Biomechanical insights into the aetiology of infraspinatus syndrome

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ABSTRACT

Objective Infraspinatus syndrome (IS) results from injury to the suprascapular nerve. For reasons that are poorly understood, volleyball players are at greater risk of developing IS than are athletes who compete in other overhead sports. Differences between the shoulder kinematics of volleyball-related overhead skills and those skills demanded by other overhead sports might explain the pronounced prevalence of IS among volleyball athletes.

Design Observational, laboratory-based, cross-sectional study.

Setting The American Sports Medicine Institute.

Participants Fourteen healthy female Division 1 collegiate volleyball athletes.

Methods Upper limb biomechanics of 14 healthy female Division 1 collegiate volleyball athletes while spiking and serving were quantified, then compared to the results from data previously obtained from female baseball pitchers and tennis players.

Results Although the general movement pattern at the shoulder girdle is qualitatively similar for the upper limb skills required by a variety of overhead sports, volleyball spiking and serving result in greater shoulder abduction and horizontal adduction at the moment of ball contact/release than do baseball pitching or tennis serving.

Conclusion The authors suggest that the unique scapular mechanics which permit the extreme shoulder abduction and horizontal adduction that characterise volleyball spiking and serving place anatomically predisposed volleyball athletes at increased risk for developing cumulative traction-related injury to the suprascapular nerve at the level of the spinoglenoid notch.

Infraspinatus syndrome (IS) results from a peripheral mononeuropathy of the suprascapular nerve. The suprascapular nerve is a mixed nerve, originating off the upper trunk of the brachial plexus. It provides motor innervation from cervical levels C5 and C6 to the infraspinatus and infraspinatus muscles, while more distal injury to the nerve at the level of the spinoglenoid notch results in selective atrophy of the infraspinatus (ie, infraspinatus syndrome). There are no definitive data available regarding the prevalence of IS in the general population, or of the frequency of proximal versus distal entrapment among those with suprascapular neuropathy.

Since the sensory component of the suprascapular nerve typically originates proximal to the spinoglenoid notch, entrapment of the terminal portion of the nerve should result in weakness of external rotation and atrophy of the infraspinatus, but no pain. Indeed, IS has typically been described as painless. Curiously, although an athlete diagnosed with IS should theoretically demonstrate significant weakness on motor testing,5 no performance deficit is typically reported.1,2 This may be because the posterior deltoid and the teres minor (as the other rotator cuff external rotator of the shoulder) maintain functional glenohumeral external rotation.

The risk factors for development of suprascapular neuropathy have long been debated. Trauma, such as a clavicular fracture, anterior glenohumeral dislocation or iatrogenic intraoperative injury, is a recognised cause of injury to the suprascapular nerve.1,2 Post-traumatic ganglion cysts arising off the glenoid labrum have also been shown to impinge upon the suprascapular nerve. The extent to which individual anatomic factors contribute to the risk of developing suprascapular neuropathy is ultimately a matter of interaction between the athlete’s phenotype and his/her environment. Proximally, hypertrophy of the superior transverse scapular ligament or variable anatomy of the suprascapular notch itself may facilitate entrapment of the suprascapular nerve.4,5 Duparc and colleagues6 proposed that the infraspinatus fascia could, if thickened, contribute to entrapment of the suprascapular nerve in the supraspinatus fossa. Rengachary and colleagues4,5 theorised that individual anatomy, combined with scapular mechanics (including extreme glenohumeral abduction), made the supraspinatus nerve vulnerable to proximal injury when kinked against the suprascapular ligament, a phenomenon termed the ‘sling effect’. More distal injury to the suprascapular nerve has been investigated by Demirhan et al,7 who observed that shoulder adduction and internal rotation made the spinoglenoid ligament taut, causing it to impinge upon the suprascapular nerve.

The course of the terminal portion of the suprascapular nerve as it exits the spinoglenoid notch could...
potentially contribute to the vulnerability of the nerve to traction-related injury at this site.

**EPIDEMIOLOGIC CONSIDERATIONS**

While there are several potential anatomic considerations to the development of IS, there is also one singularly important functional epidemiologic observation for which any mechanism of injury must account: the prevalence of IS is much greater among elite volleyball athletes than it is in other overhead athletes. Guo and Xu first described the high frequency with which IS occurs among volleyball players. Ferretti and colleagues subsequently reported that nearly 15% of elite volleyball players participating in the 1985 European volleyball championships demonstrated evidence of IS limited to the dominant side. Observational studies have confirmed that the condition is indeed extremely common among elite volleyball athletes. A recent imaging study of professional beach volleyball players revealed fatty replacement of the infraspinatus muscle consistent with IS in 30% of the athletes imaged. In addition, Witvrouw et al detected evidence of suprascapular neuropathy affecting only the infraspinatus in 25% of the Belgian men’s national volleyball team. Both of these studies are consistent with the estimated prevalence among populations (eg, IS has been estimated to occur in only 4.4% of major league baseball players). Despite these findings, no theory has yet been advanced that satisfactorily explains the observed association between volleyball and selective atrophy of the infraspinatus.

**METHODS**

Recently, Reeser and collaborators quantified the upper limb kinematics and kinetics of 14 healthy female Division 1 collegiate volleyball athletes while spiking and serving (athletes at all positions were tested). None of the participants reported any history of shoulder injury. No formal screening examination for IS was conducted; thus, subclinical or nascent entrapment of the suprascapular nerve may easily have escaped detection. None of the participants complained of any pain or limitation during the testing. For each participant, data were collected for the float serve as well as several types of attack shots distinguished by follow-through, direction of the ball, and velocity: the cross-body (cross-court) full-speed spike, the straight-ahead (down the line) full-speed spike, and the roll-shot (an off-speed spike). Each subject performed five successful trials for each type of attack. In addition, participants who were proficient at the jump serve also performed five successful jump serve trials.

Each athlete was required to wear tight-fitting clothing (ie, spandex shorts and a sleeveless shirt) with reflective markers attached to 17 bony landmarks. Data collection occurred in a large indoor biomechanics laboratory equipped with an eight-camera (240 Hz), three-dimensional automatic digitising system (Motion Analysis Corporation, Santa Rosa, California, USA). A regulation size volleyball court (18 m×9 m) was marked off in the lab, and a women’s regulation height (2.24 m) net was installed. Shoulder angle was separated into three components: external rotation, abduction and horizontal adduction. Angular velocity was computed as the derivative of the angle using the five-point central difference method. Shoulder torque was calculated using the kinematic data, documented cadaver body segment parameters, and inverse dynamics. Kinetic values were expressed as the torque applied at the shoulder by the trunk onto the arm. Kinetic values after ball contact were not calculated, since the kinetic model did not include the force generated by ball contact. Ball velocity was recorded from a point directly in line with the anticipated trajectory of the volleyball using a Tribar Sport radar gun (Jugs Pitching Machine, Tualatin, Oregon, USA). Peak kinematic and kinetic values for the shoulder at several key points of skill execution were compared. This project was reviewed and approved by the Marshfield Clinic Institutional Review Board.

**RESULTS**

Continuous data for selected kinematic and kinetic parameters related to overhead volleyball skills are presented in figures 1–5. Shoulder external rotation, horizontal adduction, and abduction are shown in figures 1–3, respectively. The torque generated by the upper arm at the shoulder is shown in figure 4: a positive value indicates internal rotational torque applied to the upper arm, whereas a negative torque indicates external rotational torque. Force applied onto the upper arm at the shoulder is shown in figure 5: a positive value indicates proximal force (resisting distraction), whereas a negative value

![Figure 1](https://example.com/figure1.png)  
*Figure 1* Shoulder external rotation during the (a) cross-body spike and (b) float serve. The solid line represents the mean value for the 14 participants in Reeser et al. The vertical line segments indicate plus or minus one SD. Zero on the horizontal axis represents the time of ball impact.
indicates distal (distracting) force. Figures 1–5 include data for the (a) cross-body spike and (b) float serve.

During both the volleyball spike and serve, the shoulder externally rotates in excess of 150 degrees. Concurrent with shoulder external rotation, horizontal adduction initially decreases (due mostly to arm lag as the upper trunk rotates to face the net) and then increases throughout the arm swing. Peak internal rotation torque occurs nearly simultaneously with achievement of the maximum external rotation angle. The observed internal rotation torque therefore decelerates shoulder external rotation and initiates internal rotation. The shoulder then continues to internally rotate while maintaining a high abduction angle through ball contact. Maximum proximal force (which functionally opposes shoulder distraction) occurs near the moment of ball contact. After ball contact, both shoulder internal rotation and horizontal adduction plateau, while shoulder abduction decreases.

Peak values for upper limb kinematic and kinetic parameters during the volleyball serve and spike were compared to previously published data for the baseball pitch and tennis serve (table 1). The volleyball, baseball and tennis publications included elite healthy adult female athletes studied by the same research institute, using the same biomechanical algorithm.\textsuperscript{16–19} For all three sports, the peak shoulder internal rotation torque was measured near the moment of maximum

external rotation. The baseball pitch yielded both the greatest maximum external rotation and the fastest internal angular rotational velocity. However, the greatest internal rotational torque was measured during the tennis serve.\textsuperscript{13} Due to the added resistance (moment of inertia) of the tennis racquet, the tennis serve generated the slowest internal rotational velocity and the greatest proximal force at the shoulder. Overhead volleyball skills resulted in the greatest shoulder abduction and horizontal adduction at the moment of ball contact/release. Also of note, the volleyball kinetic data revealed a small external rotational torque that appears to initiate deceleration of upper limb internal rotation immediately following ball contact. A similar external rotation torque had not been previously identified in the baseball and tennis studies. Unfortunately, the original data for these investigations are no longer available, making it impossible to retrospectively calculate additional biomechanical parameters.

**FIGURE 2** Shoulder horizontal adduction(+) / abduction(–) during the (a) cross-body spike and (b) float serve. The solid line represents the mean value for the 14 participants in Reeser et al. The vertical line segments indicate plus or minus one SD. Zero on the horizontal axis represents the time of ball impact.

**FIGURE 3** Shoulder abduction during the (a) cross-body spike and (b) float serve. The solid line represents the mean value for the 14 participants in Reeser et al. The vertical line segments indicate plus or minus one SD. Zero on the horizontal axis represents the time of ball impact.

**DISCUSSION**

The shoulder is vulnerable to overuse injury in all overhead sports, but compared to other overhead athletes, volleyball players appear to be at particular risk of developing distal suprascapular neuropathy resulting in IS. Beyond the anticipated atrophy and weakness on motor testing, no static physical examination finding (eg, scapular dyskinesis, glenohumeral

internal rotation deficit, postural abnormalities) have been consistently identified as risk factors for IS. However, when we compared the kinetic and kinematic data collected from female athletes performing skills characteristic of three different overhead sports, we were struck by the significantly greater shoulder abduction and horizontal adduction demanded by volleyball skills. We speculate that our findings represent a plausible biomechanical risk factor for the increased prevalence of IS among volleyball athletes.

**Previous theories on the aetiology of infraspinatus syndrome**

Based on their observation that volleyball-related IS usually occurs unilaterally on the athlete’s dominant side, Ferretti et al. reasoned that either spiking or serving was likely to be the principal risk factor for the development of IS. Ferretti assumed that the kinematics of the spike were essentially identical to those of the baseball pitch, leading him to conclude that since IS was diagnosed infrequently in baseball pitchers, volleyball spiking was not likely to be a significant risk factor for suprascapular neuropathy. Instead, Ferretti concluded that the development of IS must be principally related to the performance of the ‘float serve,’ a skill that is unique to volleyball. Ferretti and his colleagues observed that in a correctly performed float service, the infraspinatus is intensely activated after ball contact. They postulated that the eccentric activation of the infraspinatus abruptly decelerates the upper limb after ball contact, and therefore concluded that performance of a float serve could result in a traction injury of the suprascapular nerve distal to the spinoglenoid notch.

Our current kinetic data, however, do not support a unique mechanism for IS based solely upon the mechanics of the float serve. As shown in table 1 and figure 4, both the cross-body spike and the float service generate a comparable external rotational torque to decelerate the internal rotation of the upper limb. The magnitude of this torque is no greater for float serves than it is for cross-body spikes (8±4 N•m), making it unlikely that one of the overhead skills produces any greater traction on the ipsilateral suprascapular nerve than the other. Further arguing against Ferretti’s hypothesis that the float serve is the principal risk factor for developing IS is the observation that the prevalence of IS has apparently not decreased, even though the popularity of the float serve has significantly decreased in recent years (the float serve was the most popular style of serve up through the 1984 Los Angeles Olympic Games, after which time the jump serve rapidly gained popularity.).
Other theories have been advanced to explain IS. Sadow and Ilic20 observed that placing the abducted shoulder joint in extreme external rotation results in compression of the suprascapular nerve at the spinoglenoid notch by the spinati muscles, and they therefore proposed this as the mechanism of injury leading to IS. However, our kinematic data do not support this theory either. The volleyball spike and serve produce less external rotation than do the tennis serve and the baseball pitch. If extreme external rotation is the primary risk factor for development of IS, then other athletes (particularly baseball pitchers) should exhibit IS at frequencies at least as great as seen in volleyball athletes. That the prevalence of suprascapular neuropathy/infraspinatus syndrome in baseball is not greater suggests that while repetitive external rotation may be a risk factor in the development of IS, it is clearly not sufficient in and of itself to result in significant injury to the suprascapular nerve.

Incorporating biomechanics insights into the pathogenesis of IS

Although (table 1) the general movement pattern at the shoulder girdle is qualitatively similar for the overhead skills required by a variety of overhead sports, volleyball spiking and serving are associated with significantly greater shoulder abduction and horizontal adduction at the moment of ball contact/release than are baseball pitching or tennis serving. The scapula facilitates both of these motions: shoulder abduction requires a combination of posterior scapular tipping and upward and external rotation, while shoulder horizontal adduction demands a combination of anterior scapular tipping and upward and internal rotation.24 Based on the magnitude of these selected, volleyball-specific, overhead kinematic parameters, we propose that the specific scapular dynamics that repeatedly facilitate such extreme relative increases in shoulder abduction and horizontal adduction during performance of overhead volleyball attacks and serves constitute a major risk factor for the development of IS. Specifically, we suggest that the unique scapular kinematics generated by volleyball spiking and serving place volleyball athletes at increased risk for developing cumulative traction-related injury to the suprascapular nerve, particularly if combined with other permissive risk factors (eg, pheno-
typic/anatomical factors discussed above). In this regard, the proposed mechanism of injury is consistent with the observations of both Demirhan17 and Rengachary.4, 5 Importantly, this theory would appear to explain the greater prevalence of IS among volleyball players in comparison to baseball and/or tennis players. In addition, the proposed pathophysiologic mechanism accommodates the findings of Witvrouw et al,13 who detected significant differences in shoulder girdle range of motion measured in athletes diagnosed with IS compared to those without IS, and Martin et al,25 who found that the degree of stretch of the suprascapular nerve was dependent upon scapular mobility, and that more extreme arm positions may result in greater suprascapular nerve vulnerability to traction injury.

<table>
<thead>
<tr>
<th>Shoulder parameter</th>
<th>Volleyball cross-body spike16</th>
<th>Volleyball float serve16</th>
<th>Baseball fastball pitch17</th>
<th>Tennis first serve18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near the instant of maximum external rotation</td>
<td>160±10</td>
<td>158±12</td>
<td>180±10</td>
<td>172±12</td>
</tr>
<tr>
<td>Maximum external rotation (°)</td>
<td>160±10</td>
<td>158±12</td>
<td>180±10</td>
<td>172±12</td>
</tr>
<tr>
<td>Maximum internal rotation torque (N•m)</td>
<td>37±9</td>
<td>32±8</td>
<td>48±11</td>
<td>65±16</td>
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<tr>
<td>Arm acceleration phase</td>
<td>Maximum internal rotation angular velocity (°/s)</td>
<td>2440±610</td>
<td>1860±620</td>
<td>5630±1590</td>
</tr>
<tr>
<td>Near the instant of ball contact or release</td>
<td>Abduction at the instant of ball contact or release (°)</td>
<td>130±8</td>
<td>133±11</td>
<td>89±6</td>
</tr>
<tr>
<td>Horizontal adduction at the instant of ball contact or release (°)</td>
<td>29±14</td>
<td>30±16</td>
<td>9±8</td>
<td>5±10</td>
</tr>
<tr>
<td>Maximum proximal force (N)</td>
<td>400±60</td>
<td>330±60</td>
<td>510±110</td>
<td>610±110</td>
</tr>
<tr>
<td>Maximum external rotation torque (N•m)</td>
<td>8±4*</td>
<td>8±4*</td>
<td>Not available</td>
<td>Not available</td>
</tr>
</tbody>
</table>

*Maximum external rotation torque was not reported in the original publications; these numbers were calculated from the original data

CONCLUSION

Comparison of upper limb biomechanical data from overhead sports provides insight into the magnitude and nature of the load placed on the shoulder by the different overhead sporting activities. The data suggest that the performance of volleyball-specific skills demands extreme shoulder abduction and greater horizontal adduction when compared to the baseball pitcher or the tennis server. We propose that these extreme volleyball-specific biomechanics represent a significant risk factor for the development of IS.

At present, we lack rigorous clinical observational studies to prove the theory. A study comparing the shoulder kinematics of volleyball athletes with and without suprascapular nerve damage could provide insight. A prospective study initially quantifying spike biomechanics, serve biomechanics, medical history and physical examination among asymptomatic subjects, then following the participants to see how much they play and which subjects develop IS would be even more informative. Such a prospective study could correlate biomechanics (such as abduction greater than 130 degrees at the instant of ball contact) and other documented and presumed epidemiologic risk factors with the prevalence (and outcome) of IS. Additional proof of our theory could be obtained if we were able to demonstrate greater shoulder abduction and horizontal adduction at ball release for baseball pitchers with documented IS compared to a control group of pitchers without evidence of IS.

Contributors All authors have contributed to the conception and design of the article, analysis and interpretation of data, and drafting the article or revising it critically for important intellectual content. All authors can take full responsibility for its contents, and have read and seen the final copy of the manuscript.

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