaints (Paper V)

While this study provides new insights into the true prevalence and burden of knee, low back, and shoulder problems in men's volleyball, it does not give a complete overview of all injuries, since only these three areas were observed. We focused on recording all complaints rather than identifying specific injury types; further diagnostic information was not available. This provides a more accurate account on the burden of these problems, but limits further extrapolation of results related to specific conditions such as jumper's knee. We followed these players through their professional club/university seasons. As each of these teams included players who have also competed at an international level, we do not know if these results would be similar when training and competing during the national team season.

We established strong relationships with the participating teams and had motivated coaches who took ownership of data collection. As a result, we had a very high response rate with very few weekly questionnaires missing (99.6% of questionnaires had all 3 sections fully completed). This was better than previous studies that provided the OSTRC questionnaire by email (91-93% response rates).[31, 33] Future teams and research collecting similar data should be sure to include individuals who have a vested interest in the data and project.[123]

Conclusions

1. Systematic video analysis of actual injury situations revealed: (1) the majority of ankle injuries occur while blocking, often landing on an opponent; (2) the attacker is overwhelmingly to blame for injuries at the net secondary to crossing the center line and landing partially into the blocker's court; (3) injuries during the attacking phase are often from a back-row player landing on a front-row teammate and (4) landing-related injuries mostly result from rapid inversion without any ankle plantarflexion.
2. The Vert device demonstrates excellent accuracy counting volleyball-specific jumps during training and competition. While the device is not recommended to measure maximal jumping ability when precision is needed, it provides an acceptable measure of on-court jump height that can be used to monitor athlete jump load.
3. Jump demands are high in professional volleyball; performance programs should be tailored to the match and training demands required at each position. Jump loads are highly variable; substantial week-to-week increases were observed for both the team and individual players. As a result, individual monitoring of jump load seems necessary.
4. A substantial thickening of the subacromial bursa and presence of neovessels in the dominant arm were each associated with increased risk of shoulder complaints. Position matters, as outside hitters and opposites were much more likely to develop shoulder problems while greater shoulder external rotation ROM also increased risk. Players with current complaints at baseline presented with greater IR:ER strength ratios; however, neither strength nor internal rotation ROM at baseline was associated with an increased risk of developing future shoulder complaints.
5. Nearly all elite men's volleyball players experienced knee, low back, or shoulder problems during a given season, and the majority had at least one bout that substantially reduced training participation or sports performance. Almost half of the players were playing through some combination of knee, low back, and shoulder complaints each week. Notably, players who experienced preseason knee, low back, and shoulder problems continued to have more problems during the competitive season than their teammates, and position and match participation also had significant impact on these complaints. These findings suggest that knee, low back, and shoulder problems result in greater injury burden than previously reported.

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Papers I-V

Paper I

Landing-related ankle injuries do not occur in plantarflexion as once thought: a systematic video analysis of ankle injuries in world-class volleyball

British Journal of Sports Medicine

Landing-related ankle injuries do not occur in plantarflexion as once thought: a systematic video analysis of ankle injuries in world-class volleyball

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ABSTRACT

Background Ankle injuries are prevalent in elite volleyball and suggested to result from player contact at the net. Traditionally, ankle sprains are thought to happen in a plantarflexed position, but case studies suggest plantarflexion may not be involved.

Aim Describe the injury situations and mechanisms of ankle injuries in world-class volleyball based on systematic video analysis of injuries reported through the Fédération Internationale de Volleyball (FIVB) Injury Surveillance System.

Methods Videos of 24 injuries from major FIVB tournaments were included for analysis (14 men, 10 women). Five analysts reviewed the videos to determine specific situations and mechanisms leading to injuries.

Results The majority of injuries occurred during two volleyball situations, blocking (n=15) and attacking (n=6). Injuries to blockers were the result of landing on an opponent (n=11) or teammate (n=4). Attacking injuries most frequently occurred when a back-row player landed on a front-row teammate (n=4 of 6). When landing on an opponent under the net, the attacker landed into the opponent's court in 11 of 12 situations but without violating the centre line rule. Injuries mostly resulted from rapid inversion without any substantial plantarflexion.

Conclusions The majority of injuries occur while blocking, often landing on an opponent. The attacker is overwhelmingly to blame for injuries at the net secondary to crossing the centre line. Injuries while attacking often result from a back-row player landing on a front-row teammate. Landing-related injuries mostly result from rapid inversion with the absence of plantarflexion.

INTRODUCTION

Acute ankle sprains are the most prevalent injury type in volleyball,[1–5] accounting for 29%–54% of all time-loss injuries among competitive players.[1 3 5] In 2010, the Fédération Internationale de Volleyball (FIVB) Injury Surveillance System (ISS) was established. Modelled after International Olympic Committee (IOC) protocols,[6] the ISS provides information on the rate and patterns of injuries during FIVB competitions. Data from the ISS document that ankle injuries account for 25.9% of all injuries among world-class players.[4]

Volleyball players are at particular risk for ankle sprains due to sport-specific tasks, such as blocking and spiking.[1–3 5 7–9] Questionnaire data from the elite national level in Norway,[9] Sweden[2] and Denmark[8] suggest that ankle sprains are often the result of player contact at the net, for example, when a blocker lands on the foot of a teammate or opposing attacker. However, no data are available on highly skilled players at the international level. Also, injuries happen quickly and often involve other players, limiting the reliability of questionnaire data from players or witnesses.[10 11] To fully understand the mechanisms of ankle injuries and reduce the risk of injury to volleyball players, a more accurate description of the playing situations and mechanisms typically leading to injury is needed.

Furthermore, lateral ankle sprains are traditionally thought to result from ankle inversion in a plantarflexed position. However, case studies that have examined the specific kinematics associated with ankle sprains have contrasted this. Using model-based image-matching of injury videos[12–14] and marker-based motion analysis of actual injuries during running and cutting manoeuvres,[12 15] they have described the injury as occurring in a neutral or dorsiflexed position.

To best understand the factors surrounding ankle sprains, it is recommended to perform a detailed video analysis of actual injury situations.[10 11] Systematic analysis of ankle injuries has been performed in football,[16] but never in sports predominantly involving landing-related injuries.

Therefore, the aim of this study was to describe the injury situations and mechanisms for ankle injuries in elite volleyball based on systematic analyses of videos of injuries reported through the FIVB ISS.

METHODS

Injury and video recording

We analysed video recordings of injuries to the ankle that were reported through the FIVB ISS from all major men's and women's senior-level tournaments (World Championships, World Cup, World Grand Prix, World League and Olympic Games) from September 2010 through November 2014. Junior-level tournaments were excluded as video recordings were not available. There were 34 major FIVB tournaments during this period and the ISS protocol was followed in 23 of these. The Men's and Women's World Olympic Qualification Tournaments were excluded as videos were not available. The FIVB ISS is based on prospective registration of injuries, where the medical staff of participating teams are requested to provide daily reports on all newly incurred injuries among their players.[4] A newly incurred injury is defined as any musculoskeletal complaint newly sustained during match play and/or training during the event that received medical attention, regardless of the consequences with respect to absence from competition or training. Pre-existing, not fully rehabilitated injuries are not recorded.

We requested video footage from the FIVB archives of all ankle injuries with subsequent time loss (n=32); of these, 27 were available on video. Video review revealed that the injury situation was not visible in two cases and unclear in one case, resulting in 24 acute ankle injuries available for analysis. These 24 injuries included 3 injuries that were captured from one camera angle, 8 from two camera angles, 9 from three angles, 3 from four angles and 1 from six camera angles.

Video processing

The video recordings were received on DVDs as digital files of varying formats. The discs were converted using a USB 3.0 capture device and stored as AVI files. By using a video editing program (Vegas Pro 13, 64-bit; Sony Creative Software, Middleton, Wisconsin, USA) we produced two versions of each injury situation, one full version showing the entire rally from the time of serving and one short version showing the specific injury situation from all available camera angles. The video files were rendered and saved as MPEG-4 files, which allowed frame-by-frame review using QuickTime 7 (Apple, Cupertino, California, USA).

Video analysis

Five experts in the field of volleyball and sports medicine participated in the video analysis. First, three of the experts watched the videos independently and proposed a specific frame in which they believed the ankle injuries occurred. Second, these three experts reviewed the videos together and came to a consensus regarding the index frame. This was defined as the first frame in which an abnormally large movement had occurred outside of the expected normal range of physiological motion.

Third, all five analysts were asked to independently review the videos and complete an assessment form for each case. The analysts were provided basic injury information regarding the injured player's sex, team, player number, involved ankle (left/right), position (libero/defensive specialist, middle, opposite, outside, setter) and the specific index frame and any corresponding index frames where the injury was observed.

The assessment forms included a combination of open and closed questions which evaluated the playing situation, centre line infringement and the mechanism of injury. The injury situation variables examined included playing situation (blocking—lands on opponent/teammate, back-row attack—lands on teammate, front-row attack—lands on opponent, non-contact landing, collision/contact with teammate, other), row (back/front), offence/defence, court position (1–6), ankle bracing (yes, no, unclear) and questions evaluating blocking related injury situations (blocker landing on 1 or 2 feet and the number of blockers). Injuries resulting from landing on an opponent included questions assessing whether the involved attacker and blocker landed on the centre line, landed into the opponent's court and if there was a centre line violation.

The injury mechanism variables primarily examined lower extremity (ankle, knee, hip) joint positions at first contact with the ground or with another player's shoe, lower extremity joint positions at the index frame and lower extremity joint movement between initial contact and the index frame. Other injury mechanism variables assessed included the timing of whether the ankle was rapidly driven into inversion or eversion after movement into a neutral flexion position, the position of the arms (overhead, shoulder level, down at side of body) and the weightbearing status of the lower extremities at the index frame (non, partial <33%, moderate=33%–67%, significant/full weightbearing >67%).

In describing the motion about the foot and ankle, we used terminology consistent with that used by Delahunt *et al*[17] and endorsed by the International Ankle Consortium.[18] Dorsiflexion and plantarflexion were defined as the motions parallel to the sagittal plane, around a medial-lateral axis of rotation.[19] Adduction and abduction of the foot occurred about a vertical axis through the shaft of the tibia with adduction resulting in an inward rotation of the foot and abduction resulting in an outward rotation of the foot.[19] Inversion and eversion were defined as frontal plane motions in which inversion raises the medial border of the foot while eversion raises the lateral border of the foot.[19] Supination and pronation were defined as the triplanar motions about the subtalar joint, with supination consisting of plantarflexion, adduction and inversion and pronation comprising dorsiflexion, abduction and eversion.[19]

After individual assessment of the cases, the results were collated. If four or five of the reviewers came to the same conclusion, agreement was said to have been reached. In the case of three reviewers having the same conclusion and no other options were chosen by more than one reviewer, agreement was deemed to also have been reached.

Finally, three of the experts met to review cases where agreement was not reached from the completed forms. Each video was viewed as many times as needed by the analysts until consensus was determined. If all three experts agreed after reviewing the video together, agreement was said to have been reached. If not, the result was deemed 'unclear'.

RESULTS

Ankle injury characteristics

A total of 24 injury cases were included in the video analysis, 14 men and 10 women (table 1). Injury characteristics included 11 injuries to the left ankle and 13 injuries to the right ankle. The majority of ankle injuries were to front-row players (n=20) compared with back-row players (n=4). Of the 24 injury cases, 20 resulted from one player landing on another player, 2 included non-contact landings (1 jump set, 1 back-row attack), 1 injury occurred during a small, celebratory hop after the play, and 1 was a collision between teammates in which the player diving after a tipped ball slid into his teammate's lower leg. Most of the 24 injuries occurred during one of two volleyball situations, blocking (n=15) or attacking (n=6) (table 1).

Blocking injuries

The 15 injuries to blockers were all related to the blocker landing on another player. These included 11 cases in which the blocker landed on an opponent (figure 1) and 4 cases where the blocker landed on a teammate. In 10 of these 15 cases, the blocker was injured landing primarily on one foot, whereas the blocker landed on 2 feet in four cases and was unclear in one situation. Observation of the four cases where a blocker is injured landing on a teammate revealed that the middle blocker was late to block and drifting laterally in all four incidents. In two of these situations, the middle blocker was injured; in the other two the teammate was injured. Figure 2 reveals a typical situation, where the middle blocker is injured landing on a teammate.

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Table 1 Playing situation and injury information for 24 cases of ankle injuries in world-class volleyball

		Injury information							Blocking	
Injury #	**Playing situation**	**Sex**	**Player position**	**Row**	**Offence/defence**	**Court position**	**L/R ankle**	**Ankle bracing**	**Lands: 1 or 2 feet**	**# blockers**
Blocking—lands on opponent										
1	Blocking—lands on opponent	Male	Opposite	Front	Defence	(2) Front right	Right	No	1	2
2	Blocking—lands on opponent	Male	Opposite	Front	Defence	(2) Front right	Left	Yes	1	2
3	Blocking—lands on opponent	Male	Opposite	Front	Defence	(2) Front right	Left	No	2	2
4	Blocking—lands on opponent	Female	Outside	Front	Defence	(4) Front left	Right	Yes	1	2
5	Blocking—lands on opponent	Male	Middle	Front	Defence	(3) Front middle	Left	No	1	1
6	Blocking—lands on opponent	Female	Middle	Front	Defence	(3) Front middle	Right	Yes	1	1
7	Blocking—lands on opponent	Female	Middle	Front	Defence	(3) Front middle	Left	Yes	1	2
8	Blocking—lands on opponent	Female	Outside	Front	Defence	(4) Front left	Right	No	2	2
9	Blocking—lands on opponent	Male	Outside	Front	Defence	(2) Front right	Left	No	2	2
10	Blocking—lands on opponent	Female	Opposite	Front	Defence	(2) Front right	Right	No	1	1
11	Blocking—lands on opponent	Female	Outside	Front	Defence	(4) Front left	Right	Unclear	Unclear	2
Blocking—lands on teammate										
12	Blocking—lands on teammate	Male	Outside	Front	Defence	(4) Front left	Left	No	2	2
13	Blocking—lands on teammate	Male	Middle	Front	Defence	(3) Front middle	Right	No	1	2
14	Blocking—lands on teammate	Male	Opposite	Front	Defence	(2) Front right	Right	No	1	2
15	Blocking—lands on teammate	Male	Middle	Front	Defence	(3) Front middle	Left	No	1	2
Attacking—back row, lands on teammate										
16	Back row—lands on teammate	Male	Outside	Back	Offence	(6) Back middle	Left	No	–	–
17	Back row—lands on teammate	Female	Outside	Back	Offence	(6) Back middle	Right	Yes	–	–
18	Back row—lands on teammate	Female	Opposite	Back	Offence	(1) Back right	Right	Unclear	–	–
Attacking—back row, landed on by teammate										
19	Back row—landed on by teammate	Male	Setter	Front	Offence	(2) Front right	Left	Yes	–	–
Attacking—front row, lands on opponent										
20	Attacking—lands on opponent	Female	Opposite	Front	Offence	(2) Front right	Right	No	–	–
Other injury situations										
21	Jump setting—lands (non-contact)	Female	Setter	Front	Offence	(2) Front right	Right	No	–	–
22	Back-row attack—lands (non-contact)	Male	Middle	Back	Offence	(6) Back middle	Left	No	–	–
23	Collision/contact with teammate	Male	Opposite	Front	Defence	(2) Front right	Left	No	–	–
24	Celebration (non-contact)	Male	Middle	Front	Offence	(3) Front middle	Right	No	–	–

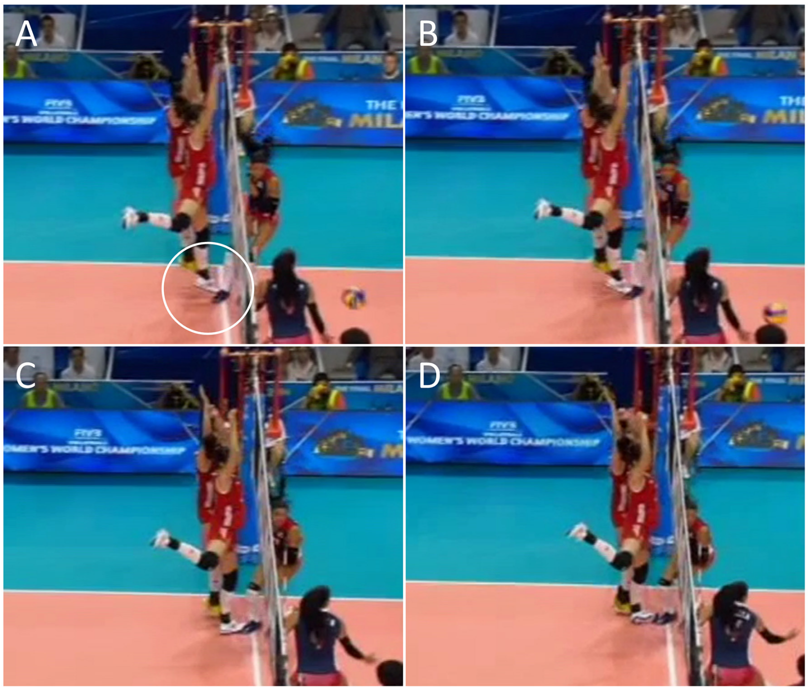

Figure 1 Injury situation: middle blocker (in red) landing on the foot of an opposing attacker who has landed on the centre line and partially into the injured player's court. (A) Left ankle of middle blocker in plantarflexion just prior to landing. (B) Initial contact with opponent's foot, ankle plantarflexed. (C) Left ankle in neutral 'foot flat' position. (D) Left ankle in inverted position following rapid inversion moment. The videos from which these figures have been taken are available online as supplementary material.

Attacking injuries

There were six cases where attacking players were injured. In five of these, the attacker was hitting out of the back row. In four of these cases, a back-row player landed on a front-row teammate; three leading to the back-row attacker being injured and one situation where the front-row player was landed on and injured. Figures 3 and 4 show two of these situations. During all four cases where a back-row attacker landed on a front-row teammate, it was observed that the offence developed out of system,[20] in which the play during the rally took the team away from running the preferred pass, set, hit sequence. Of these four cases, three resulted in the player landing on the front-row middle blocker and one resulted in the setter being landed on. There was one remaining attacking injury case, which included a front-row attacker who landed on a blocking opponent at the net.

Centre line infringements

There were 12 injury situations which resulted in a player landing on an opponent under the net (table 2). The majority of these were blockers landing on opponents (n=11), with one situation of an attacking player landing on an opponent. In all 12 situations, the attacking player landed on the centre line, compared with 6 situations where the blocker landed on the centre line. Furthermore, in 11 of the 12 situations the attacker landed partially into the opponent's court while only 2 of the situations resulted in the blocker landing partially into the opponent's court. None of the 12 cases resulted in a centre line violation call from the officials and in none of the cases was a centre line violation by either player observed in the video analysis.

Landing-related injury mechanisms

Of the 24 injuries observed, 21 were landing-related injuries that involved the injured player landing from a traditional volleyball play which included attacking, blocking and setting. These landing-related injuries included 19 situations where the injured player landed on another player and 2 occasions where the injured player landed without any contact with another individual.

Table 3 shows the information on the mechanism for these 21 landing-related injuries in addition to the other 3 injuries observed on video. These included 18 inversion injuries and 1 eversion injury (2 injuries were unclear from the videos obtained). At initial contact by the foot with either the ground or shoe of another individual, the ankle was in a relatively neutral position in 16 situations and an inverted position in 3 situations. At initial contact the ankle was also in plantarflexion in 15 cases and in dorsiflexion in 3 cases. When examined from the point of initial contact of the foot to the index frame, the ankle moved toward dorsiflexion in 16 cases, remained in a static position in 2 cases and was unclear in 3 additional situations. Of the 19 situations where a player landed on another player, it was determined that the ankle first moved into a neutral dorsiflexed position prior to rapid inversion/eversion in 15 situations compared with 1 situation in which the ankle was not first in a neutral dorsiflexed position (3 situations were unclear).

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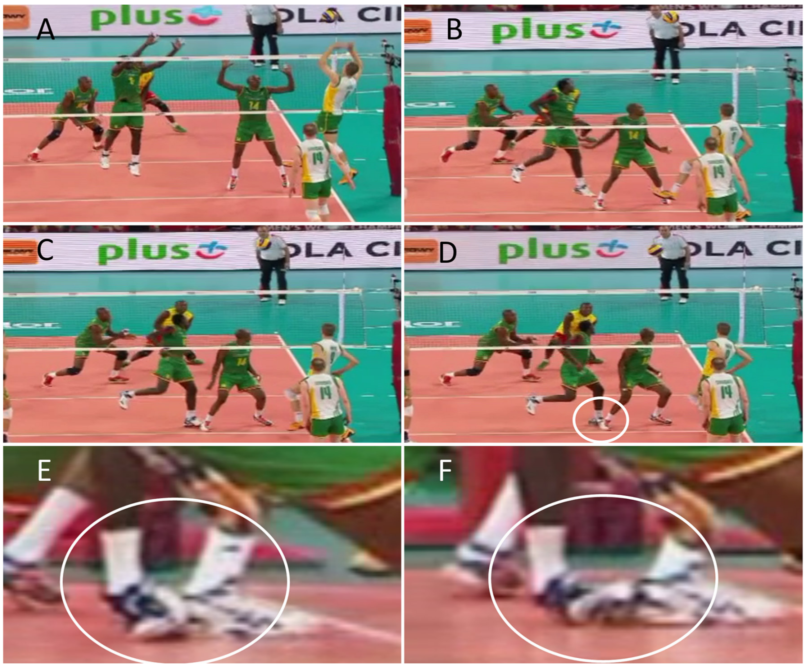

Figure 2 Injury situation: middle blocker landing on teammate. (A) The middle blocker jumps laterally to attempt to block the opposing player's attack. (B) The left ankle of the middle blocker immediately prior to landing on the back of his teammate's shoe. (C) Left foot flat on ground and ankle partially inverted. (D) Moment of injury following rapid inversion moment. (E, F) Alternate views of left ankle inversion injury taken from camera placed behind and to the right of the injured blocker's position and correspond to images (C) and (D).

At the index frame, the involved limb had significant/full weightbearing in 16 of the cases while moderate weight bearing of the limb was present in 5 additional cases. Table 3 also reveals the position of the knee and hip for the involved limb in the sagittal plane as well as the arms at the index frame. Attempts to perform assessment of the knee and hip positions in the frontal and transverse planes were inconsistent among reviewers and no consensus was reached.

DISCUSSION

This is the first study to describe injury situations and injury mechanisms for acute ankle injuries sustained among world-class volleyball players. Through systematic video analysis of actual injury situations, the main findings of this study were (1) the majority of injuries occur while blocking, often landing on an opponent; (2) the attacker is overwhelmingly to blame for injuries at the net secondary to crossing the centre line and landing partially into the blocker's court; (3) injuries during the attacking phase are often from a back-row player landing on a front-row teammate and (4) landing-related injuries mostly result from rapid inversion without any substantial plantarflexion.

Landing on another individual is the most common inciting event

Landing-related injuries during traditional volleyball play including blocking, attacking and setting accounted for nearly all of the acute ankle injuries observed in world-class players. Of these, the vast majority (90%) were the result of one individual landing on another. This is consistent with previous studies that used questionnaires, including examination of ankle sprains in Norwegian volleyball that found 87% occurred when landing on the foot of an opponent or teammate.[3 9] Any interventions designed to prevent acute ankle sprains in the sport likely need to focus on minimising the risk of players landing on one another through education on typical injury situations and technical training for take-offs and landings.[21]

Blocking injuries mostly involve landing on another player and an attacker crossing the centre line

The act of blocking puts players more at risk than other components of the game. Blockers sustained 62.5% of ankle sprains in this study, which is consistent with previous findings that 61% of ankle injuries transpired while blocking in the top Swedish division.[2] Typically, blockers are injured when landing on an opponent or teammate. When blockers land on a teammate, the injury often happens because one or both of the blockers are moving laterally during an attempt to close the block to make it difficult on the hitter. In these situations, the middle blocker was drifting laterally in all of the incidents that resulted in injuries to middle blockers or their teammates.

Plays in which the blocker landed on an opponent mostly resulted from the attacker landing under the net and partially into the blocker's side of the court. This mainly happens if the set is tight to the net and the attacker jumps and lands under the net, but can also result from an errant jump in which the

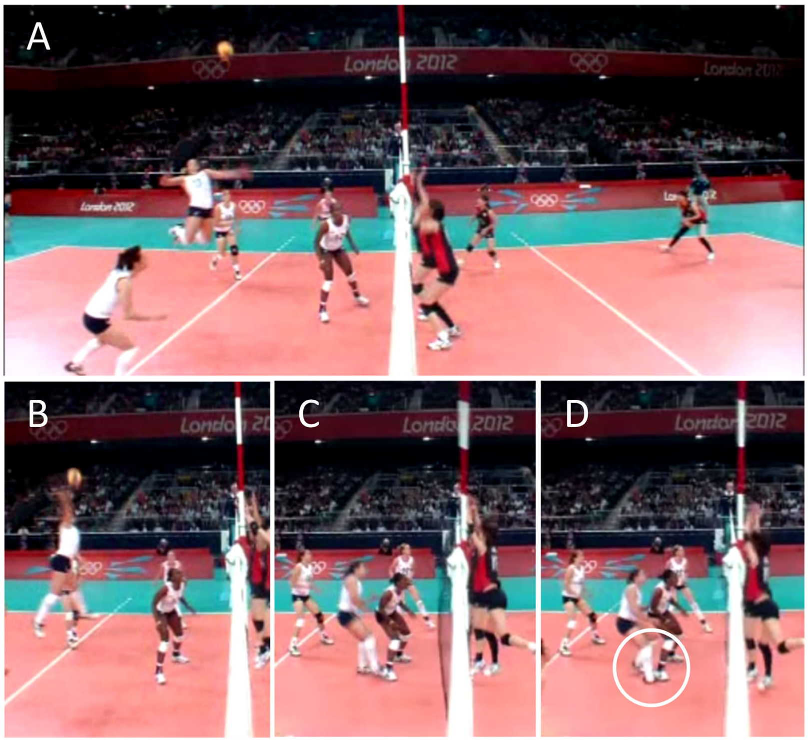

Figure 3 Injury situation: player landing on front-row teammate during back-row attack. (A) Overview of playing situation after attacker jumps from behind the 3 m line (white line) and just prior to ball contact. (B) The involved player contacts the ball. (C) The injured player at initial contact with front-row middle hitter, who is attempting to cover her attack. (D) Moment of injury, where the back-row player's right ankle has inverted after landing on the right foot of her front-row teammate.

attacker simply jumped and landed too tight despite a good set.

No centre line violations, but all injuries under the net involve landings on the centre line

All the injuries involving contact with the opposition were a result of players landing on the centre line under the net. The attacking player landed on the centre line in every situation and landed partially into the opponent's court in all but one play. FIVB rules allow a player to land with a foot partially into the opponent's court as long as the penetrating foot maintains contact with the centre line or is directly over the centre line.[22]

No centre line violations were incurred by any of the players; however, a player landing on the centre line was a contributing factor in all of the situations examined. Injuries to blockers landing on opposing attackers continue to be the most common situation associated with ankle injuries at this level of the sport. One previous attempt to make the centre line rule more strict during a preseason tournament in Norway resulted in substantial disruption to the game through a significant increase in centre line violations and the rule being changed back prior to the start of the regular season.[23] If players were given more time to adjust to the strict centre line rules, the number of violations may decrease. Additional consideration may be given for a rule change that makes centre line violations strict for attacking players but lenient in other scenarios where there is no/less risk of ankle injury. While it is unclear exactly what effect changes to the centre line rules would have on injury incidence, proposals to restrict contact with the centre line or opponent's court within the conflict zone under the net should be considered.[24]

Attacking injuries: most commonly resulting from back-row attacks

This study is the first to describe back-row attacks as a common injury situation. In fact, two-thirds of attacking injuries resulted from a back-row attacker landing on an inattentive front-row teammate. Each of these injuries was the result of offences operating out of system. Coaches and players need to recognise these potential at-risk situations and be certain that no front-row players move into the landing path of the back-row hitter, eager to cover potential block returns.

Injuries mostly occur through inversion, with the absence of plantarflexion

The typical injury involves the ankle dorsiflexing from a plantarflexed position at initial contact towards a foot flat position on the ground. In most injury cases, inversion does not occur until the ankle is in neutral flexion with the absence of any significant plantarflexion.

This confirms recent case studies of accidental ankle sprains during laboratory cutting manoeuvres that found the ankle was in a dorsiflexed position at the moment of peak inversion.[12 15]

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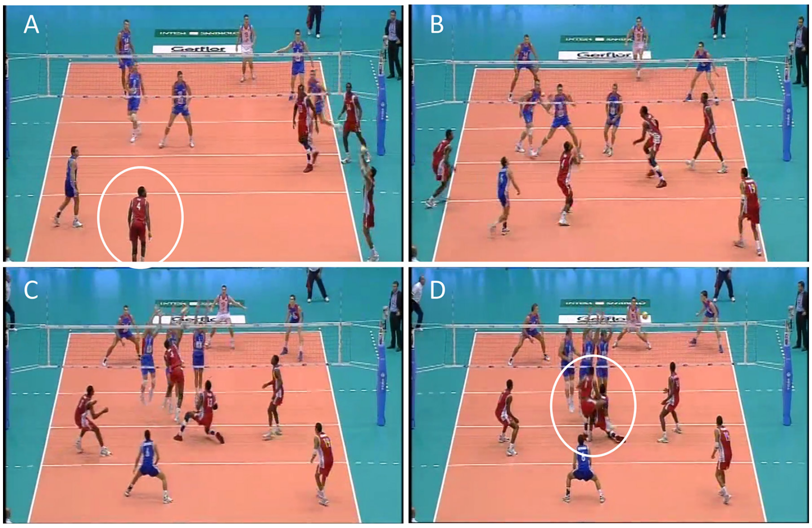

Figure 4 Injury situation: player landing on front-row teammate during back-row attack. (A) The involved player (red #4) begins his approach as the ball is set from the back row during a broken play. (B) Involved player begins to jump from beyond the 3 m line. (C) Involved player makes contact with ball as the front-row middle moves into the landing path while attempting to cover the hitter's attack. (D) Moment of injury where the left foot of the injured player lands on top of the back of the left foot of his front-row teammate.

Injuries during high jumping and field hockey also report the ankle not being plantarflexed at the moment where maximal inversion occurred,[13] and five cases from tennis found no significant plantarflexion component.[14] Rather, inversion and internal rotation was the primary mechanism. The authors suggested that ankle sprains from jump landing in sports such as volleyball may still occur from an inversion plus plantarflexion mechanism. Our results, however, reveal that landing-related injuries in volleyball also mainly occur through inversion without any substantial plantarflexion.

Methodological considerations

This study is the first to describe injury situations and mechanisms for acute ankle injuries sustained among world-class volleyball players. The inclusion of injuries registered prospectively during the FIVB ISS has minimised the risk of selection bias of included injuries and videos. Through the use of systematic video analysis, the description of injury situations and mechanisms has been reported with improved detail and accuracy over those previously described through questionnaires which may contain recall bias from participants. While a systematic approach was used to uphold the highest levels of scientific rigour, there are several limitations which should be borne in mind when interpreting the results of this study.

One limitation is that the cases included are limited to only senior-level world-class competitions. Injury mechanisms within younger players and lower levels of adult competitors may differ. Second, injuries were only available from match play; there may be additional or other risks involved during training. Additionally, video analysis studies are dependent on the quality of the video and

Table 2 Landing position of the attacker and blocker relative to the centre line and opponent's court

		On centre line		Into opponent's court		Centre line violation
Injury #	**Playing situation**	**Attacker**	**Blocker**	**Attacker**	**Blocker**	**Either player**
Blocking—lands on opponent						
1	Blocking—lands on opponent	Yes	Yes	No	No	No
2	Blocking—lands on opponent	Yes	No	Yes	No	No
3	Blocking—lands on opponent	Yes	No	Yes	No	No
4	Blocking—lands on opponent	Yes	No	Yes	No	No
5	Blocking—lands on opponent	Yes	Yes	Yes	No	No
6	Blocking—lands on opponent	Yes	No	Yes	No	No
7	Blocking—lands on opponent	Yes	No	Yes	No	No
8	Blocking—lands on opponent	Yes	Yes	Yes	Yes	No
9	Blocking—lands on opponent	Yes	Yes	Yes	Yes	No
10	Blocking—lands on opponent	Yes	Yes	Yes	No	No
11	Blocking—lands on opponent	Yes	Unclear	Yes	Unclear	No
Attacking—front row, lands on opponent						
20	Attacking—lands on opponent	Yes	Yes	Yes	No	No

Table 3 Injury mechanisms for the involved ankle and limb during ankle injuries sustained by world-class volleyball players

		Joint position *First contact (ground or shoe)*		Joint movement *First contact to index frame*			Joint position *Index injury frame*						
		Ankle position		Ankle movement			Ankle position		Knee position	Hip position	Position of the arms		
Injury #	Landing-related	DF/PF	Inv/Ev	Towards DF/PF	Towards Inv/Ev	Rapid Inv/Ev in neutral flexion	DF/PF	Inv/Ev	Flexion/extension	Flexion/extension	Left	Right	Weightbearing at index frame
Blocking—lands on opponent (n=11)													
1	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Extended	Overhead	Overhead	Significant
2	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Significant
3	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Shoulder level	Moderate
4	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Significant
5	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Significant
6	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Significant
7	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Extended	Flexed (0–45°)	Overhead	Overhead	Significant
8	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Moderate
9	Yes	PF	Neutral	Unclear	Inv	Unclear	PF	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Moderate
10	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Flexed (0–45°)	Flexed (0–45°)	Shoulder level	Shoulder level	Significant
11	Yes	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Flexed (0–45°)	Overhead	Overhead	Significant
Blocking—lands on teammate (n=4)													
12	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Overhead	Overhead	Moderate
13	Yes	PF	Inv	DF	Inv	Yes	PF	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Overhead	Significant
14	Yes	PF	Inv	DF	Inv	No	PF	Inv	Extended	Extended	Overhead	Overhead	Significant
15	Yes	DF	Neutral	Static	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Significant
Attacking—back row, lands on teammate (n=3)													
16	Yes	DF	Neutral	DF	Ev	Yes	DF	Ev	Flexed (45–90°)	Flexed (0–45°)	Down	Down	Significant
17	Yes	PF	Neutral	DF	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Significant
18	Yes	DF	Neutral	Static	Inv	Yes	Neutral	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Significant
Attacking—back row, landed on by teammate (n=1)													
19	No	DF	Neutral	Static	Ev	–	Neutral	Ev	Flexed (>90°)	Flexed (0–45°)	Down	Down	Partial
Attacking—front row, lands on opponent (n=1)													
20	Yes	PF	Neutral	DF	Inv	Yes	PF	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Moderate
Other injury situations (n=4)													
21	Yes	PF	Inv	DF	Inv	–	PF	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Significant
22	Yes	Unclear	Neutral	DF	Inv	–	PF	Inv	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Significant
23	No	DF	Neutral	DF	Inv	–	DF	Neutral	Flexed (0–45°)	Flexed (0–45°)	Down	Down	Moderate
24	No	PF	Neutral	PF	Inv	–	PF	Inv	Flexed (0–45°)	Extended	Down	Down	Significant

DF, dorsiflexion; Ev, eversion; Inv, inversion; PF, plantarflexion.

the number of camera views available. While most of the current videos had good quality with multiple views, there were a couple of cases in which the injury situation was easily observed but the motion of the ankle was obscured. We used a systematic approach to best determine the exact moment of injury and to ensure each reviewer evaluated the same time point, but although correspondence between reviewers was near perfect, we cannot be sure that this was when the ligament tear occurred. Also, the videos received were from television broadcasts and while this provided high-quality views from different vantage points, in the majority of cases the index frames analysed were from slow motion replays at unknown speeds. This left us with unknown time gaps between frames and the inability to perform an accuracy calculation of the proposed index frame estimates prior to eventual consensus of the final index frames by all three reviewers, as performed by Bere *et al*.[25] Furthermore, the injury reporting forms used within the ISS do not include information relating to the specific anatomical structures involved; we therefore cannot draw conclusions on the relationship between injury mechanisms and associated structural involvement. Finally, reports of hip and knee mechanics were limited as attempts to assess their positions in the frontal and transverse planes were inconsistent among reviewers.

CONCLUSIONS

Systematic video analysis of actual injury situations revealed that the majority of injuries occur while blocking—often landing on an opponent, the attacking player is overwhelmingly to blame for injuries at the net secondary to crossing the centre line and landing partially into the opponent's court, and injuries during the attacking phase are often from a back-row player landing on a front-row teammate. Also, landing-related injuries mostly result from rapid inversion in neutral flexion without any substantial plantarflexion.

What are the new findings?

- The majority of injuries occur while blocking, often landing on an opponent
- The attacker is overwhelmingly to blame for injuries at the net secondary to crossing the centre line and landing partially into the blocker's court
- Injuries during the attacking phase are often from a back-row player landing on a front-row teammate
- Landing-related injuries mostly result from rapid inversion in neutral flexion without any substantial plantarflexion

How might it impact on clinical practice in the near future?

- Education should be given to front-row attackers on jump technique so that they do not land under the net and into the opponent's court regardless of the location of the set.
- Education should be given to front-row players to avoid standing in the landing path of back-row attackers
- Rule changes regarding a stricter centre line rule, especially for attacking players, may be considered and attempts to abolish the current centre line rule should be resisted.

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Paper II

A valid and reliable method to measure jump-specific training and competition load in elite volleyball players

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ORIGINAL ARTICLE

WILEY

A valid and reliable method to measure jump-specific training and competition load in elite volleyball players

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Use of a commercially available wearable device to monitor jump load with elite volleyball players has become common practice. The purpose of this study was to evaluate the validity and reliability of this device, the Vert, to count jumps and measure jump height with professional volleyball players. Jump count accuracy was determined by comparing jumps recorded by the device to jumps observed through systematic video analysis of three practice sessions and two league matches performed by a men's professional volleyball team. Jumps performed by 14 players were each coded for time and jump type and individually matched to device recorded jumps. Jump height validity of the device was examined against reference standards as participants performed countermovement jumps on a force plate and volleyball-specific jumps with a Vertec. The Vert device accurately counted 99.3% of the 3637 jumps performed during practice and match play. The device showed excellent jump height interdevice reliability for two devices placed in the same pouch during volleyball jumps (r = .99, 95% CI 0.98-0.99). The device had a minimum detectable change (MDC) of 9.7 cm and overestimated jump height by an average of 5.5 cm (95% CI 4.5-6.5) across all volleyball jumps. The Vert device demonstrates excellent accuracy counting volleyball-specific jumps during training and competition. While the device is not recommended to measure maximal jumping ability when precision is needed, it provides an acceptable measure of on-court jump height that can be used to monitor athlete jump load.

KEYWORDS
injury prevention, jump load, load monitoring, vert, volleyball, workload

1 | INTRODUCTION

The sport of volleyball is fast-paced, hard-hitting, and requires its athletes to perform a large volume of jumps. Unfortunately, the repetitive jumping often leads to knee complaints among players. A study from 1984,[1] in which athletes who played at least five times per week were more likely to report jumper's knee complaints than those who trained less, suggested a relationship between training load and overuse knee complaints in volleyball. More recently, the prevalence of current symptoms of jumper's knee, or patellar tendinopathy, is reported as high as 44%-51% in men's volleyball.[2,3] A four-year prospective study in elite, junior-level players reported a 3.9-fold increased risk for developing jumper's knee for every extra set of match play each week and a 1.7-fold increased risk for every additional hour of volleyball training each week.[4] Additionally, other studies have shown that players with the greatest jumping ability[3,5,6] are most susceptible to developing complaints.

As a result, a method to measure and control jump load is needed. Bahr and Bahr[7] recently highlighted that using time as a measure of jump load may not be valid in volleyball. They observed substantial variation between players—jump frequency ranged from 50 to 666 jumps/week among males and 11 to 251 jumps/week among females.[7] Previously, manual counting of jumps through direct observation or video review was the only method available and is extremely time-consuming.[7] Ideally, not only the number of jumps, but also jump intensity should be monitored. However, using force plates, the gold standard method for measuring jump height, is clearly not feasible in volleyball or most other sports. With improved technology, we may be able to examine jump load for individual players by monitoring not only jump count, but also jump height through the use of an inertial measurement unit (IMU). Two small studies have reported acceptable validity of a commercially available IMU with adolescent volleyball players.[8,9] Use of the IMU has grown significantly as university programs, professional clubs, and national teams have started to monitor jump load. However, this device has never been validated with adult professional volleyball players.

Therefore, the aim of this study was to assess the validity and reliability of this method to count jumps and measure jump height in male professional volleyball players.

2 | METHODS

This study was conducted in two stages. The first stage examined the validity of the IMU to accurately count jumps in men's volleyball and the second stage assessed the validity of the device to measure jump height. Participants provided informed consent and were excluded if they had an injury that restricted their ability to fully participate in each respective stage of the study. Ethics approval was obtained from the Anti-Doping Lab Qatar Institutional Review Board.

2.1 | Device

Participants wore a commercially available IMU, Vert Classic (Model #JEM, Mayfonk Athletic, Fort Lauderdale, FL, USA), measuring 5.3 × 2.3 × 0.9 cm. Each device was inserted into a small pouch on an elastic waistband with the device placed slightly inferior and lateral to the participant's umbilicus as recommended by the manufacturer. The devices were all connected via Bluetooth to an Apple iPad mini 2 with the Vert Coach application (version 2.0.6, Mayfonk Athletic, Fort Lauderdale, FL, USA). All jumps were timestamped, individually assigned, and recorded for jump height prior to being downloaded and exported for analysis.

2.2 | Jump count

Fourteen adult male professional volleyball players from an elite club in Qatar wore Vert devices during three practice sessions (3.4 h in total) and two league matches (nine sets, 3.7 h). Thirteen of the players wore devices and participated in practice sessions, while eight players participated in match play. The practice sessions consisted of routine, structured training including serving, hitting, and blocking drills, and incorporated various 4-on-6 and 6-on-6 team scenarios. All jumps performed from the opening point to the final match point were included in the match play analysis. Warm-up jumps were not included. All practice and match sessions were recorded by a high-definition video camera placed beyond the end line at one end of the court. This video was later analyzed by two examiners, each with greater than ten years of experience playing and working in competitive volleyball.

The two examiners watched video of the sessions, and each jump was individually coded with the time, jump type, and player name. Jump types were categorized as block, attack, set, jump float, jump serve, defensive overhead, defensive bump, and miscellaneous. Examiner one, blinded from the Vert results, was the primary reviewer of the video, while examiner two simultaneously coded each jump and consulted the video for clarification on individual jumps. A jump was defined using the same definition as Charlton et al[8] of: "any occasion where both feet of the athlete were visually inspected to leave the ground at approximately the same time." The Vert device, however, uses a minimum threshold of 15 cm before recording a jump. To account for this, all jumps that were observed on video and not recorded by the device were reassessed by both examiners and jumps estimated to be <15 cm were categorized as "small" and not included for analysis. Additionally, any jumps that occurred out of view of the camera were not included.

Data from visual observation of jumps and from the Vert device were synchronized using their respective timestamps. Any jumps recorded by the device but not observed upon visual observation were re-examined on video to confirm the presence or absence of a jump. Jumps recorded by the device were compared against visual observation to observe the number of true positives (jumps recorded by the Vert device and observed on video), false negatives (jumps not recorded by the device but observed on video), and false positives (jumps recorded by the device but not observed on video).

2.3 | Jump height

The second stage of this study examined the Vert device for jump height validity and reliability through a series of volleyball-specific jumps and countermovement jumps. Ten male professional volleyball players and 12 male recreational athletes participated, which provided a large distribution of jump heights. Participants wore an elastic waistband with two devices placed in the same pouch to examine interdevice reliability. To assess the ability of the device to be worn in different locations on the body, each participant wore a third device placed in an elastic waistband around his chest (as if the device was placed in a sports bra) and a fourth device placed in the participant's sock (or in a compression sleeve against the lower leg if long socks were not worn).

Individuals first performed a series of easy (50%), medium (75%), and maximal effort countermovement jumps on a force plate (ForceDecks, NMP Technologies, London, UK). From a standing position, participants were instructed to place their hands on their hips, lower to a squat position, and quickly jump straight up while maintaining lower limb extension in the air.

TABLE 1 Jump description and session demographics of jump count validation during volleyball practice and match play

	Practice	Match	Total
Total session time (minutes)	204	224	428
Player hours	37.5	24.5	62.0
Participants	13	8	14
Number of sessions	3	2 (9 sets)	5
Included jumps	2521	1116	3637
Excluded jumps			
Occurred off camera	6	4	10
"Small" jumps[a]	76 (2.9%)	1 (0.1%)	77(2.1%)
Set	59	1	60
Block	8	0	8
Spike	2	0	2
Defensive overhead	5	0	5
Defensive bump jump	2	0	2

[a]"Small" jumps that were not recorded by Vert but were observed on video and estimated to be less than the 15 cm threshold used by Vert.

Next, participants performed a series of three vertical jumps using a Vertec (Sports Imports, Hilliard, OH, USA). The Vertec is a commonly used apparatus for measuring vertical jump ability in volleyball players and is comprised of a vertical post containing horizontal vanes that can be pushed out of the way to measure jump height and reach of athletes. Each jump was performed with four repetitions; two submaximal attempts at 50% effort and two maximal attempts. The jumps included a 1-hand reach to Vertec, 2-hand reach to Vertec, and a spike approach jump which included a two- or three-step approach and a 1-hand reach to Vertec.

During jump height validation, a Vert device would intermittently not detect a jump resulting in no height being reported from that particular device. This occurred most frequently with devices placed in the participant's sock. All jump heights measured by devices were included in this analysis. Additionally, a participant would occasionally ask to perform one additional repetition of a maximal effort jump test and these jumps were also included in the final analysis.

Vert device data were analyzed against force plate and Vertec measurements across a range of test conditions to determine the device bias (mean difference, 95% CI) and minimum detectable change (MDC). Data were also assessed using intraclass correlation coefficients (ICC, two-way mixed, consistency). Analyses were conducted using SPSS version 21 (IBM Corporation, New York, NY, USA).

3 | RESULTS

3.1 | Jump count

A total of 3637 jumps were observed on camera and included for analysis (Table 1). An additional 87 jumps were excluded because they occurred off camera (n = 10) or were

TABLE 2 Jump count accuracy of the Vert device compared to video analysis based on jump type and session type

	Video	True positives (n, %)	False negatives (n, %)	False positives (n, %)
Jump type				
Block	1266	1259 (99.4%)	7 (0.6%)	0 (0.0%)
Attack	1170	1162 (99.3%)	8 (0.7%)	0 (0.0%)
Set	426	424 (99.5%)	2 (0.5%)	0 (0.0%)
Jump float	347	344 (99.1%)	3 (0.9%)	0 (0.0%)
Jump serve	308	305 (99.0%)	3 (1.0%)	0 (0.0%)
Defensive overhead	32	32 (100.0%)	0 (0.0%)	0 (0.0%)
Defensive bump	25	25 (100.0%)	0 (0.0%)	1 (3.8%)
Miscellaneous	63	61 (96.8%)	2 (3.2%)	11 (15.3%)
Session type				
Practice	2521	2503 (99.3%)	18 (0.7%)	7 (0.3%)
Match	1116	1109 (99.4%)	7 (0.6%)	5 (0.4%)
Total	3637	3612 (99.3%)	25 (0.7%)	12 (0.3%)

TABLE 3 Bias, MDC, and reliability of the Vert device based on jump type, effort level, athlete type, and device placement on the body

	Vert bias (cm)[a]	MDC (cm)	ICC[a]	Number of jumps
Volleyball jump type (Vert vs Vertec)				
All volleyball jumps	5.5 (4.5-6.5)	9.7	0.85 (0.80-0.89)	188
Spike approach	5.4 (3.8-7.1)	9.5	0.88 (0.81-0.92)	68
1-hand reach	3.2 (1.4-5.0)	9.8	0.78 (0.66-0.86)	60
2-hand reach	8.0 (6.4-9.6)	8.8	0.75 (0.61-0.84)	60
Effort level (Vert vs Vertec, volleyball jumps)				
Maximal effort	4.6 (3.2-6.0)	9.7	0.86 (0.80-0.90)	98
Submaximal effort	6.6 (5.2-8.0)	9.5	0.72 (0.60-0.80)	90
Athlete type (volleyball jumps)				
Professional volleyball player	2.2 (1.0-3.4)	11.6	0.82 (0.68-0.90)	41
Recreational athlete	6.5 (5.6-7.4)	8.7	0.79 (0.72-0.84)	147
Vert placement (volleyball jumps)				
Waist vs Vertec	5.5 (4.5-6.5)	9.7	0.85 (0.80-0.89)	188
Chest vs Vertec	6.6 (5.7-7.5)	8.1	0.90 (0.86-0.92)	170
Sock vs Vertec	1.2 (−1.5 to 4.0)	23.0	0.44 (0.30-0.57)	139
Interdevice reliability by Vert placement (volleyball jumps)				
Waist vs Waist	−0.3 (−0.6 to 0.0)	2.3	0.99 (0.98-0.99)	147
Chest vs Waist	0.9 (0.3-1.5)	5.9	0.94 (0.92-0.96)	170
Sock vs Waist	−4.6 (−7.4 to −1.7)	23.6	0.39 (0.24-0.52)	139
Countermovement jump (Vert vs force plate)				
Force plate	9.1 (8.1-10.0)	5.5	0.93 (0.89-0.96)	65

ICC, intraclass correlation coefficient (two-way mixed, consistency); MDC, minimum detectable change.
[a]95% Confidence intervals are shown in parenthesis.

categorized as "small" jumps (ie, estimated to be <15 cm; n = 77) (Table 1). Of the included jumps, 3612 (99.3%) were correctly identified by the Vert device (Table 2). The device accurately identified 99.0% to 100% of jumps during blocking, attacking, setting, serving, bumping, and other defensive overhead attempts.

Few false negatives (n = 25, 0.7%) and false positives (n = 12, 0.3%) were observed across all jumps, resulting in one false positive per 303 jumps or 5.17 player hours of training and match play. The false positives occurred when players stopped their spike approach (n = 4), dove for a ball (n = 2), attempted a defensive bump/dig (n = 1), or tossed the belt off-court (n = 1). The remaining four instances resulted from suspected device/syncing errors in which a jump was recorded for a player who made no distinct movements.

3.2 | Jump height

Information on Vert device bias, MDC, and ICC of the devices can be found in Table 3. The Vert device showed good correlation with the Vertec during volleyball-specific jumps, but consistently overestimated jump height by an average of 5.5 cm (12% of mean jump height). MDC was stable across all volleyball jump types and effort levels, ranging from 8.8 cm to 9.8 cm (18% to 24% of mean jump height). Figure 1 shows the correlation between the Vert device and force plate measurements during countermovement jumps (see also Table 3), as well as the relationship between the Vert device and Vertec measurements during three different volleyball jumps (Table 3).

The Vert device showed excellent interdevice reliability for two devices placed in the same pouch and worn around the waist during volleyball jumps ($r = .99$, 95% CI 0.98-0.99) with no bias between the devices (Table 3 and Figure 2). However, placing the device at other locations on the body impacted jump height measures substantially. Devices placed on the waist and chest corresponded well, while placement of the device within a sock resulted in unacceptable recordings (Table 3 and Figure 2).

4 | DISCUSSION

This is the first study to examine validity of the Vert device in professional male volleyball players and with 3637

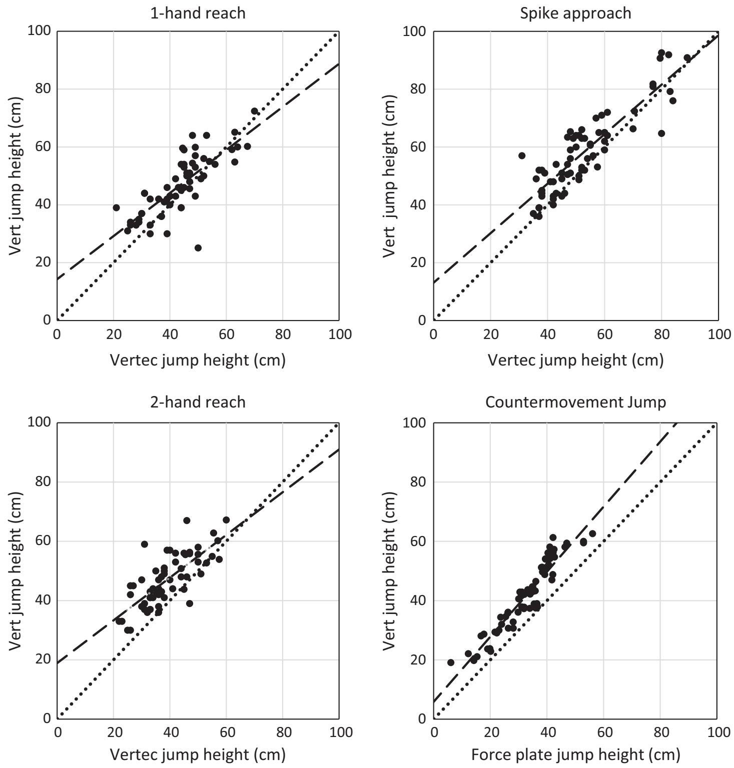

FIGURE 1 Jump height during three different volleyball jumps (Vert vs Vertec) and a countermovement jump with force plate (Vert vs force plate). The dashed line represents the line of best fit, and the dotted line represents the line of equality ($x = y$)

jumps, individually matched to video analysis, it is the largest to explore jump count accuracy across any level of volleyball. The device demonstrates excellent accuracy in counting volleyball-specific jumps during both practice and match play. Our results also show that, while the device provides a good measure of on-court jump intensity at the group level, it should not be used to measure maximal jumping ability when precision is needed.

4.1 | Jump count is recorded accurately

The number of jumps included in this study was substantially greater than two previous studies which examined jump count validity in junior-level players.[8,9] We found a small prevalence of false positives (0.7%) compared to the study by Charlton et al (12%).[8] The use of different definitions to classify and include jumps for analysis likely contributes to this apparent discrepancy. Charlton et al included all jumps, regardless of jump height. In the current study, we did not include jumps that we perceived to be less than the device's 15 cm detection threshold. MacDonald et al[9] also compensated for the device's minimum threshold by only counting jumps that subjectively were believed to be higher than this cutoff. MacDonald et al reported that the device overestimated the total number of jumps observed via visual observation by nearly 6% during match play, but were unable to report false positives and false negatives as jumps were not matched individually. For the purpose of managing jump load, the Vert device does an excellent job at accurately counting jumps in professional players. The high level of accuracy allows coaches and staff to trust the daily, weekly, and season-long jump counts provided by the device when planning individual and team-wide training and recovery sessions.

4.2 | Jump height is slightly overestimated and limitations exist when measuring jumps of similar heights

The Vert device showed excellent interdevice reliability for two devices placed at the waist, consistent with previous research in junior-level athletes.[8] However, the large MDC during countermovement and volleyball jumps limits the use of the device for jump height testing. The device does not appear to represent a valid method to detect differences of <5 cm during jump testing and should not replace more accurate methods for measuring maximal jumping ability (eg, force plates). The Vert device may not be alone as the measurement error using other vertical jump testing methods, including jump and reach tests, contact mats, and belt mat systems, also is too large to detect small differences in jump height.[10]

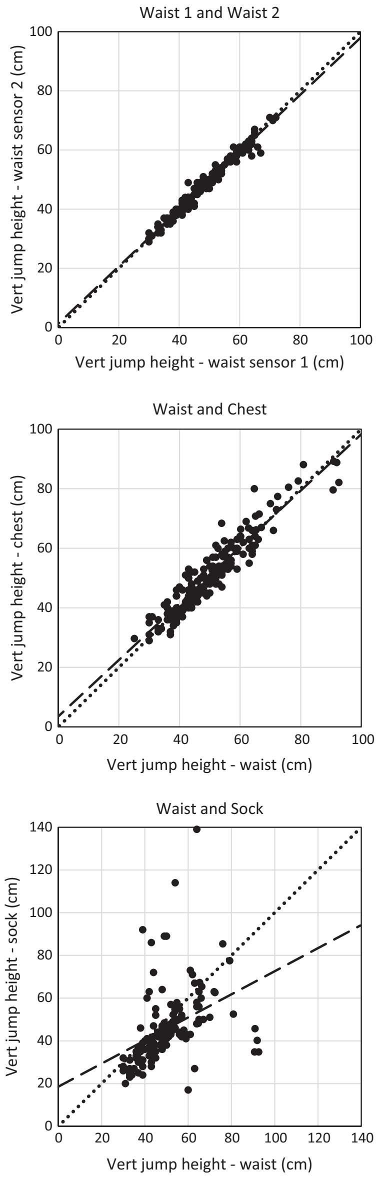

FIGURE 2 Relationship of Vert devices during volleyball jumps (submaximal and maximal efforts) based on location of device on body. The dashed line represents the line of best fit, and the dotted line represents the line of equality ($x = y$)

Force plate testing has long been used as the gold standard for measuring jump height.[11-13] However, practical challenges and costs associated with using force plates have resulted in adoption of other reference standards for on-site testing apparatuses, such as that commonly used to measure jump and reach tests (ie, the Vertec). The Vertec has been found to be a valid method of measuring jump height with high reliability.[10,14] However, research examining validity and reliability of the Vertec is limited, uses different methodology,[10,11,14,15] and leaves conflicting views about the validity of the Vertec and other on-site jump height methods (eg, contact mats, accelerometers, and belt mats) to be able to detect small changes in jump height. In the present study, the Vert device demonstrated a twofold larger MDC during jumps compared to the Vertec than compared to a countermovement jump on the force plate. This is no surprise, as increased jump height variability by the Vertec compared to a criterion reference, including a force plate, has been reported in previous studies.[11,14] However, use of the Vertec allowed testing of volleyball-specific jumps which have been recommended when testing volleyball players and have been shown to have high reliability, equal to that of squat and countermovement jumps.[16]

4.3 | The Vert device provides an acceptable measure of jump intensity—possible use for load monitoring

Despite the relatively large MDC, which limits use of the Vert device for jump testing, the device does report jump height accurately enough to gauge general jump intensity and discriminate between jumps of different gross intensity levels. For example, we cannot confidently discriminate between two jumps similar in height (eg, Vert recording of 72 cm and 75 cm) and identify which jump is higher; however, we can be highly certain that a recorded jump of 85 cm is higher than a jump of 72 cm because the 13 cm difference falls outside the bounds of the MDC observed across all volleyball jumps. This provides an opportunity to categorize jumps based on different height ranges and monitor jump loads not only by total jump count, but also by different intensities.

4.4 | Device placement should be near the center of mass

In preparing for this study, it was observed that some athletes prefer to wear the device in a location that is convenient for them. This resulted in players wearing the device around the waist, others placing it in a sock, and some placing the device within their sports bra. These findings reveal good results for placement on the chest compared to the waist. As the device is intended to be worn near the center of mass, it is no surprise that placement of the device in the sock had poor results and did not yield valid, accurate results.

We do not know whether differences in device placement can explain the apparent discrepancy in jump height accuracy between the studies available. MacDonald et al,[9] placing the device in the lumbar region, found that the device underestimated jump height by 2.5 cm (maximal jumps) to 4.1 cm (submaximal jumps). In contrast, placing the device in front, our study and that by Charlton et al[8] found the device to overestimate jump height across all volleyball jumps, by 5.5 cm and 3.6-4.3 cm, respectively.

4.5 | Methodological considerations

As this study is the first to examine validity of the device in male professional volleyball players, extrapolation of the results to different levels of play or to female athletes may be limited. When examining device placement, every effort was made to simulate placement of the device as if it were tucked into the sports bra of a female player; however, use of a properly fitted sports bra may yield different results. Additionally, the accuracy of the Vertec during jump testing is dependent on accurate initial reach measurements, timing, and coordination of participants to hit the vanes at the apex of their jump and is limited in precision with the smallest incremental heights bound by the spacing between each horizontal vane.

It is important to note that, while performing the jump height validation with our professional players, there was an issue where not all of the data recorded on the Vert devices synced properly with the iPad. As a result, some data were lost, limiting the total number of jumps available for analysis from our professional cohort. Detailed analysis revealed the only substantial difference between the professional and recreational groups was an observation of greater jump heights in the professional group; the very reason for including both groups in the jump height validation.

5 | CONCLUSION

This is the first study to validate the Vert device with professional male volleyball players. The device demonstrates excellent accuracy counting volleyball-specific jumps during training and competition and also provides an acceptable measure of on-court jump height that can be used to monitor athlete jump intensity.

6 | PERSPECTIVE

The Vert device provides excellent accuracy counting volleyball-specific jumps and provides an acceptable measure of on-court jump height. The ability to record jump height during volleyball training and competition and its contribution to jump load was previously impossible when jump load monitoring was limited to time-consuming methods of manual counting and coding of jumps through direct observation. Coaches and staff working with professional volleyball players, as well as elite junior-level players, can now use this device to monitor jump load and incorporate this into the planning of individual and team-wide training and recovery sessions.

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Paper III

High jump demands in professional volleyball – large variability exists between players and player positions

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ORIGINAL ARTICLE

WILEY

High jump demands in professional volleyball—large variability exists between players and player positions

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Training volume has been associated with jumper's knee in volleyball players, but jump variability among professionals has not been investigated and individual jump demands are unknown. The purpose of this study was to examine position-specific jump demands required for training and competition during a professional volleyball season and to investigate the individual variability associated with jump load. Jumps performed by 14 professional players during one season of training and competition were timestamped, individually assigned, and recorded for jump height. Jump counts, heights, and frequency were analyzed to determine the specific jump load performed by players at each position during training and match play. A total of 129 173 jumps were performed during 142 sessions (108 practices, 27 matches, 7 friendly matches). Setters performed the greatest volume of jumps (121 jumps/training session). Opposites performed more high-intensity jumps than their teammates (median season jump height: 69% of maximum). Substantial weekly jump count variability was observed, 18 of 28 weeks included at least one player with a twofold increase in jump load or a player returning to volleyball after performing no jumps the previous week. Additionally, each player had at least 1 week with a twofold increase in jumps. Jump demands are high in professional volleyball, and performance programs should be tailored to the match and training demands required at each position. Jump loads are highly variable—substantial week-to-week increases were observed for both the team and individual players. As a result, monitoring individual jump load seems necessary.

KEYWORDS
injury prevention, jump load, load monitoring, vert, volleyball, workload

1 | INTRODUCTION

Volleyball requires players to perform a large volume of jumps, often leading to knee complaints. The prevalence of jumper's knee, or patellar tendinopathy, is high in elite volleyball, where 44% of players report symptoms.[1] Training volume has been shown to increase the risk of developing jumper's knee in elite, junior-level players with a 3.9-fold increase per extra set of match play and a 1.7-fold increase for every additional hour of volleyball training during the week.[2] However, time may not be a valid measure of jump load in volleyball as substantial between-player variation in jump frequency has been observed among junior-level players during 1 week of training.[3]

The ability to measure and monitor training load has become an essential part of addressing injury risk in elite sport. For example, the sport of baseball and its institutions have developed strict rules regarding pitch counts for adolescent players and guidelines for professionals in an attempt to avoid overuse injuries to the shoulder and elbow.[4-7] Recent advancements in technology have allowed for the creation of a commercially available inertial measurement unit (IMU) that provides a valid and reliable measure of jump-specific training and competition load in elite volleyball players.[8-10] Individual jump variability among professional players has not been investigated, and the jump demands required for each player position during a full season are unknown.

Therefore, the aim of this study was to examine position-specific jump demands required for training and competition during a professional volleyball season and to investigate the individual variability associated with jump load.

2 | METHODS

Jump data were collected from 14 players training and competing on the first team from an elite, professional volleyball club in Qatar. Player positions were recorded (middle, opposite, outside, setter). The libero did not participate in the study as his position does not require any substantial jumping. Data were obtained for all jumps performed during the 2016-17 volleyball season. The season included two matches against each of the 10 league opponents, an international tournament, and a league tournament to conclude the season. Ethics approval was obtained from the Anti-Doping Lab Qatar Institutional Review Board (E2018000268).

Players wore a commercially available IMU, Vert Classic (Model #JEM, Mayfonk Athletic, Fort Lauderdale, FL, USA). Each device was placed in an elastic waistband with the device positioned slightly inferior and lateral to the participant's umbilicus, as recommended by the manufacturer and as we described previously in a validation study.[8] Devices were given to players at the start of training, prior to any jumping. The devices were connected via Bluetooth to an Apple iPad mini 2 using the Vert Coach application (version 2.0.6; Mayfonk Athletic, Fort Lauderdale, FL, USA).[8] All jumps were time-stamped, individually assigned, and recorded for jump height.[8]

Jump data were matched against attendance records to confirm player participation for each session. If a player did not participate in a session, the reason for absence was noted (injured, inactive, or trained with the junior team). Occasionally, a player performed full training with the team but recorded no jumps—either from not wearing a device or because of a technical error where the jumps were not successfully registered. To impute this missing data, a session-specific jump count was calculated for each player. This was based on player-specific average jump counts and a team-weighted jump count for that particular session. All jumps performed in training were included. To determine the jump demands required during match play, only jumps performed during competition were included. Matchday jumps were assigned separate sessions in the Vert Coach application, including pre-match warm-ups and a new session for each set. Jumps performed during the pre-match warm-up or between sets were not included in this match total; however, they were still included in the weekly and season jump totals.

Individual jump frequency (jumps/h) was calculated for each training session throughout the season. This was determined from the first jump until the last jump performed by the team during each session. Jump frequency during matches was calculated from the cumulative set times and did not include pre-match warm-ups or rest times between sets. Additionally, an adjusted jump frequency during matches was calculated for middles. This reflected the jump frequency by middles during the 7/12ths of the serve and serve receive rotations they completed on the court during match play—as they were substituted off the court in favor of a libero in the back row.

To compare the jump heights performed between individuals and position groups, maximum jump height was determined for each player based on all jumps performed during the season. Jumps were sorted from highest to lowest for each player. Occasionally, a jump was registered with an errant height, not physiologically possible for the player. Jumps greater than 120 cm were considered to be in error and were confirmed to be outliers for each player based on season values. Each of these jump height values were replaced with the individual's median jump height when included in further analyses. After addressing substantial outliers, some variability remained in the maximum jump height values. As a result, the median of the top 15 remaining jumps was used to determine each player's maximum jump height.

Jump counts were used to describe the essential jump demands in professional volleyball, as well as the individual player and position variability. Match jump counts were presented with 95% confidence intervals (CI). Individual jump count average during match play was calculated from matches the player participated in, irrespective of their status as starters or substitutes. That is, any match a player participated in, either as a starter or coming off the bench, had these jumps included as a match exposure, while those who did not step on the court were not included. Jump frequency was expressed as the number of jumps per hour and each player's average weekly jump count was presented alongside the interquartile range (IQR). Jump heights were expressed as a percentage of maximum jump height for each player.

3 | RESULTS

A total of 129 173 jumps were performed during training and competition over one professional volleyball season (Table 1). These jumps were observed during 142 sessions (108 practices, 27 matches, 7 friendly matches). Of the 1988 possible player sessions, 1833 (92.2%) included the full number of actual jumps performed, while 155 (7.8%) were imputed using player and session averages. In 23 of these 155 sessions, the player trained with the junior team rather than the first team and the remaining 132 sessions were lacking jump data as a result of a device syncing error or because the player did not wear a device that session.

3.1 | Jump count

Setters performed the most jumps per training session (121 jumps/session), followed by middles (92 jumps/session),

TABLE 1 Individual jump variability during one professional club volleyball season—including season jump totals, session and weekly jump averages, and jump frequency

		Session jump count average			Weekly jump count				Jump frequency (jumps/hour)		
	Total jumps	All	Training	Match	Average (IQR)	High	Low	Variance	All	Training	Match (adj.)
Opposites											
Opposite 1	10 175	76	73	82	363 (109)	562	83	479	54	55	53
Opposite 2	8085	78	82	-	289 (194)	499	0	499	60	62	-
Outsides											
Outside 1	9591	70	71	62	343 (115)	485	154	331	52	54	43
Outside 2	8623	64	70	42	308 (139)	502	13	489	47	54	29
Outside 3	6229	45	51	27	222 (81)	362	73	289	36	39	18
Outside 4	5939	72	77	56	213 (349)	527	0	527	51	55	38
Outside 5	4922	58	59	-	179 (187)	414	0	414	45	45	-
Outside 6	3848	55	56	64	136 (277)	496	0	496	45	46	43
Middles											
Middle 1	13 565	110	115	87	484 (181)	755	141	614	81	89	58 (100)
Middle 2	13 311	94	97	81	475 (147)	762	333	429	69	74	55 (94)
Middle 3	8029	79	81	-	287 (179)	524	20	504	61	61	-
Middle 4	6783	72	75	33	242 (200)	574	114	460	57	58	32 (55)
Setters											
Setter 1	18 282	128	134	100	653 (205)	1047	277	770	94	105	67
Setter 2	11 791	107	109	-	421 (187)	708	139	569	80	82	-
All players	129 173	80	83	71	330 (231)	1047	0	1047	61	64	47

IQR, interquartile range; adj., adjusted match frequency for middles to represent their jumps per hour during the 7/12ths of a match they spent on the court.
Session averages and jump frequency based on player participation during 142 sessions (108 practices, 27 matches, 7 friendly matches). Injuries were responsible for the four players with weekly lows of 0 jumps. Match jump count average and jump frequency determined from jumps performed during match play (pre-match warm-up jumps not included).

opposites (75 jumps/session), and outside hitters (62 jumps/session). The match demand for each position is presented in Table 2. Setters (92 jumps/h) demonstrated the highest jump frequency in training, followed by middles (70 jumps/h), opposites (58 jumps/h), and outsides (49 jumps/h). Setters also had the highest jump frequency during matches (67 jumps/h), followed by middles (57 jumps/h), opposites (53 jumps/h), and outsides (47 jumps/h). When adjusted for each middle position only playing 7/12ths of a match, the middles had the highest jump frequency (98 jumps/h of on-court time).

Weekly jump count averages, ranges, and variance are shown for each individual in Table 1 and are depicted over the 28-week team season in Figure 1. Weekly average jump count per player fluctuated considerably throughout the season ranging from a 44% week-on-week decrease to a 2.4-fold week-on-week increase. Nine of 27 weeks had an increased team average jump count of 10% or more compared to the previous week while six of 27 weeks had at least a 30% increase (Figure 1). Substantial individual weekly jump count variability was observed with each player having at least 1 week in which he performed a twofold increase in jumps compared to the prior week. Additionally, 18 of 28 weeks included at least one player with a twofold increase in weekly jump count (12 weeks) or at least one player returning to training after performing no jumps the previous week (11 weeks).

3.2 | Jump height

Jump heights observed during the season varied based on player position and session type (Figure 2 and Table 2). Setters (median season jump height: 41% of maximum) performed most of their jumps at lower heights, while opposites (median season jump height: 69% of maximum) performed the greatest number of higher jumps throughout the season. Maximum player jump height averaged 92 cm (range: 82-102 cm) across the team.

TABLE 2 Positional jump demands for 3-set, 4-set, and 5-set volleyball matches and average jump height used during match play over one professional men's club volleyball season

	Jump count				Jump height			
	All matches[a]	3-set	4-set	5-set	All matches[b] (%)	3-set (%)	4-set (%)	5-set (%)
Opposite	82 (72-92)	59	89	116	76	73	77	77
Outsides	68 (62-75)	55	74	88	62	60	64	60
Middles	85 (77-93)	67	89	115	64	63	65	66
Setter	100 (89-110)	76	110	128	56	56	56	57

[a]95% confidence intervals are shown in parenthesis.
[b]Jump height as a percentage of maximum jump height (median).

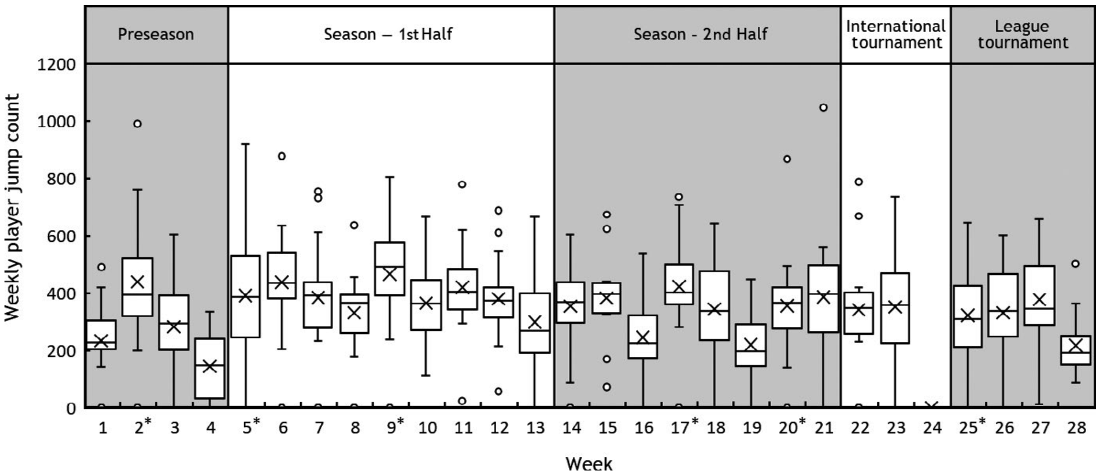

FIGURE 1 Weekly jump count variance for all players during one club season (n = 14 players). The 6 weeks with a week-on-week increase in average player jump count of >30% are denoted with an asterisk (*). The box represents 50% of the dataset, the ends of the box show the 1st and 3rd quartiles, whiskers extend to the furthest data point within 1.5*IQR from the 1st and 3rd quartiles, and circles represent data points further than 1.5*IQR. A horizontal line within the box signifies the median and an 'X' represents the mean

4 | DISCUSSION

This is the first study to examine the season demands and variability in jump load in elite, male professional volleyball players. Despite a relatively stable average weekly team jump load from the beginning to the end of the season, substantial week-to-week increases were observed both for the team and within individual players. Additionally, large positional differences were observed for jump counts and jump heights during training and competition.

4.1 | Substantial week-to-week jump load variability observed at both the team and individual level

Research in other sports has reported greater injury risk associated with large week-to-week changes in training load and has suggested that in order to minimize risk of injury, week-to-week changes should be limited to no more than a 10% increase in training load.[11-14] During the observed season, there was an increased week-to-week team jump load of at least 10% in one-third of the weeks and an increased week-to-week team jump load of at least 30% in six of 27 weeks. Some jump load variation is expected over a long professional season and even the most well-intentioned coaches trying to minimize spikes in team loads will have high and low weeks of varying intensity levels.

One surprising finding during this study was that all 14 players had at least 1 week in which his weekly jump count increased twofold or greater. This happened to eight of the players during the transition from preseason to the first week of the regular season. Additionally, there were 18 of 28 weeks in which at least one player increased his weekly jump load by twofold or returned to the club following an injury/absence

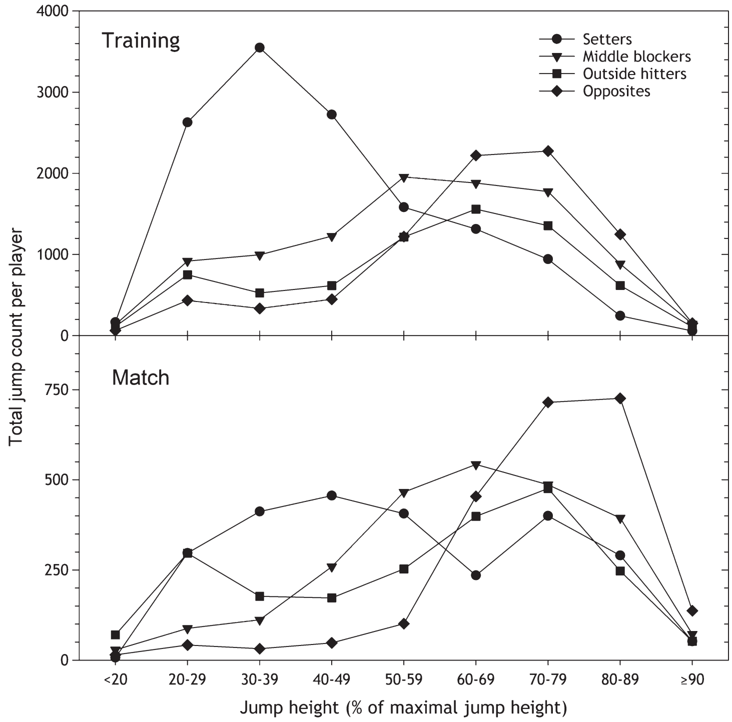

FIGURE 2 Distribution of jump height from training (n = 108 sessions) and matches (n = 27) during one professional club volleyball season broken down by player position

in which he performed no jumps the previous week. While a coach may plan team training loads and adjust jump loads accordingly, one of the greatest challenges may be accounting for the at-risk individuals, rather than the team as a whole. The present findings expand on those by Bahr and Bahr[3] who observed substantial between-player differences in jump volume and frequency during 1 week of training among elite adolescent players. Substantial session, weekly, and within-player jump volume differences existed in the present study. This highlights the large individual jump load variability observed in professional volleyball players and we suggest this infers a need to monitor individual player jump loads.

4.2 | Setters, followed by middle blockers, perform high volume and frequency of jumps

Setters and middle blockers performed the largest volume of jumps during training and had the highest weekly jump averages. Sheppard et al.[15] performed an analysis of spike jumps, block jumps, and jump serves during 16 international volleyball matches, providing additional insight on the specific jumps required during match play. In particular, middle blockers performed a greater number of block jumps while setters performed very few attack jumps.[15] While these studies cannot be compared directly—as not all jumps were analyzed in the former study and no data from trainings were included, insight can be gained on the type of jumps each of these positions must perform during competition.

One additional observation was that middle blockers performed a high frequency of jumps/h during match play, especially when adjusted for their limited match participation secondary to being substituted out of the back row in favor of a libero. This unique aspect of match jump demands for middles (bouts of high jump frequency with periods of rest) should be considered when designing training programs.

4.3 | Opposites perform more high-intensity jumps than their teammates

Opposites performed more high-intensity jumps than other position groups. This was evident during training and even more pronounced during match play, when the majority of their jumps were greater than 70%-80% of their maximum jump height. This is not surprising, as the opposite hitter is often the “go-to” attacker when a kill is needed and maximal jump height is required. This finding may be unique to the men’s game, as younger levels and women’s volleyball often place their best players and attackers in the outside positions. Further research is needed.

4.4 | Methodological considerations

This is the first study to examine the jump demands and individualized nature of jump load in elite, professional volleyball players. While this study includes over 120 000 jumps, extrapolation of the results to other national leagues, teams, and levels of competition may be limited. Different coaching styles and training regimens may also limit generalizability, but the take-home message remains—there is a need to monitor individual jump load. Every attempt was made to record all jumps performed during the season. However, missing data were imputed using player- and session-specific season averages. The imputed data were not used in the calculations of training and match jump count averages, jump frequencies, or jump height averages and should have minimal impact on the weekly jump counts, as they accounted for a small percentage of all player sessions.

5 | PERSPECTIVE

This study highlights the large jump demands and considerable individual and position-specific jump load variability present in professional volleyball. Coaches may plan to minimize large spikes in weekly team loads; however, it seems important to monitor individual player load as spikes in individual loads were substantial. We do not know how this relates to injury risk, as future studies are needed.

This study describes the jump demands needed to compete at the elite level. This information is important when designing fitness and performance programs. Programs should be tailored to the match and training demands required for different position groups. Additionally, jump loads performed in training should prepare players for what they will do during competition. Adjustments can be made for younger players as fewer jumps are performed during match play at the youth levels.[16]

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Paper IV

Shoulder complaints more likely in volleyball players with a thickened bursa or supraspinatus tendon neovessels

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ORIGINAL ARTICLE

WILEY

Shoulder complaints more likely in volleyball players with a thickened bursa or supraspinatus tendon neovessels

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Shoulder problems are common in volleyball and greatly impede both training and player performance. Subacromial bursa (SAB) thickening and tendon neovascularity have shown relevance in other populations, but their relationship with the development of shoulder complaints has not been investigated in volleyball players or overhead-throwing athletes. The study aim was to examine the role of SAB thickness, neovascularization of the supraspinatus tendon, shoulder strength, range of motion (ROM), player position, and age in the development of shoulder complaints in professional volleyball players. Players underwent preseason baseline testing (n = 86) and reported shoulder complaints during the subsequent 12-week period. Generalized estimating equations were used to model for probabilities of complaints after adjusting for player position, SAB side-to-side difference, neovessel presence, shoulder external rotation (ER) ROM, and age. Outside hitters and opposites were 12.2-fold more likely to develop complaints, and greater shoulder ER ROM increased risk by 8% for each additional degree. A side-to-side difference in SAB thickness ≥0.3 mm in the dominant compared with the non-dominant arm was associated with a 10.2-fold increased risk. Those with neovessels were 6.5 times more likely to develop complaints. Players without neovessels and with normal SAB thickness were very unlikely to develop complaints. This stark contrast to players with neovessels or increased SAB thickness, where nearly half of the players developed complaints, is of interest. Players with current complaints at baseline presented with greater IR:ER strength ratios; however, neither strength nor IR ROM at baseline was associated with an increased risk of developing complaints.

KEYWORDS
overhead athlete, rotator cuff, shoulder pain, shoulder ultrasound, volleyball injuries

1 | INTRODUCTION

Elite volleyball is a fast-paced, hard-hitting sport that sees large loads transmitted through the athlete's shoulder. While shoulder motion is similar between the volleyball spike and the throwing motion in other overhead sports, the spike and jump serve have unique biomechanical properties that differ from sports such as baseball and tennis.[1-3] The stresses applied to the arm during overhead attacks result in a high prevalence of shoulder problems.[4-6] As many as 23%-43% of competitive volleyball players report shoulder complaints during a given season.[4,7,8] Furthermore, 58% of collegiate club-level players report a history of shoulder problems.[4] Still, most players continue to train and compete, with little to no time away from the sport. The majority of amateur players with spiking-related shoulder pain report having pain hitting to all areas of the court (60%) and pain limiting how hard they can spike (77%).[9]

Little is known regarding the risk factors that contribute to shoulder-related complaints in elite volleyball players and prospective studies are limited.[7,10] Limited evidence suggests that muscle imbalance and playing position may represent risk factors for shoulder problems, while range of motion (ROM), humeral torsion, and age have been associated with injuries in other overhead sports.[4,7,10-14] In addition to these traditional risk factors, examination of the shoulder's subacromial bursa (SAB) and neovascularity of the supraspinatus tendon may be of interest. Thickening of the SAB has been associated with shoulder pain and injuries in overhead athletes. In open water endurance swimmers, SAB thickness was related to both training volume and pain after completion of the event.[15] SAB thickness has not been investigated in volleyball players or other overhead athletes, and its relationship with the development of shoulder complaints is unknown.

A recent systematic review and meta-analysis documented that tendon abnormalities on ultrasound were associated with a five-fold risk of future symptoms in lower extremity tendinopathies.[16] Additionally, a large prospective study in runners found a 6.9-fold increased risk of Achilles tendinopathy in those with neovascularization.[17] It is unknown whether similar findings can be expected in the upper extremity. The presence of neovessels in overhead athletes and their relationship with symptoms should be explored.

Prospective studies examining traditional risk factors for shoulder complaints in elite volleyball are needed, and the inclusion of shoulder tendon and bursa characteristics is of interest. Therefore, the aim of this prospective cohort study was to examine the role of SAB thickness, neovascularization of the supraspinatus tendon, shoulder strength, ROM, player position, and age in the development of shoulder-related complaints in professional volleyball players.

2 | METHODS

2.1 | Study design

Professional volleyball players were followed for 12 weeks after preseason baseline testing. Players from three professional men's club teams in Qatar participated during the 2016-2017 club season and national team players competing during at least one of three consecutive national team seasons (2015-2017) were included. A group of testers visited each team prior to a preseason training session to minimize the acute effects of exercise on the neovascular assessment. All players, regardless of current or past shoulder problems, were eligible for study inclusion and invited to participate. Players needed to remain with the team during the subsequent 12 weeks to be included. A total of 86 preseason musculoskeletal assessments were performed between May 2015 and May 2017. Participants provided informed consent, the rights of participants were protected, and study approval was obtained from the Anti-Doping Lab Qatar Institutional Review Board.

2.2 | Baseline testing

Trained physical therapists and strength and conditioning coaches with experience in volleyball and the musculoskeletal screening of athletes conducted the tests. A sports physical therapist with >10 years of musculoskeletal ultrasound experience performed all humeral torsion, SAB thickness, and neovascularization assessments, blinded to the results of the baseline questionnaire. In addition, player height, weight, date of birth, position, and dominant arm were recorded.

2.3 | Shoulder strength

We measured shoulder external rotation (ER) and internal rotation (IR) strength using a handheld dynamometer (HHD; ergoFET500, Hoggan Scientific LLC, Salt Lake City, UT, USA). The maximum score from 3 trials was recorded using an eccentric "break test."[18] Scores were converted to percent body weight and calculations made to determine each player's IR:ER strength ratio. Strength tests were performed with the athlete standing, feet shoulder width apart, arm at the side, and elbow bent 90°. The HHD was positioned in-line with the ulnar styloid process. The athlete rotated the arm into the HHD for 3 seconds, performing a maximal isometric contraction, before the examiner applied a small overpressure to complete the "break test." When the examiner felt the arm start to give way, he stopped the test and recorded the value. Care was taken to avoid compensatory movements by the athletes and limit the motion to shoulder rotation only.

2.4 | Range of motion

Glenohumeral ER and IR passive ROM were measured in supine for both the dominant and non-dominant arms, similar to methods previously described.[12,19] The arm was abducted 90° in the frontal plane and elbow bent 90°. The examiner stabilized the scapula and gradually rotated the arm into maximal ER and stopped at end range or when the athlete reported he could not rotate any further. An inclinometer placed flat along the distal portion of the ulna was used to determine the angle. This process was repeated for IR and end range was determined when a firm end feel was felt without compensatory movements or when the athlete reported he could not rotate any further. When necessary, the athlete's arm was placed on a towel or the examiner's thigh to maintain alignment of the upper arm in the frontal plane. Total rotational ROM was calculated from combining ER and IR values. Glenohumeral IR was also measured in 90° of shoulder flexion. The examiner rotated the arm into maximal IR and stopped when a firm end feel was felt prior to shoulder elevation or compensation.

2.5 | Humeral torsion

Humeral torsion was measured for both arms using a diagnostic ultrasound device (MyLab25 Gold with LA523 transducer, Esaote, Genoa, Italy) and a method previously described with excellent inter-tester reliability and a minimal detectable change (MDC) of 2.9° ± 2.6°.[20] The amount of humeral torsion in the dominant arm compared with the non-dominant arm was calculated. An adjusted measure of dominant arm ER and IR ROM that accounts for this side-to-side difference in humeral torsion was created so that glenohumeral ROM could be adequately compared with the non-dominant arm. This calculation kept the non-dominant arm ROM values the same while subtracting the humeral torsion side-to-side difference from the dominant arm ER ROM and adding the difference to the IR ROM.

2.6 | Subacromial bursa thickness and neovascularity

With the athlete seated, and the arm supported at approximately 30° of scapular plane abduction (Figure 1), the bicipital groove was identified in a transverse view, and then immediately lateral to this, now in a longitudinal plane, the supraspinatus insertion was carefully visualized from anterior to posterior. After examining the visible tendon from anterior to posterior, color Doppler was activated, and the presence or absence of vessels within the supraspinatus tendon was noted using a similar approach. Neovascularity was recorded as none, slight (appearance of one vessel, not more than approximately 1 mm in diameter), or marked (more than one vessel, or one vessel more than approximately 1 mm in diameter). Ultimately, our final analysis included a binary classification of vascularity present or not present, similar to previous research.[21] Finally, with the Doppler disengaged, the SAB was examined for the point where it was seen to be thickest, as the location of maximum thickness is often utilized.[22-24] This distance was documented, measuring the depth of fluid in the bursa, without including the peribursal fat tissue.

2.7 | Monitoring of shoulder problems

Shoulder problems were reported by players at baseline and throughout the 12-week follow-up period by completing the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire.[25] Players reported any pain related to their sport and the extent to which shoulder problems affected participation, training volume, and performance. Shoulder problems were defined as "pain, aching, stiffness, looseness, or other complaints."[25] The team physical therapist or strength and conditioning coach was responsible for providing and collecting paper copies of the questionnaire. Team representatives were encouraged to have players complete the questionnaires every 2 weeks at a minimum, with the goal of completing six questionnaires during the 12-week period. A player needed to complete at least three questionnaires to be included in the analysis.

2.8 | Statistical methods

Players representing the national team for multiple seasons were included each year. This resulted in 56 unique players completing 86 player-seasons. As the number of players completing baseline tests varied from year to year, results were analyzed using these 86 player-seasons. On five

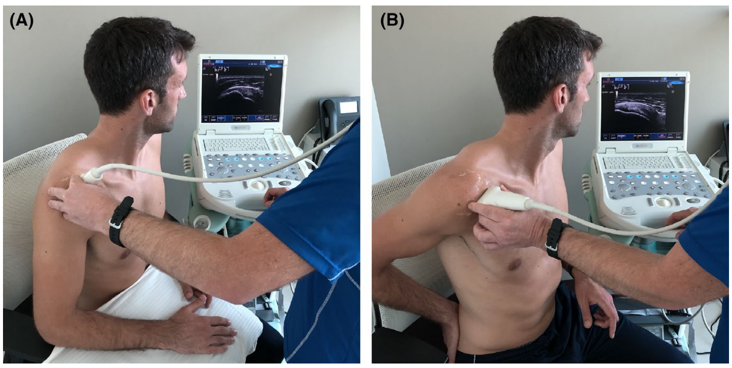

FIGURE 1 Modified subject positioning (A) during neovascular assessment of the Supraspinatus tendon on ultrasound — used to avoid possible "wringing out" of the tendon that may limit vascular assessment when the tendon is stretched in the traditional position (B)

occasions, the player tested was not included in the final analysis. This was secondary to missing a baseline questionnaire (n = 4) or incomplete follow-up questionnaires as a result of changing clubs (n = 1). Baseline test results were reported for all of the remaining 81 player-seasons, but only those without baseline shoulder complaints were included in the prospective risk factor analysis. Preliminary inferential statistical analyses were performed to determine which baseline variables were significantly different ($P \leq .05$) between: (1) players without shoulder complaints; and (2) players who developed shoulder complaints during the 12-week follow-up. These variables were then assessed and considered for inclusion into the final model. SAB side-to-side difference was further evaluated by examining the area under the curve of a receiver operating characteristic (ROC) curve to determine an appropriate cutoff value for players with and without substantially thicker bursas between the dominant and non-dominant arms. Generalized estimating equations (GEEs) were used to model for probabilities of shoulder complaints after adjusting for all factors (position, SAB side-to-side difference, neovessel presence, shoulder ER ROM, age) and repeated variables (team, subject) using unstructured working correlations. Analyses were conducted using SPSS version 21 (IBM Corporation, New York, NY, USA).

3 | RESULTS

A total of 81 player-seasons were analyzed, including baseline testing and 12-week questionnaire follow-up. In 22 (27.2%) cases, the player reported shoulder complaints at baseline while the remaining 59 (72.8%) reported no baseline complaints. Of these remaining 59 player-seasons, 16 (27.1%) developed complaints during the subsequent 12 weeks. Players completed 5.7 questionnaires on average (SD 1.5) and no differences were observed between players who developed complaints and those who did not. The majority of players with complaints reported shoulder problems that affected their performance (84.2%) and a need to reduce training volume secondary to shoulder complaints (73.7%).

Table 1 shows the relationship between preseason musculoskeletal screening measures and development of shoulder complaints for the 59 player-seasons without baseline complaints.

3.1 | Player position and age

Outside hitters (11 of 19) and opposites (2 of 4) were most likely to develop shoulder problems; few middle blockers (2 of 19), setters (0 of 12), and liberos (1 of 5) developed complaints. When combining position groups, outside hitters and opposites were 12.2-fold more likely to develop complaints compared with other players (Table 2). Age was also a significant protective factor. For a 1-year increase, a player was 21% less likely to develop complaints (Table 2).

3.2 | Shoulder strength and range of motion

Collectively, players presented with significantly greater shoulder ER ROM (dominant: 129°, 95% CI 125-133; non-dominant: 122°, 95% CI 119-125) and less shoulder IR ROM (dominant: 82°, 95% CI 78-86; non-dominant: 88°, 95% CI 84-91) in their dominant versus non-dominant arms. However, no statistically significant side-to-side differences were observed when humeral torsion was accounted for (dominant ER: 118°, 95% CI 114-122; dominant IR: 93°, 95% CI 89-98). We could not detect any differences in dominant shoulder IR ROM between players with baseline complaints and those without complaints (measured IR ROM: 76° vs 84°, $P = .057$; adjusted IR ROM: 89° vs 95°, $P = .195$; Table 1).

Having greater shoulder ER ROM increased a player's risk of developing complaints by 8% for every additional degree (Table 2). Therefore, an increase of 12° of ER ROM — the group mean difference between those who developed complaints and those who did not — increased a player's risk by 96%.

Greater IR strength and greater IR:ER strength ratios were observed in players with baseline complaints (Table 1); however, no strength differences were observed between players who went on to develop complaints and those who did not.

3.3 | SAB thickness and neovessel presence

The majority of players (81%) had increased SAB thickness in the dominant shoulder compared with the non-dominant side. Players without neovessels present and without a substantial increase in SAB thickness in their dominant arm rarely developed complaints (Figure 2). ROC analysis revealed an optimal SAB thickness side-to-side difference cutoff point of 0.3 mm. Having a ≥0.3 mm increased SAB thickness in the dominant arm compared with the non-dominant arm was associated with a 10.2-fold increased risk of developing complaints (Table 2). Those with neovessels present were 6.5 times more likely to develop shoulder complaints (Table 2).

The GEE analysis revealed that position, SAB side-to-side difference, neovessel presence, shoulder ER ROM, and age all had substantial influence in the final model (Table 2).

TABLE 1 Relationship between preseason musculoskeletal screening measures and development of shoulder complaints in professional volleyball players without complaints at baseline (n = 59)

Category	Players with baseline complaints (n = 22) Mean (95% CI)	SD	Players without baseline complaints: Developed season complaints (n = 16) Mean (95% CI)	SD	Players without baseline complaints: No complaints (n = 43) Mean (95% CI)	SD
Player characteristics						
Age (y)	25.1 (23.7-26.5)	3.1	23.5 (21.4-25.6)**	3.9	26.5 (25.2-27.9)	4.3
Body weight (kg)	90.9 (87.1-94.7)	8.6	89.5 (86.7-92.2)	5.1	90.3 (87.8-92.8)	8.2
SAB thickness (mm)						
Dominant arm	0.89 (0.73-1.06)	0.37	0.87 (0.63-1.11)	0.44	0.75 (0.66-0.85)[a]	0.30
Non-dominant arm	0.56 (0.43-0.70)	0.30	0.44 (0.34-0.54)**	0.19	0.58 (0.49-0.67)[a]	0.30
Side-to-side difference (d-nd)	0.33 (0.12-0.54)	0.48	0.44 (0.22-0.65)**	0.41	0.17 (0.08-0.26)[a]	0.29
Range of motion — dominant shoulder (degrees)						
External rotation (measured)	128 (120-137)	19	136 (126–146)	18	126 (122-131)	15
Internal rotation (measured)	76 (68-83)	17	85 (77-94)	16	84 (78-90)	19
External rotation (adj.)[b]	115 (107-124)	19	127 (118-137)**	18	115 (110-121)	17
Internal rotation (adj.)[b]	89 (81-97)	18	94 (85-104)	18	95 (88-102)	22
Total range of motion	204 (191-218)	30	221 (213-229)**	15	210 (203-218)	24
Humeral torsion difference	13 (11-16)	6	9 (4-15)	10	11 (9-14)	8
Range of motion — non-dominant shoulder (degrees)						
External rotation (measured)	123 (116-130)	16	123 (115-130)	14	120 (117-124)	11
Internal rotation (measured)	83 (75-91)	18	93 (87-99)	11	88 (82-93)	17
Total range of motion	206 (194-219)	29	216 (208-224)	15	208 (202-214)	19
Strength — dominant shoulder (% body weight)						
External rotation	0.21 (0.19-0.24)	0.05	0.24 (0.22-0.26)	0.04	0.23 (0.21-0.24)	0.05
Internal rotation	0.32 (0.30-0.35)*	0.06	0.29 (0.28-0.31)	0.03	0.29 (0.28-0.31)	0.05
IR:ER ratio	1.63 (1.34-1.91)*	0.64	1.26 (1.15-1.37)	0.21	1.35 (1.26-1.44)	0.30

Abbreviations: d, dominant; ER, external rotation; IR, internal rotation; nd, non-dominant; SAB, subacromial bursa.

[a]One player did not have SAB thickness measurements performed (n = 42).

[b]An adjusted measure of external and internal rotation range of motion that accounts for the amount of humeral torsion in the dominant arm compared with the non-dominant arm.

*Players with baseline complaints significantly different from players without baseline complaints ($P \le .05$).

**Players who developed season complaints significantly different from group with no complaints ($P \le .05$).

4 | DISCUSSION

This is the largest prospective study to date exploring risk factors for shoulder complaints in volleyball players and the first prospective study to examine the relationship between SAB thickness and neovascularization in the development of shoulder complaints in overhead athletes. Athletes with a substantially thicker SAB in their dominant shoulder and those with neovessels present were both much more likely to develop complaints. Younger players and players with greater shoulder ER ROM were also at increased risk. Finally, outside hitters and opposites were 12.2-fold more likely to develop shoulder complaints compared with their teammates.

4.1 | Increased SAB thickness associated with shoulder complaints

Overhead athletes presenting with shoulder pain and a thickened SAB is nothing new. In this study, SAB thickening in the dominant arm was a normal finding among professional volleyball players. However, a substantial side-to-side difference was associated with shoulder complaints. These findings are consistent with previous work in endurance swimmers that found swimmers with pain 1 week post-race had greater SAB thickness than those without pain.[15] This relationship between SAB thickness and pain is also supported in cross-sectional studies. A small study of waterpolo players

	B	SE	Wald	*df*	*P* value	Odds ratio (95% CI)
Position (Out/Opp vs MB/S/L)[a]	2.50	1.03	5.85	1	.016	12.15 (1.60-92.07)
SAB difference (≥0.3 mm, yes/no)	2.33	0.86	7.34	1	.007	10.24 (1.90-55.16)
Neovessel presence (yes/no)	1.88	0.99	3.58	1	.058	6.52 (0.94-45.50)
Shoulder ER ROM (°)	0.07	0.04	3.17	1	.075	1.08[b] (0.99-1.17)
Age (y)	-0.23	0.10	5.88	1	.015	0.79 (0.66-0.96)

Abbreviations: B, beta; *df*, degrees of freedom; ER, external rotation; ROM, range of motion; SAB, subacromial bursa; SE, standard error; Wald, Wald chi-square.

[a]Position grouped as outsides/opposites vs middle blockers/setters/liberos.

[b]For every 1° of change.

TABLE 2 Generalized estimating equations displaying the likelihood of in-season shoulder complaints based on position, side-to-side difference in subacromial bursa thickness, neovessel presence, shoulder ER ROM, and age (n = 58, players without baseline shoulder complaints)

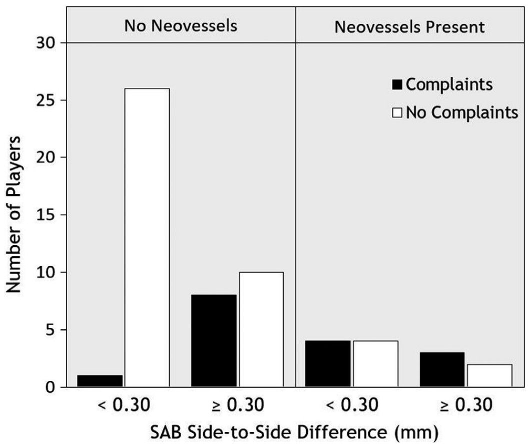

FIGURE 2 Development of shoulder complaints in professional volleyball players based on preseason ultrasound findings: players without substantial increased side-to-side subacromial bursa (SAB) thickness (<0.3 mm) and without neovessels present in the dominant arm rarely developed complaints (n = 58, players without baseline shoulder complaints)

reported observation of subacromial bursitis on US in 63% of players with pain.[26] In a larger group of non-athletes with unilateral shoulder pain during overhead activity, increased SAB thickness was observed in the symptomatic shoulder compared with the non-symptomatic side.[24]

The relationship between SAB thickness and shoulder pain appears clear, but may be more nuanced as it also appears to be a normal adaptation in response to loading of the shoulder. Among endurance swimmers, SAB thickness increased over a 4-month training period and correlated with swimming volume.[15] Our study found that the majority of players had greater SAB thickness in the dominant shoulder compared with the non-dominant arm. This likely represents an adaptation in the dominant arm, due to the repetitive unilateral nature of spiking throughout a player's career. It has been suggested that asymptomatic thickening of the SAB may be common, similar to observations of asymptomatic rotator cuff tears.[27]

It is difficult to compare specific values across studies as populations and methods differ. One study in young healthy subjects reported a MDC of 0.18 mm when measuring SAB thickness.[23] Another study reported an intra-rater MDC of 22% and inter-rater MDC of 26%; equivalent to 0.18 and 0.21 mm based on the mean dominant arm SAB thickness in our study (0.82 mm).[28] With this in mind, the side-to-side cutoff of 0.3 mm determined from the ROC analysis appears reasonable to separate those with substantially thickened bursas.

4.2 | Neovascularization of the supraspinatus tendon may not be so different to that of the lower extremity tendons

Research examining patellar and Achilles tendons has found neovascularization and tendon abnormalities to represent risk factors for future development of symptoms.[16,17] However, there is limited understanding of the relationship between neovascularization and shoulder complaints in general, let alone in overhead athletes. One cross-sectional study in overhead athletes with subacromial pain syndrome suggests there may be a relationship, as there was supraspinatus tendon vascularization in 85% of painful shoulders compared with 38% of non-painful shoulders.[29] Building on this, our prospective findings revealed that players with neovessels were 6.5-fold more likely to develop future complaints.

Neovascular assessment of the shoulder can be performed with near-perfect reliability, but methodological differences make comparisons difficult between studies.[30] Two previous studies in non-athletic populations with rotator cuff tendinopathy investigated neovessels in both the tendon and the bursa.[21,31] Inclusion of peribursal neovascularization increased the prevalence from 45% to 65% in symptomatic shoulders and 15% to 25% on the asymptomatic side.[31] We observed similar findings in the 22 players with shoulder complaints at baseline; 12 (55%) had neovessels in their dominant shoulder and only 1 (5%) on the non-dominant side. In the entire sample, 22% had neovessels in the dominant arm and 9% in the non-dominant arm.

Combining the neovessel and SAB thickness results (Figure 2) provides additional insight. Players without neovessels and without increased SAB thickness were unlikely to develop shoulder complaints (4%). This is in stark contrast to players with neovessels and/or increased SAB thickness; as many as 48% developed complaints. The reasoning for this is unknown, but it is of clinical interest to determine how to properly load the shoulder of players with increased SAB thickness or neovascularization in a manner that minimizes future complaints.

4.3 | Our novel method to assess neovascularization may avoid "wringing out" the supraspinatus tendon

When assessing neovascularity in the lower extremity, joints are traditionally examined in a relaxed position, avoiding significant tension to the tendon.[32,33] Conventional grayscale ultrasound assessment of the supraspinatus tendon places the tendon in a stretched position, allowing good visualization of the tendon. However, this position is believed to "wring out" the tendon, leading to decreased blood flow.[34] Two previous studies examining neovessels in the shoulder noted that positioning of the arm and the stretch placed on the tendon may alter findings.[30,31] While neovascularization of the supraspinatus tendon has previously been observed with the tendon under stretch, the current study found substantial prospective value through a slight modification of the shoulder position.

4.4 | Outside hitters and opposites at greatest risk for developing shoulder complaints

Outside hitters and opposites developed substantially more shoulder complaints than other position groups. This is consistent with previous findings in collegiate volleyball players — attackers (outside hitters, opposites, and middles) reported a greater prevalence of shoulder pain than setters and liberos.[4] A greater proportion of outside hitters than other players also experienced shoulder injuries during major FIVB tournaments.[35] In the current study, very few middles reported shoulder complaints. It is unclear from the literature whether middles typically have fewer shoulder complaints than other attackers or whether this is related to our limited sample size. Setters and middles perform the greatest volume and frequency of jumps during training and competition,[36] but have fewer shoulder complaints. This discrepancy in complaints compared with outside hitters and opposites is likely related to decreased attack load and different hitting mechanics.

4.5 | Range of motion, strength, and age as risk factors

A recent systematic review found volleyball players, on average, have more shoulder ER and less IR ROM in the dominant arm compared with the non-dominant arm.[13] This greater shoulder ER motion appears to be a natural adaptation to the sport, resulting from increased humeral torsion in the dominant arm. This was evident in the current study as substantial side-to-side differences were observed in the raw ER and IR measurements, but those differences dissipated after accounting for humeral torsion. Additionally, the observation of apparent ER gain and concomitant glenohumeral IR deficit existed within our population and became problematic when ER gain led to greater total rotational ROM. Players with the greatest ER motion were at increased risk of developing shoulder complaints, but no relationship between IR ROM and shoulder complaints was observed. It is unclear from this and previous studies as to the cause of symptoms associated with ER gain.[37]

Previous cross-sectional studies have reported mixed findings on a possible relationship between shoulder strength imbalance and previous shoulder injury.[4,7,13,38] One prospective study with 16 players suggests an association between muscle strength imbalance and the risk of shoulder problems.[10] In the current study, we found no relationship between the risk of shoulder complaints and shoulder rotation strength or IR:ER strength ratio.

For clinicians, it is of interest that players with current shoulder complaints at baseline presented with greater IR:ER strength ratios and (non-significantly) less IR ROM. These differences could be acute or long term in nature, and while we did not detect any relationship with subsequent complaints, it is unknown whether serial testing on a daily or weekly basis would allow for early detection of deficits prior to the onset of substantial complaints. Additionally, younger players were found to be at increased risk for developing shoulder complaints. This was surprising; it may be that the older players represented a select group of "survivors" or that the younger players were not yet adapted to this elite level of training and match play.

4.6 | Methodological considerations

Our findings may have implications for other overhead athletes, but as we only included professional volleyball players, extrapolation of these results to other sports and different levels should be done with caution. Direct comparison of the SAB thickness and neovessel assessments to previous studies is difficult as different methods are often used. Similar to others, we measured the SAB thickness at its thickest point without including the peribursal fat; some have measured at set distances from nearby landmarks and/or included the peribursal tissue.[22-24,28] Assessment of the SAB thickness and neovessels in different positions also limits direct comparison across studies. While the SAB side-to-side cutoff of 0.3 mm is reasonable based on previously reported MDC data for ultrasound assessment,[23,28] it should be recalled that this was calculated post hoc; clinicians should be cautious in adopting this until confirmed in other athlete populations. As some players were included multiple times from different seasons, we assessed for group differences that may have biased the results. Subgroup analyses examining SAB thickness, neovessel presence, and shoulder complaints revealed only one player who presented twice with complaints and increased side-to-side SAB thickness (≥0.3 mm) and one player twice with complaints and neovessels. Additional subgroup analyses revealed no group differences in the questionnaire response rate or distribution of responses among players included over multiple seasons. Players were tested and followed systematically for 12 weeks through the use of structured questionnaires; however, other variables such as individual player load were not assessed and may also contribute to complaints.

5 | PERSPECTIVE

Players without neovessels and with normal SAB thickness were very unlikely to develop complaints. This stark contrast to players with neovessels or increased SAB thickness, where nearly half of the players developed complaints, is of interest. Position matters — outside hitters and opposites were much more likely to develop shoulder problems. Players with current complaints at baseline presented with greater IR:ER strength ratios; however, neither strength nor IR ROM at baseline was associated with an increased risk of developing future shoulder complaints.

Clinicians with ultrasound machines may want to consider assessing SAB thickness and neovascularity in their overhead athletes. For all clinicians, it is important to note that thickening of the SAB may be a normal adaptation to the sport. However, a substantial increase in thickening in the dominant arm compared with the non-dominant arm increases the risk of developing shoulder complaints. For players with increased risk, monitoring load and response to load are recommended, in addition to interventions to maximize player health and performance.

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IRB APPROVAL STATEMENT

This study has been approved by the Anti-Doping Lab Qatar Institutional Review Board (E2013000003).

CONFLICT OF INTEREST

We have no other conflict of interests.

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Paper V

Playing with pain: knee, low back, and shoulder problems rampant among university and professional volleyball players

Manuscript in Submission

Playing with pain: knee, low back, and shoulder problems rampant among university and professional volleyball players

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TITLE

Playing with pain: knee, low back, and shoulder problems rampant among university and professional volleyball players

ABSTRACT

Context: The knee, low back, and shoulder account for the majority of overuse injuries in volleyball; unfortunately, previous studies utilized methodology that failed to examine the extent of their injury burden and impact on performance. Research using appropriate methods to capture the true prevalence of overuse complaints among elite players is needed; how these complaints change throughout the season is also unknown.

Objective: To develop a more accurate and complete understanding regarding the weekly prevalence and burden of knee, low back, and shoulder problems within the highest levels of men's volleyball – including the role that preseason complaints, match participation, player position, team, and age have on complaints.

Design: Descriptive epidemiology study.

Setting: Professional volleyball clubs and NCAA Division I program

Patients or Other Participants: Seventy-five male volleyball players, representing four teams playing in their country's respective premier league participated over a 3-season period.

Main Outcome Measure(s): Players completed a weekly questionnaire (Oslo Sports Trauma Research Center Overuse Injury Questionnaire; OSTRC-O) reporting pain related to their sport and the extent to which knee, low back, and shoulder problems affected participation, training volume, and performance.

Results: The average weekly prevalence of knee, low back, and shoulder problems, based on 102 player-seasons, was: knee – 31% (95% confidence interval 28-34), low back – 21% (18-23), and shoulder – 19% (18-21). Most players (93%) reported some level of knee, low back, and/or shoulder complaints during the season (knee: 79%; low back: 75%; shoulder: 67%) and 58% experienced at least one episode of substantial problems that resulted in moderate or severe reductions in training volume or sport performance (knee: 33%; low back: 27%; shoulder: 27%). Players with preseason complaints continued to have more in-season complaints than teammates without preseason problems (average weekly prevalence – knee: 42% vs. 13%, P <.001; low back: 34% vs. 8%, P <.001; shoulder: 38% vs. 12%, P <.001).

Conclusion: Nearly all elite male volleyball players experienced knee, low back, or shoulder problems – and the majority had at least one bout that substantially reduced training participation or sports performance. These findings suggest that knee, low back, and shoulder problems result in greater injury burden than previously reported.

Keywords: back pain; injury burden; injury prevalence; jumper's knee; overuse injuries

Word Count (abstract): 352

Word Count (manuscript): 3024

Key Point (1): Nearly all elite male volleyball players experienced knee, low back, or shoulder problems – and the majority had at least one bout that substantially reduced training participation or sports performance each season.

Key Point (2): Despite many knee, low back, and shoulder problems not resulting in time-loss injuries, nearly half of all players (46%) were playing through some combination of complaints at any given time.

Key Point (3): Players who experienced problems in the preseason continued to have more problems during the competitive season; player position and match participation had significant impact on these complaints.

INTRODUCTION

Volleyball is a high-intensity sport whose repetitive nature leads to a substantial number of knee, low back, and shoulder problems. The knee (20-33%), low back (18-32%), and shoulder (20-32%)[1,2] are the predominate locations for overuse injuries – gradual onset injuries that lack an identifiable inciting event.[3,4]

These early studies on volleyball injury epidemiology used time-loss injury definitions, requiring players to miss or alter their participation in team events to be recorded.[1,2] More recent reviews examining the incidence and etiology of volleyball injuries[5] and specifically overuse injuries to the shoulder and back[6] found large variability in injury incidence and noted that using a time-loss definition likely leads to an underestimation in the reported prevalence of overuse injuries. This was further highlighted among professional *beach* volleyball players in a study that examined the methodology for recording overuse symptoms in sports – using a time-loss definition led to a conclusion of very low injury risk, whereas survey data reported a high prevalence of knee, low back, and shoulder pain (previous 7 days: 64%; previous 2 months: 83%).[7] These studies highlight that future epidemiologic research should (1) examine all complaints, rather than only time-loss complaints to better understand overuse injuries;[6,7] (2) report the prevalence, and not simply the incidence of injuries;[5,7] (3) be prospective with serial measurements of symptoms;[7] and (4) focus on other areas in addition to the knee and ankle, the most common locations for time-loss injuries.[5]

An 'all complaints' injury definition has been widely recommended in sport-specific consensus statements, despite the common implementation of time-loss definitions in injury surveillance programs.[4,8] Development of an overuse injury questionnaire has enabled use of this broad injury definition that is not dependent on time loss and is recommended for studying overuse problems in sports.[3,7] Using an all-complaints definition within high school volleyball revealed that the highest average weekly prevalence of problems were to the knee (36%), followed by the shoulder (16%) and low back (14%) during a 13-week study window.[9] Studies examining the weekly prevalence of knee, low back, and shoulder complaints among elite players are needed. The extent to which these complaints change over the course of a full season has also not been examined. As a result, the injury burden and impact on performance from knee, low back, and shoulder problems in volleyball is unknown.

Therefore, the aim of this study was to develop a more accurate and complete understanding regarding the weekly prevalence and burden of knee, low back, and shoulder problems within the highest levels of men's volleyball – including the role that preseason complaints, match participation, player position, team, and age have on complaints.

METHODS

Study Design

Four elite men's volleyball teams, playing in the premier league in Japan, Qatar, Turkey, and the United States, participated in this study over a 3-season period (2017-18 through 2019-20). Seventy-five players participated during eight team seasons (3 seasons – one team, 2 seasons – two teams, 1 season – one team) with a mean season length of 6.9±0.9 months. Eight (10.7%) players participated over three seasons, 29 (38.7%) players over two seasons, and 38 (50.7%) players over one season; totaling 120 player-seasons. All players from participating teams were included, but any players with the team for less than one-third of the season were excluded. Liberos fulfill a unique roll on the team that requires little to no jumping or overhead attacks. As a result, the weekly prevalence of complaints for liberos was reported for comparison between position groups, but they were not included in further analyses – resulting in 102 player-seasons completed by outside hitters (n=42), middle blockers (n=28), setters (n=18), and opposites (n=14). Their mean age was 26.2±4.4 (SD) years, height 195±8 cm, and weight 88±10 kg. Participants provided informed consent, the rights of participants were protected, and study approval was obtained from the Anti-Doping Lab Qatar Institutional Review Board.

Reporting of Knee, Low Back, and Shoulder Problems

Knee, low back, and shoulder complaints were reported weekly by players completing paper versions of the Oslo Sports Trauma Research Center (OSTRC-O) Overuse Injury Questionnaire.[3,10] Players reported any pain related to their sport and the extent to which knee, low back, and shoulder problems affected participation, training volume, and performance. Knee problems were defined as "pain, ache, stiffness, swelling, instability/giving way, locking or other complaints" with similar definitions for shoulder and low back problems.[3] Coaches and support staff were responsible for collecting the questionnaires and inputting the results into a standardized spreadsheet. No further instructions were given to the coaches. The questionnaire consists of four questions (each scored 0-25) that can be summed to provide a total severity score of 0 to 100. Substantial problems were defined as moderate or severe reductions in training volume or sports performance, or the complete inability to participate in training or competition.[3]

Data Analysis

Questionnaire responses were collated from each team at intermittent intervals during the season and at the end of the season. Data and reasons for any missing questionnaires were confirmed by the primary investigator with the coaches and checked against attendance logs. Questionnaire response rate was calculated based on the number of players who did not complete a team's weekly questionnaire; weeks in which the team did not train and therefore no questionnaires were provided were not considered missing nor if a player was not training with the team (e.g. international player late to join team).

Questionnaires were completed during the preseason and in-season for all teams. To best compare results, the questionnaire from the first week of each regular season was defined as week 0; resulting in preseason questionnaires defined as week -1, -2, -3, etc. The weekly prevalence of all problems and substantial problems were determined for all players and examined based on the individual player's preseason complaints status, match participation, position, team, and age. Each player was classified as either a substantial match contributor (start or play the majority of at least 25% of the team's matches) or as having limited/no match participation and verified against match reports, attendance logs, and match video. A total of 52 player-seasons were classified as substantial match contributors (six team seasons with six substantial match contributors; two team seasons with eight substantial contributors). Data are reported as mean values with 95% confidence intervals (CI) unless otherwise noted.

RESULTS

A total of 2867 weekly injury questionnaires were analyzed. Five weekly questionnaires were missing (0.17% of questionnaires) and eight additional questionnaires were partially completed with the low back section missing (99.6% of possible questionnaires had all 3 sections fully completed).

A total of 102 player-seasons were analyzed, revealing a weekly prevalence of knee, low back, and shoulder problems of 31% for the knee (95% CI 28-34%), 21% for the low back (95% CI 18-23%), and 19% for the shoulder (95% CI 18-21%; Table 1). Figure 1 reveals that 93% of players had some level of knee, low back, and/or shoulder complaints during the season (knee: 79%; low back: 75%; shoulder: 67%) and 58% experienced substantial problems that resulted in moderate or severe reduction in training volume or sport performance (knee: 33%; low back: 27%; shoulder: 27%). The average weekly severity scores for players reporting problems were 23 (knee; 95% CI 22-25), 23 (low back; 95% CI 21-25), 22 (shoulder; 95% CI 20-23), and 35 (95% CI 34-37) for all problems combined.

Duration of Problems

Problems were reported for an average of 6 (knee; 95% CI 5-7), 5 (low back; 95% CI 4-6), 5 (shoulder; 95% CI 4-6), and 7 (95% CI 6-8) consecutive weeks for all problems combined. Figure 2 shows the duration of the season that individual players reported problems with the average player noting knee problems for 36% (95% CI 29-43%) of the season, low back problems for 23% (95% CI 17-29%), shoulder problems for 21% (95% CI 16-27%), and the combination of knee, low back, and shoulder problems for 51% (95% CI 44-58%) of the season.

Preseason and In-season Complaints

There was a higher weekly prevalence of knee (38% vs. 29%; P = .005) and low back (27% vs. 19%; P = .009) problems observed in the preseason compared to in-season with no change in shoulder problems (19% vs. 19%; *P* = .745). Additionally, those players with preseason knee, low back, and shoulder complaints continue to have more complaints throughout the regular season (knee: 42% vs. 13%, *P* < .001; low back: 34% vs. 8%, *P* < .001; shoulder: 38% vs. 12%, *P* < .001; Table 2, Figure 3).

DISCUSSION

The prevalence of knee, low back, and shoulder problems among elite men's volleyball players is high; nearly all players (93%) experienced complaints at some point during the season. The collective impact of knee, low back, and shoulder problems resulted in an average weekly prevalence of 46%, with higher prevalence during the preseason that decreased throughout the season. Of note, players who experienced problems during the preseason, continued to have more problems during the regular season as well.

It was not unusual for players to experience knee, low back, or shoulder problems for a substantial portion of the season – 51% of players reported some combination of knee, low back, and shoulder problems for more than half the season. While a portion of these problems were minor with little burden to the athlete, 58% of players reported at least one bout of substantial knee, low back, or shoulder problems that led to a reduction in training volume or sports performance each season.

Knee. There was a higher weekly prevalence of knee complaints (31%) compared with the low back (21%) and shoulder (19%) and players on average experienced knee problems for a greater percentage of the season (36%) than compared with low back (23%) and shoulder problems (21%). These findings among elite and professional men's volleyball players are remarkably similar to previous research that utilized the same questionnaire among elite high school volleyball players – they reported the highest weekly prevalence of problems were to the knee (36%), followed by the shoulder (16%) and low back (14%) during the 13-week study window.[9] These similar findings emphasize the high prevalence of knee, low back, and shoulder problems that exist among competitive players of all ages – high school, university, and professional.

Patellar tendinopathy, commonly referred to as jumper's knee, has been reported to afflict volleyball players more than other athletes, with a point prevalence as high as 45-51%.[11,12] This common finding of jumper's knee symptoms in volleyball players makes it no surprise that both the weekly and season prevalence of knee complaints were high in this study. Previous research also found jumper's knee symptoms to have the highest prevalence in outside hitters (67%, 12 of 18) and middle blockers (64%, 9 of 14) compared to setters (22%, 2 of 9) and liberos (17%, 1 of 6).[12] Outside hitters/opposites also had the highest weekly prevalence of knee complaints in this study with relatively few complaints among liberos (outside hitters/opposites: 36%; middle blockers: 26%, setters: 26%, liberos: 11%).

Low back. The average weekly prevalence of low back complaints was slightly higher in this cohort (21%; 95% CI 18-23) compared to that observed over the 13-week study in high school players (14%; 95% CI 11-16) using the same questionnaire.[9] No other studies have prospectively examined the prevalence of low back problems throughout a volleyball season. A few have examined the incidence or proportion of low back problems utilizing time-loss or medical attention injury definitions,[2,13-17] leaving little to compare with the present study. This highlights the important contribution that the present findings add to our understanding of the injury burden that low back problems have in volleyball.

Two prior studies have begun to further our understanding on the prevalence, rather than incidence, of low back pain within different populations of volleyball players; both limited by the use of one-time retrospective questionnaires.[7,18] The first study examined low back pain within female university athletes and reported a point prevalence of 20% and 1-year prevalence of 40% among female volleyball players.[18] Despite the different athlete population, this point prevalence is comparable to the average weekly prevalence of 21% in the current study. The second study reported a 7-day prevalence of low back pain of 32% and 2-month prevalence of 46% within men's professional *beach* volleyball players.[7] While beach volleyball is a different sport than indoor volleyball, the study emphasized how traditional time-loss injury surveillance programs fail to accurately detect and quantify the burden associated with overuse injuries in sports. This is evident when comparing studies in indoor and beach volleyball in which traditional time-loss injury definitions report injury risks as low and fail to detect the high prevalence of knee, low back, and shoulder problems.[7,13]

Shoulder. The average weekly prevalence of shoulder complaints was 19% in the present study. This is similar to the 16% weekly prevalence reported in high school volleyball players.[9] A previous shoulder injury risk factor study within professional men's players reported a shoulder complaints point prevalence of 27% during the preseason; with 47% of players ultimately reporting shoulder problems at some point during the 12-week study.[19] Another study sampled men's and women's university players and reported a combined point prevalence of shoulder pain of 22%.[20] Finally, a season prevalence of shoulder problems was reported in 44% of male players competing at a university club national championships with 45% of those reporting shoulder problems also stating that their sport performance was adversely affected.[21] In the present study we found 67% of players reported shoulder problems during the season which is more than the previous studies reported.[19-21] While previous studies used retrospective questionnaires or shorter study windows, we recorded complaints prospectively on a weekly basis and for the length of each team's season (>6 months on average); it is unsurprising that additional shoulder problems were detected.

Previous research has reported that attackers (outside hitters, opposites, and middle blockers) have a greater prevalence of shoulder problems than setters and liberos.[19,21] We also observed few problems among liberos; however, setters surprisingly had the highest weekly prevalence of shoulder problems compared to the other positions. It is not clear if this was just an exceptional finding, or if the use of the current study methodology (prospective, season-long, weekly serial reporting, all-complaints injury definition) unmasked shoulder problems that may be more common among setters than previously believed.

Preseason complaints. Unsurprisingly, the prevalence of knee (38% vs. 29%) and low back problems (27% vs. 19%) was higher during the preseason than in-season. This is consistent with previous research that has reported a higher incidence of volleyball injuries during the preseason.[14,22] It is unclear why this same finding was not observed for shoulder problems, where the average prevalence did not change from the preseason to the regular season. The most striking observation may be that players who experienced preseason knee, low back, or shoulder problems of any kind continued to have significantly more problems during the regular season as well. Furthermore, there appears to be an apparent dose-response relationship, where players who experienced substantial knee problems in the preseason had an even higher prevalence of in-season complaints compared to both those without complaints and those with less severe preseason complaints. While it may not be surprising that players with preseason complaints continue to have a greater prevalence of complaints during the competitive season, this does suggest that this population should be actively managed rather than hoping for a regression to the mean throughout the season.

Substantial problems and injury management. Knee, low back, and shoulder problems that resulted in moderate or severe reductions in training volume or sports performance collectively affected an average of 1 in 11 players each week. Time and resources will be spent on best managing these injured players, but attention must still be given to the additional one-third of the team that regularly report less severe complaints. These players with less severe complaints may need to receive extra attention through a variety of focused and individualized management options (e.g. conversations with coaches and support staff, rehabilitation and recovery, warm-ups and strength programs, and training load modifications) to minimize the risk of these complaints progressing into substantial problems.

Methodological considerations. While this study provides new insights into the true prevalence and burden of knee, low back, and shoulder problems in men's volleyball, it does not give a complete overview of all injuries, since only these three areas were observed. We focused on recording all complaints rather than identifying specific injuries. This provides a more accurate account on the burden of these problems, but limits further extrapolation of results related to specific conditions such as jumper's knee. We followed these players through their professional club/university seasons. As each of these teams included players who have also competed at an international level, we do not know if these results would be similar when training and competing during the national team season. It is unclear why professional teams 1 and 2 had a lower weekly prevalence of complaints compared to the other teams; these team-specific observations highlight the importance for systematic monitoring and management of complaints within all teams.

We established strong relationships with the participating teams and had motivated coaches who took ownership of data collection. As a result, we had a very high response rate with very few weekly questionnaires missing (99.6% of questionnaires had all 3 sections fully completed). This was better than previous studies that provided the OSTRC questionnaire by email (91-93% response rates).[3,9] Future teams and research collecting similar data should be sure to include individuals who have a vested interest in the data and project.[23]

CONCLUSION

Nearly all elite men's volleyball players experienced knee, low back, or shoulder problems during a given season – and the majority had at least one bout that substantially reduced training participation or sports performance. While many knee, low back, and shoulder problems do not result in time-loss injuries, almost half of the players (46%) were playing through some combination of knee, low back, and shoulder complaints each week. Notably, players who experienced preseason knee, low back, and shoulder problems continued to have more problems during the competitive season than their teammates. This is pertinent information for those trying to best manage their athletes and hoping to minimize the risk of these complaints progressing into substantial problems over the course of the season.

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FIGURE LEGENDS

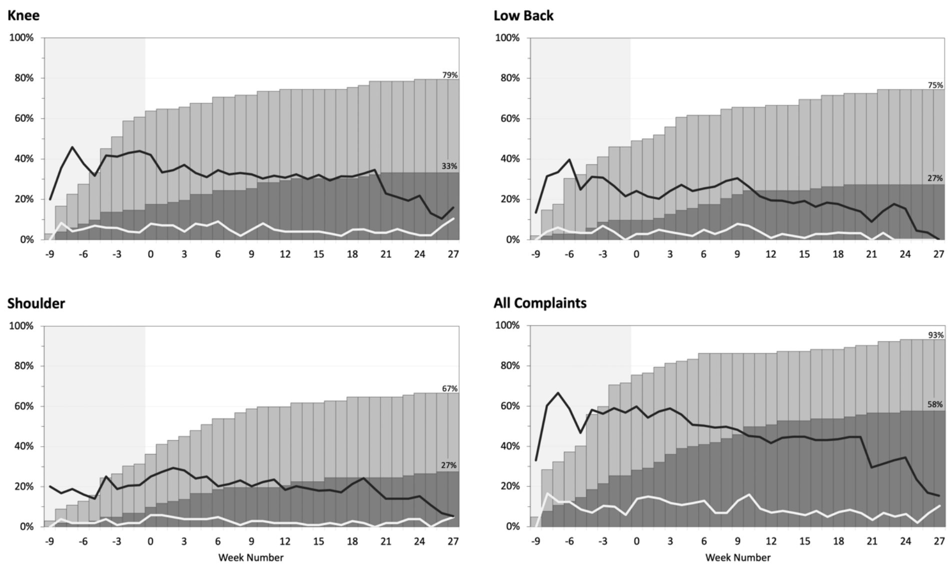

Figure 1 Weekly prevalence of knee, low back, and shoulder complaints throughout the preseason and in-season (black line = any complaint, white line = substantial complaints). The cumulative prevalence of volleyball players with complaints throughout the season is considerable (light grey bars = any complaint, dark grey bars = substantial complaints; n = 102 player-seasons, week 0 indicates start of regular season).

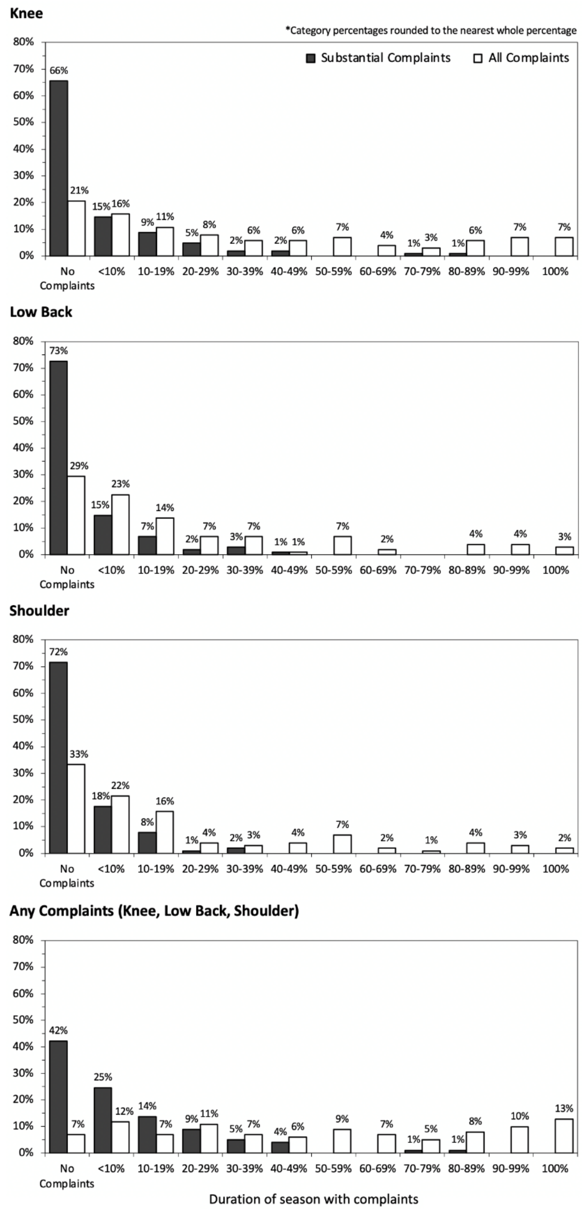

Figure 2 Duration of the season that individual volleyball players reported knee, low back, and shoulder complaints – it is not unusual for players to experience some level of knee, low back, or shoulder problems for a substantial portion of the season (n = 102 player-seasons).

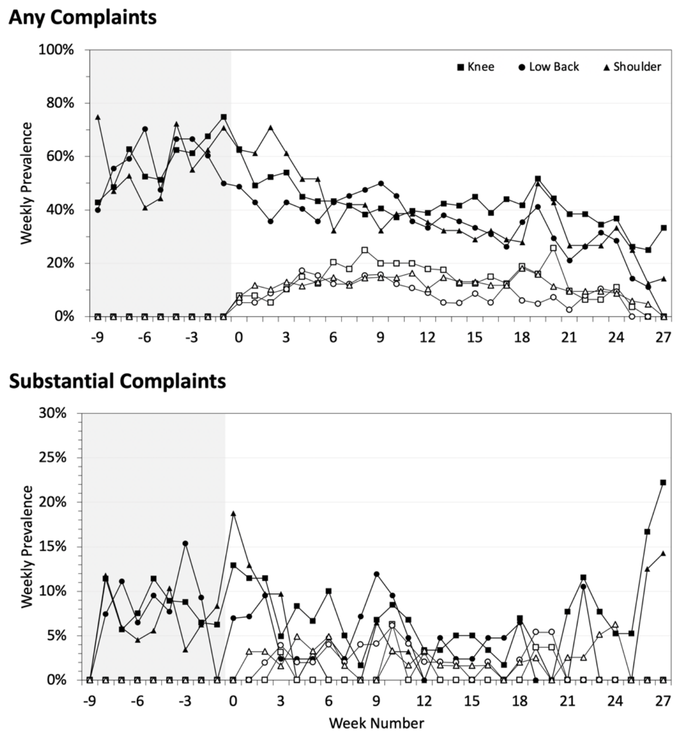

Figure 3 Volleyball players with preseason knee, low back, and shoulder complaints continue to have a greater prevalence of complaints throughout the season compared to players without preseason complaints. More substantial complaints are also observed but with noticeably smaller prevalence (solid marker = players with preseason complaints, open marker = players without preseason complaints; week 0 indicates start of regular season).

Table 1 Average Weekly Prevalence of Knee, Low Back, and Shoulder Complaints Based on Preseason Complaint Status, Match Participation, Position, Team, and Age (n = 102 Player-Seasons).[a]

	Knee	Low Back	Shoulder	Total Problems
All players				
All problems	31% (28-34)	21% (18-23)	19% (18-21)	46% (42-50)
Substantial problems[b]	5% (4-6)	3% (2-4)	3% (2-3)	9% (8-10)
Preseason complaints[c]				
Yes	42% (39-45) *	34% (29-38) *	38% (32-43) *	52% (47-57) *
No	13% (10-16)	8% (7-10)	12% (10-13)	23% (20-26)
Match participation				
Substantial contributor	36% (33-39) *	24% (21-28) *	26% (24-28) *	52% (48-56) *
Limited/none	26% (23-30)	17% (14-20)	13% (11-15)	39% (34-44)
Position				
Outside hitters/opposites	36% (33-39) *	16% (13-18)	18% (16-21)	48% (44-51)
Middle blockers	26% (23-30)	29% (25-34) *	16% (12-20)	45% (39-51)
Setters	26% (22-30)	22% (17-26)	27% (26-29) *	41% (36-45)
Liberos[d]	11% (9-14) *	7% (5-9) *	1% (0-2) *	19% (15-23) *
Team				
Professional 1	22% (19-25)	7% (5-10) *	9% (6-12) *	30% (26-35)
Professional 2	22% (19-26)	17% (14-20) *	17% (15-19) *	37% (33-40)
Professional 3	55% (50-59) *	34% (30-39)	41% (37-45) *	73% (68-77) §
University - Division 1 (USA)	47% (44-49) *	39% (35-43)	22% (18-25) *	72% (67-77) §
Age				
Quartile 1 (< 22.65 years)	36% (32-40)	26% (22-30) †	15% (12-18)	51% (46-57) ±
Quartile 2 (22.65 to 26.33 years)	28% (25-31) *	11% (9-14) *	13% (10-15)	42% (38-47) ±
Quartile 3 (26.34 to 29.70 years)	19% (15-24) *	19% (16-23) †	18% (15-21)	35% (29-41) ±
Quartile 4 (> 29.70 years)	41% (38-45)	25% (22-29)	32% (29-35) *	54% (50-58) ±

[a]Data reported as mean values with 95% CI in parentheses
[b]Substantial problems defined as moderate/severe reductions in training volume or sports performance, or complete inability to participate in training or competition.
[c]Weekly prevalence for preseason complaints calculated for regular season only
[d]Liberos included in table for reference only - not included in other analyses in table or paper secondary to being very different position group with different sport demands
*Subgroup significantly different from all other subgroups in respective category ($P \leq .05$)
§University - Division 1 (USA) and professional 3 are significantly different from both professional 1 and 2
†Quartile 1 and 3 are significantly different from each other ($P \leq .05$)
±Quartile 1 is significantly different from 2 and 3, Quartile 2 is significantly different from 1 and 4, Quartile 3 is significantly different from 1 and 4

Table 2 Average Weekly Prevalence of In-Season Knee, Low Back, and Shoulder Problems Among Elite Men's Volleyball Players Based on Preseason Complaints Status – Greater Prevalence of Problems Among Players with Preseason Complaints (n = 102 Player-Seasons).[a]

	Knee	Low Back	Shoulder	Total Problems
All problems				
No preseason complaints	8 (5-10)	6 (5-8)	8 (7-10)	11 (9-14)
Preseason complaints (excluding substantial problems)	38 (36-41)	32 (27-36)	39 (34-44)	53 (48-58)
Preseason complaints - substantial problems	54 (46-61)	40 (33-48)	39 (31-47)	50 (43-57)
Substantial problems[b]				
No preseason complaints	1 (0-1)	2 (1-3)	2 (1-3)	2 (1-3)
Preseason complaints (excluding substantial problems)	5 (4-6)	2 (1-3)	3 (1-6)	8 (6-9)
Preseason complaints - substantial problems	16 (10-21)	11 (6-17)	5 (0-9)	16 (11-21)

[a]Data reported as mean values (%) with 95% CI in parentheses

[b]Substantial problems defined as moderate/severe reductions in training volume or sports performance, or complete inability to participate in training or competition.

Appendix

Approval letters from the Regional Committee for Medical and Health Research Ethics and the Anti-Doping Lab Qatar Institutional Review Board

Fra: Regional komite for medisinsk og helsefaglig forskningsetikk REK midt

Til:
Roald Bahr
roald@nih.no roald@nih.no

Dokumentreferanse: 2010/2048-3
Dokumentdato: 15.09.2010

FIVB INJURY SURVEILLANCE PROGRAM - OVERVÅKING AV SKADER I INTERNASJONAL VOLLEYBALL INFORMASJON OM VEDTAK

Prosjektleders prosjektomtale: Volleyball er en idrett som har en relativt lav risiko for akutte ska, sammenliknet med andre lagidretter. Utøvere på øverste nivå utsettes imidlertid for et stadig hardere konkurranseprogram, og det er ønskelig å etablere en kontinuerlig skadeovervåking av alle større turneringer (to større turneringer per kjønn hvert år; VM, World League, World Grand Prix, Grand Champions Cup) i regi av det internasjonale volleyballforbundet (FIVB). Idretten er i stadig utvikling, bl.a. med regelmessige endringer av spilleregler og konkurranseformat, og det er ønskelig med et bedre datagrunnlag for å vurdere eventuelle konsekvenser for skaderisiko. Formålet med FIVB Injury Surveillance Program er derfor å overvåke skadefrekvens og/eller skadepanorama på internasjonalt toppnivå.

Prosjektleder: Professor Roald Bahr

Forskningsansvarlig: Senter for idrettsskadeforskning, Norges Idrettshøyskole

Med hjemmel i lov om behandling av etikk og redelighet i forskning § 4 og helseforskningsloven (hfl.) § 10 har Regional komité for medisinsk og helsefaglig forskningsetikk Midt-Norge vurdert prosjektet i sitt møte 27. august 2010. Komiteen viser til prosjektprotokoll, målsetting og plan for gjennomføring, og finner at prosjektet har et forsvarlig opplegg som kan gjennomføres under henvisning til evt. merknader og vilkår for godkjenning, jf. hfl. § 5.

Merknader og vilkår:

- Komiteen viser til at det i søknaden er ufullstendige opplysninger om hvem som er forskningsansvarlig. Prosjektleder kan ikke være kontaktperson hos den forskningsansvarlige institusjonen. Det naturlige er at avdelingsleder eller instituttleder står som kontaktperson, og komiteen ber om å få en slik endring bekreftet.

- Prosjektleder skal sende sluttmelding til den regionale komiteen for medisinsk og helsefaglig forskningsetikk når forskningsprosjektet avsluttes. I sluttmeldingen skal resultatene presenteres på en objektiv og etterrettelig måte, som sikrer at både positive og negative funn fremgår, jf. hfl. § 12.

Vedtak :

"Regional komité for medisinsk og helsefaglig forskningsetikk, Midt-Norge godkjenner at prosjektet gjennomføres med de vilkår som er gitt."

Vedtaket kan påklages og klagefristen er tre uker fra mottagelsen av dette brev, jf. hfl. § 10 og fvl. §§ 28 og 29. Klageinstans er Den nasjonale forskningsetiske komité for medisin og helsefag (NEM), men en eventuell klage skal rettes til REK Midt-Norge. Avgjørelsen i NEM er endelig. Det følger av fvl. § 18 at en part har rett til å gjøre seg kjent med sakens dokumenter, med mindre annet følger av de unntak loven oppstiller i §§ 18 og 19.

Med hilsen

Sven Erik Gisvold
Professor dr.med.
Leder REK Midt

Siv Tone Natland
Rådgiver REK Midt

Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
Fax: 44132997
Email: ADLQ-RO@adlqatar.com

IRB SCH Registration: SCH-ADL-070
SCH Assurance: SCH-ADL-A-071

APPROVAL NOTICE

Date	23/09/2014
Lead Principal Investigator	**Dr Stephen Targett**
IRB Application #	**E2013000003**
Protocol Title	**The benefits of periodic health examination (PHE) in athletes - a prospective cohort study from athlete screening in a Middle Eastern setting.**
Submission Type	**Ethical Approval Extension**
Review Type	**Expedited Review**
Approval Period	**23/09/2014– 22/09/2015**

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.

As the Principal Investigator of this research project, you are responsible for:

- Ethical Compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval (i.e., with regards to obtaining prior approval of any deviation of protocol, reporting of unanticipated events, and submission of progress reports).
- To inform the ADLQ-RO of the date of commencement of the research*.

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

Director – ORS/ADLQ (Office of Research Support)
Ms. Noor AlMotawa

**For Commencement of Research, Protocol Deviation Reporting, Unanticipated Problem Reporting & Research Progress Annual Report, please contact - Education & Research Office, Anti-Doping Lab Qatar.*

Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
Fax: 44132997
Email: ADLQ-RO@adlqatar.com

IRB MoPH Registration: SCH-ADL-070
MoPH Assurance: MOPH-A-ADL-Q-071

Approval Notice

Date	**20th Feb, 2018**
Lead Principal Investigator	**Christopher Skazalski**
Co-PI	-
IRB Application #	E2018000268
Sites	**Aspetar**
Funding Entity	**Aspetar**
Protocol Title	**Season jump variability and jump load demands in elite volleyball players**
Submission Type	**Initial Submission**
Review Type	**Expedited**
Approval Period	**20th Feb, 2018 – 19th Feb, 2019**

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.

As the Principal Investigator of this research project, you are responsible for:

- Ethical compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval which includes:-
  - Obtaining prior approval of any modifications to the approved protocol including the change of research team members.
  - Reporting deviations and unanticipated events; major deviations within 24 hours.
  - Renewing Ethics annually or every six months if IRB requires it.
  - Submission of progress reports annually
  - Informing the ADLQ-RO of the date of commencement of the research.
- LPI may use the content of the approved Informed Consent form in their own organizational letter head, if it deems fit for the nature of the project.

ADLQ IRB ORS (Office of Research Support)
Ms. Noor Al Motawa

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

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Anti- Doping Lab Qatar Institutional Review Board

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IRB MoPH Registration: SCH-ADL-070
MoPH Assurance: MOPH-A-ADL-Q-071

Approval Notice

Date	25th March, 2018
Lead Principal Investigator	**Christopher Skazalski**
Co-PI	-
IRB Application #	**E2018000269**
Sites	**Aspetar, TBD**
Funding Entity	**Aspetar**
Protocol Title	**Load monitoring and overuse complaints in elite volleyball players**
Submission Type	**Initial Submission**
Review Type	**Expedited**
Approval Period	**25th March, 2018 – 24th March, 2019**

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.

As the Principal Investigator of this research project, you are responsible for:

- Ethical compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval which includes:-
  - Obtaining prior approval of any modifications to the approved protocol including the change of research team members.
  - Reporting deviations and unanticipated events; major deviations within 24 hours.
  - Renewing Ethics annually or every six months if IRB requires it.
  - Submission of progress reports annually
  - Informing the ADLQ-RO of the date of commencement of the research.
- LPI may use the content of the approved Informed Consent form in their own organizational letter head, if it deems fit for the nature of the project.

مختبر مكافحة المنشطات قطر
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*For Commencement of Research, Protocol Deviation Reporting, Unanticipated Problem Reporting & Research Progress Annual Report, please contact - Education & Research Office, Anti-Doping Lab Qatar.

Christopher Skazalski // Understanding volleyball injuries