Kinematics of the Shoulder Joint in Tennis Players

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ABSTRACT

Background: Shoulder pain and injury are common in tennis players. The precise causes for such pain remain unclear. Impingement at critical tennis positions and glenohumeral instability have never been dynamically evaluated in-vivo. The purpose of this study was to evaluate the different types of impingement and stability during tennis movements.

Methods: Type and frequency of impingement as well as percentage of subluxation were evaluated in 10 tennis players through a novel dedicated patient-specific measurement technique based on optical motion capture and Magnetic Resonance Imaging (MRI).

Results: All volunteers, nine male and one female, had a clinically functional rotator cuff. MRI revealed 11 rotator cuff lesions in six subjects and six labral lesions in five subjects. Lateral subacromial, anterior subacromial, internal anterosuperior, and internal posterosuperior impingements were observed in four, three, two and seven subjects, respectively. No instability could be demonstrated in this population.

Conclusion: Tennis players presented frequent radiographic signs of structural lesions that could mainly be related to posterosuperior impingements due to repetitive abnormal motion contacts. This is the first study demonstrating that a dynamic and precise motion analysis of the entire kinematic chain of the shoulder is possible through a non-invasive method of investigation. This premier kinematic observation offers novel insights into the analysis of shoulder impingement and instability that could, with future studies, be generalized to other shoulder pathologies and sports. This original method may open new horizons leading to improvement in impingement comprehension.

Keywords: Shoulder kinematics modeling; Biomechanics, Tennis players; Overhead athletes; Impingement; Magnetic resonance imaging.

INTRODUCTION

Shoulder pain and injury are common in tennis players, with a prevalence of 50% for certain categories of age.[1] A majority of shoulder pain is caused by impingement and instability due to repetitive lifting and overhead arm movements. Two types of impingement have been described: external and internal. External types include subacromial impingement of the rotator cuff between the anterior acromion[2] or lateral acromion[3] and the superior humeral head that could occur with serves and overhead shots. Another type of external impingement is the less common subcoracoid impingement[4] of the subscapularis or biceps tendon. It results from contact between the coracoid process against the lesser tuberosity of the humeral head and is more likely to occur at the backhand preparation phase and the late follow-through phase of the forehand. Internal impingement consists of (1) posterosuperior impingement[5] of the supraspinatus and infraspinatus tendons between the greater tuberosity of the humeral head and the posterosuperior aspect of the glenoid when the arm is in extreme abduction, extension and external rotation during the late cocking stage of the serve; and (2) anterosuperior impingement[6] of the deep surface of the subscapularis tendon and the reflection pulley on the anterosuperior glenoid rim that could also occur at the backhand preparation phase and the late follow-through phase of forehand.

The precise causes for these impingements remain unclear, but it is believed that repetitive contact (Figure 1A and 1B), glenohumeral instability (Figure 1C), scapular orientation, rotator cuff dysfunction, and posteroinferior capsular contracture with resultant glenohumeral internal rotation deficit (GIRD) may play a role in the development of symptomatic impingement.[5,7,8] Measuring the dynamic in-vivo shoulder kinematics seems crucial to better understand these pathologies and to propose an adequate treatment. Indeed, a patient with an internal impingement will be treated differently if the etiology is a posteroinferior capsular contracture with resultant GIRD (that generally responds positively to a compliant posteroinferior capsular stretching program or to an arthroscopic selective posteroinferior capsulotomy and concomitant partial articular sided tendon avulsion (SLAP) lesion repair[9]) or a repetitive contact of the undersurface of the rotator cuff on the posterosuperior glenoid labrum (that can respond to debridement, glenoidplasty or derotational humeral osteotomy).[10-12] However, such kinematic measurements remain a challenging problem due to the complicated anatomy and large range of motion of the shoulder. To our knowledge, impingements at critical tennis positions and glenohumeral stability have never been dynamically evaluated. Unfortunately, the motion of the shoulder cannot be explored with standard Magnetic Resonance Imaging (MRI) or Computed Tomography (CT) because they are limited by space and the velocity of the movement and might therefore miss dynamic motion. Fluoroscopy-based measurements provide sufficient accuracy for dynamic shoulder analysis,[13] but they use ionizing radiation. Motion capture systems using skin-mounted markers provide a non-invasive method to determine shoulder kinematics during dynamic movements.[14] However, none of the current motion capture techniques have reported translation values at the glenohumeral joint. One reason that might explain this void is that current techniques have either concentrated their efforts on the analysis of a single shoulder bone (e.g., scapula) or focused on the description of humeral motion relative to the thorax rather than to its proximal bone.

The purpose of the study was thus: (1) to develop a dedicated patient-specific measurement technique based on optical motion capture and MRI to accurately determine glenohumeral kinematics (rotations and translations) taking into account the whole kinematic chain of the shoulder complex from the thorax to the humerus through the clavicle and scapula, (2) to evaluate impingement, stability, and other motion-related disorders during dynamic movements in high-level tennis players.

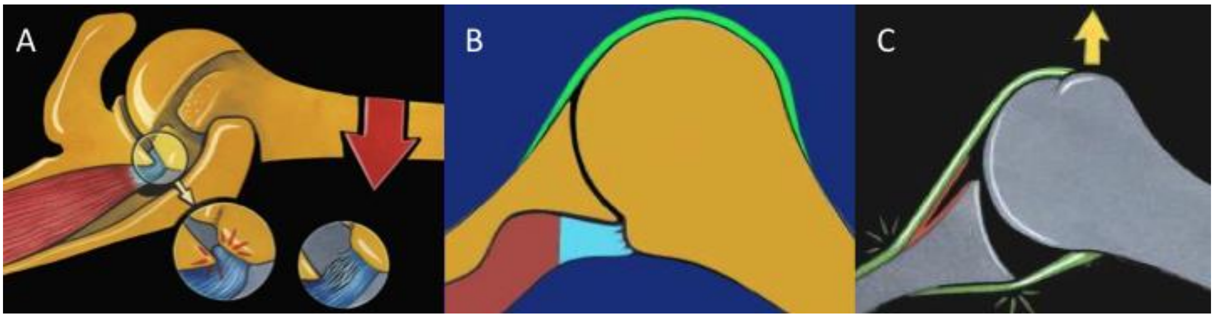

Figure 1: (A) Gilles Walch's theory: the deep layer of the posterosuperior rotator cuff impinged with the posterior labrum and glenoid. (B) Christopher Jobe's theory: the impingement is mainly due to hyperextension of the humerus relative to the scapula. (C) Frank Jobe's theory: lesions in throwing athletes are related to subtle anterior instability.

METHODS

Ten volunteers who were intermediate or ex-professional tennis players were recruited for this study. Ethical approval was gained from the local Institutional Review Board, and all participants gave their written informed consent prior to taking part in the study. Exclusion criteria were reported previous shoulder injuries, shoulder surgery or contraindications for MRI.

The outcomes of interest were the prevalence of internal and external impingement and glenohumeral instability in this particular population. Furthermore, the prevalence of other radiographic pathologies was evaluated in relation to the main outcomes of interest. The following baseline characteristics were assessed: age, sex, body mass index, shoulder side, and limb dominance.

Rotator cuff examination included the belly-press, bear hug, Jobe tests, and external rotation strength again resistance. Constant score,[15] American Shoulder and Elbow Surgeons (ASES) score,[16] a single assessment numeric evaluation (SANE) score,[17] and a visual analog scale (VAS) pain score graded from 0 points (no pain) to 10 points (maximal pain) were recorded.

All volunteers underwent an MR shoulder arthrography. The MRI examinations were conducted after a fluoroscopically guided arthrography with a contrast agent and with an anterior approach. MRI was performed with a 1.5 T HDxT system (General Electric Healthcare, Milwaukee WI, USA). A dedicated shoulder surface coil was used. A sagittal T1 weighted fast spin echo sequence, a coronal and sagittal T2 weighted fast spin echo sequence with fat saturation, a coronal and axial T1 weighted fast spin echo sequence with fat saturation, and three 3D fast gradient echo (Cosmic® and Lava®) sequences were achieved. Table 1 details the imaging parameters of each MRI sequence.

MR arthrograms were assessed by a musculoskeletal radiologist for shoulder pathology including rotator cuff, labral or ligament (HAGL) lesion and bony changes.

Based on the 3D MR images, patient-specific 3D models of the shoulder bones (humerus, scapula, clavicle and sternum) were reconstructed for each volunteer using ITK-SNAP software (Penn Image Computing and Science Laboratory, Philadelphia, PA).

Kinematic data was recorded using a Vicon MX T-Series motion capture system (Vicon, Oxford Metrics, UK) consisting of 24 cameras (24 × T40S) sampling at 240 Hz. The volunteers were equipped with spherical retroreflective markers placed directly onto the skin using double-sided adhesive tape (Figure 2). Four markers (Ø 14 mm) were attached to the thorax (sternal notch, xyphoid process, C7 and T8 vertebra). Four markers (Ø 6.5 mm) were placed on the clavicle. Four markers (Ø 14 mm) were fixed on the upper arm, two placed on anatomical landmarks (lateral and medial epicondyles) and two as far as possible from the deltoid. For the scapula, one marker (Ø 14 mm) was fixed on the acromion. In addition, the scapula was covered with 56 markers (Ø 6.5 mm) to form a 7×8 regular grid. Finally, additional markers were distributed over the body (non-dominant arm and legs).

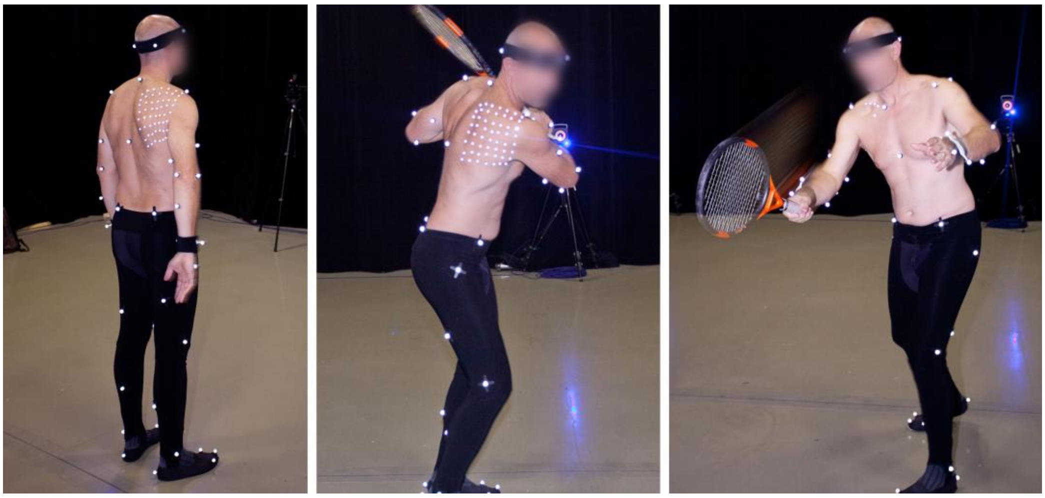

Figure 2: Markers placement.

After appropriate warm-up, participants were asked to perform the following tennis movements: forehand, backhand, flat and kick serves. They were also instructed to perform three motor tasks: internal-external rotation of the arm with 90° abduction and the elbow flexed 90°, flexion of the arm from neutral to maximum flexion, and empty-can abduction from neutral to maximum abduction in the scapular plane. Three trials of each motion were recorded. The same investigators attached all markers and performed all measurements.

Shoulder kinematics were computed with custom-made software using the recorded markers' trajectories. The major drawback with optical motion capture systems is the soft tissue deformation due to muscle contractions and skin sliding, causing marker movements with respect to the underlying bones. In the upper extremity, the scapula is particularly affected. To solve this issue, it was demonstrated that the use of global optimization could help reduce soft tissue artifacts (STA) errors globally.[18] Therefore, we developed a patient-specific kinematic chain model of the shoulder complex (including the thorax, clavicle, scapula and humerus) using the subject's 3D bony models[19]. The shoulder joints were each modeled as a ball-and-socket joint (3 degrees of freedom) with loose constraints on joint translations. The optimal pose of the kinematic chain was then obtained using a global optimization algorithm. To verify its accuracy, kinematic data was collected simultaneously from an X-ray fluoroscopy unit (MultiDiagnost Eleva, Philips Medical Systems, The Netherlands) and the motion capture system during clinical motion patterns (flexion, abduction and internal-external rotation of the arm) in a validation test. Glenohumeral kinematics were derived from the marker position data and compared with the one obtained with the fluoroscopy gold-standard.[13,19] The accuracy of the model for glenohumeral orientation was within 4° for each anatomical plane and between 1.9 and 3.3 mm in average for glenohumeral translation. Moreover, the results showed that the translation patterns computed with the model were in good agreement with previous research.[20]

Finally, the computed motions were applied to the tennis player's shoulder 3D models reconstructed from their MRI data. Figure 3 shows examples of computed tennis positions. A ball and stick representation of the overall skeleton was also added to improve the analysis and visualization of the motion. The method is summarized in video 1.

To permit motion description of the shoulder kinematic chain, local coordinate systems (Figure 4) were established based on the definitions suggested by the International Society of Biomechanics[21] to represent the thorax, clavicle, scapula and humerus segments using anatomical landmarks identified on the subject's bony 3D models. The glenohumeral joint center was calculated based on a sphere fitting method[22] that fits the optimal sphere to the humeral head using the points of the 3D humeral model.

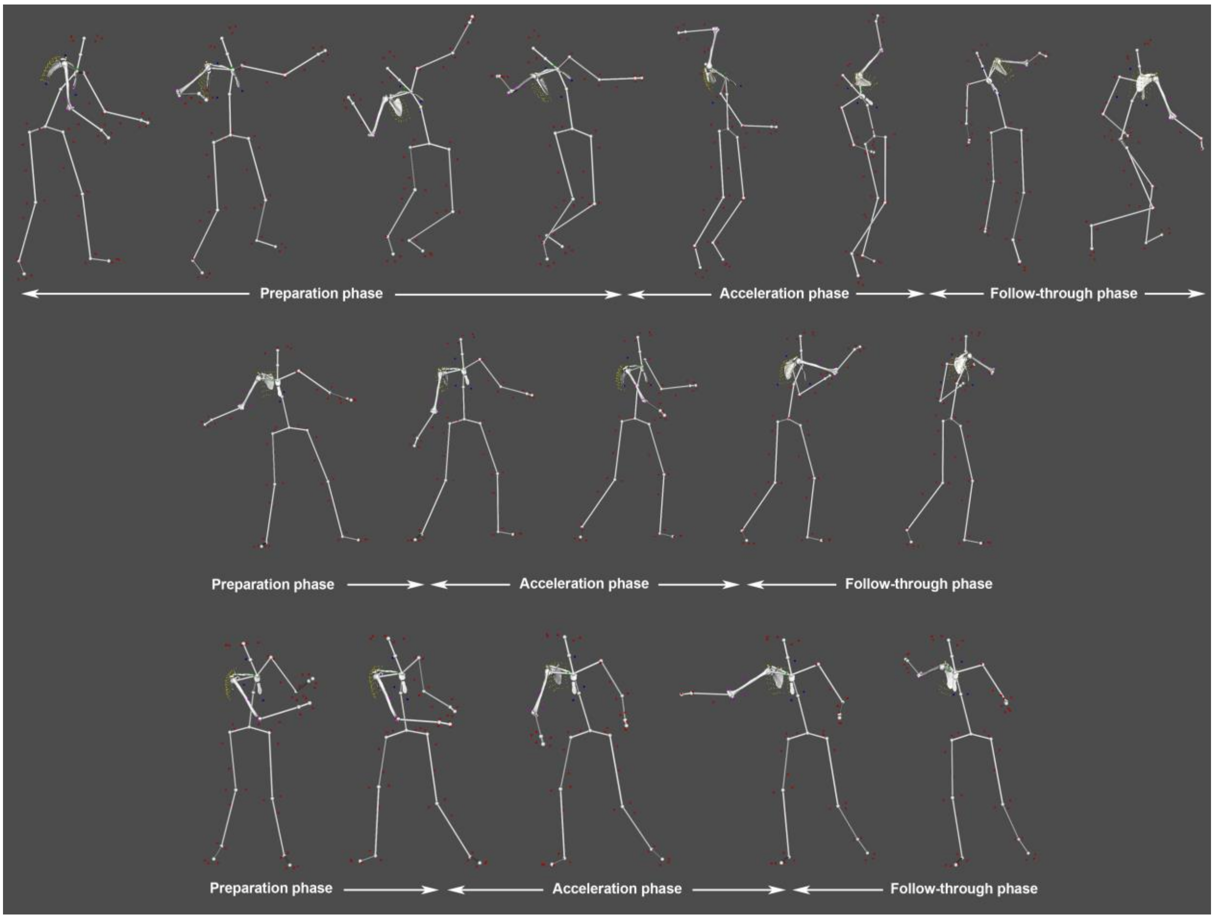

Figure 3: Computed tennis positions (here the right shoulder) according to the three main phases, showing the markers setup (small colored spheres) and the virtual skeleton. Top: serve shot. Position 4, 7 and 8 are commonly known as the cocking, deceleration and finish stages, respectively. Middle: forehand shot. Bottom: backhand shot.

Glenohumeral range of motion (ROM) was quantified for flexion, abduction and internal-external rotation movements. This was obtained by calculating the relative orientation between the scapula and humerus coordinate systems at each point of movement and then expressed in clinically recognizable terms (flex/ext, abd/add and IR/ER) by decomposing the relative orientation into three successive rotations. It is important to note that these computations were performed independently from the major anatomical planes (i.e., sagittal, transverse, frontal planes). To facilitate clinical comprehension and comparison, motion of the humerus with respect to the thorax was also calculated. This was achieved with the same method but using the thorax and humerus coordinate systems.

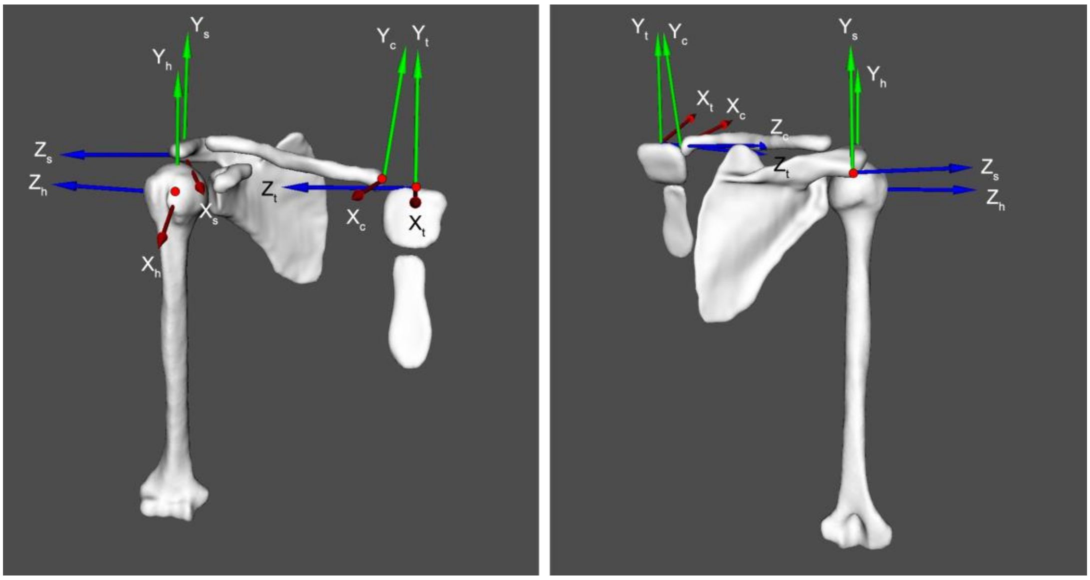

Figure 4: Bone coordinate systems for the thorax (X_t Y_t Z_t), clavicle (X_c Y_c Z_c), scapula (X_s Y_s Z_s) and humerus (X_h Y_h Z_h).

Glenohumeral stability was assessed during flexion and abduction movements and during flat and kick serves at the late cocking, deceleration and finish stages. Glenohumeral translation was defined as anterior-posterior and superior-inferior motion of the humeral head center relative to the glenoid coordinate system. This coordinate system was determined by an anterior-posterior X-axis and a superior-inferior Y-axis with origin placed at the intersection of the anteroposterior aspects and superoinferior aspects of the glenoid rim (Figure 5A). Subluxation was defined as the ratio (in %) between the translation of the humeral head center and the radius of width (anteroposterior subluxation) or height (superoinferior subluxation) of the glenoid surface (Figure 5B). Instability was defined as subluxation >50%.

Impingement was evaluated at critical tennis positions. While visualizing the tennis player's shoulder joint in motion, minimum humero-acromial, humero-coracoid and humero-glenoid distances that are typically used for the diagnosis of impingement were measured (Figure 6). The distances were calculated in 3D based on position of the simulated bone's model and were reported in millimeters.

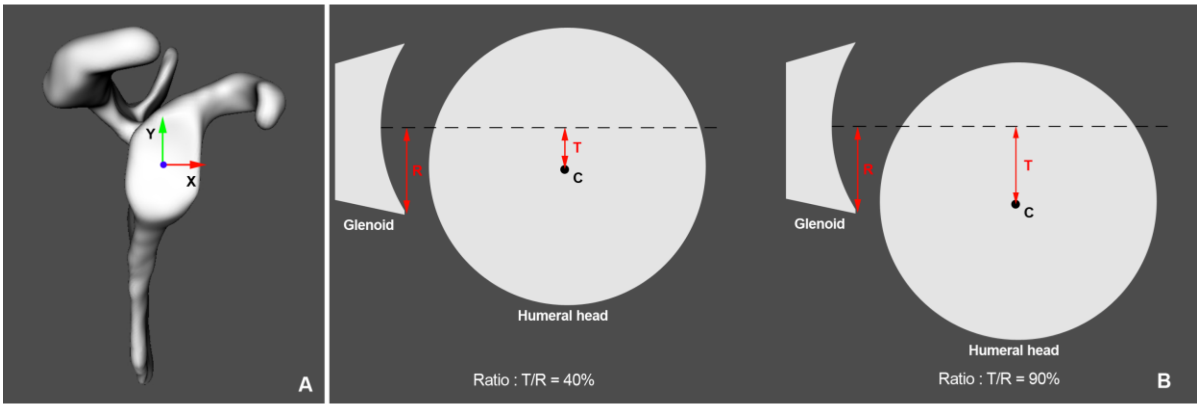

Figure 5: (A) Definition of the glenoid coordinate system used in this study. (B) Schematic representation of glenohumeral subluxation (C = center of the humeral head; R = radius of the width or height of the glenoid surface; T = translation of the humeral head center). Left: the ratio is 40%, there is no instability. Right: the ratio is >50%, instability is noted.

Given the thickness of the potential impinged tissues, impingement was considered when the computed distance was <6 mm for the humero-acromial distance and <5 mm for the other distances, as suggested in previous studies.[23-25]

For the three trials of flexion, abduction and internal-external rotation movements, we computed the mean values and the standard deviations (SD) of the ROM at the maximal range of motion. For all critical tennis positions, we calculated the frequency of impingement and the mean and SD of the minimum humero-acromial, humero-coracoid and humero-glenoid distances. We also computed the percentage of subluxation at the different stages of serve. Finally, we analyzed glenohumeral translations at the different elevation angles during flexion and abduction movements.

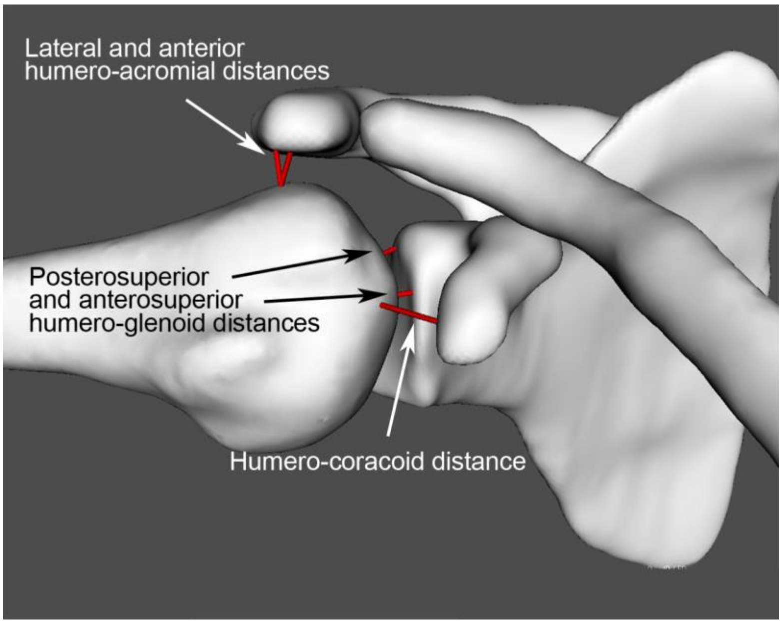

Figure 6: Visualization of the humero-acromial, humero-coracoid and humero-glenoid distances during motion. The red lines represent the minimum distances.

RESULTS

The ten volunteers, nine male and one female, had all been playing tennis for more than 17 years. The mean ± SD age, weight, height and body mass index of the subjects were 39.7 ± 8.9 years, 180.2 ± 7.1 cm, 76.7 ± 8.62 kg, and 23.5 ± 1.9 kg/m^2, respectively. Nine volunteers were right-handed.

None of the tennis players displayed sudden loss of serving ability during the late cocking stage (so-called “dead arm”). All subjects had a competent rotator cuff. The mean Constant, ASES, SANE and VAS pain scores were 99.2 ± 1.4 points (range, 96 to 100 points), 99.5 ± 1.6 points (range, 95 to 100 points), 95.0 ± 7.5 points (range, 80 to 100 points) and 0.6 ± 1.3 points (range, 0 to 4 points), respectively. Only 2 of the 10 subjects reported shoulder pain at the time of the examination. Nine had a history of shoulder pain during their career. Shoulder ROM determined by motion capture during clinical motor tasks are shown in Table 2. None of the tennis players had 180° ROM in internal-external rotation.

MR images revealed 11 rotator cuff lesions in six subjects (three interstitial tears of the supraspinatus and PASTA tears in three supraspinatus, three infraspinatus and two subscapularis tendons), and 6 labral lesions in five subjects (two inferior, two posterior and two posterosuperior). There was no radiographic evidence of Bennett lesions, thrower's exostosis, intraosseous cysts or Bankart lesions.

The type and prevalence of impingement and the bony distances are summarized in Table 3. No subcoracoid impingement was detected during the late follow-through phase of forehand or the backhand preparation phase, but anterosuperior impingement was observed in two subjects during forehand (29% of the cases). Anterior and lateral subacromial impingement occurred during the late cocking stage of serve in three and four subjects, respectively. Posterosuperior impingement during the late cocking stage of serve was the most frequent (seven subjects, 75% of the cases). In this position, glenohumeral translation was anterior (flat serve, mean: 34%; kick serve, mean: 34%) and superior (flat serve, mean: 12%; kick serve, mean: 13%), as shown in Table 4. During the deceleration stage of serve, anterior and superior translation varied from 8% to 57% and from 5% to 34%, respectively. During the finish stage of serve, anterior translation was slightly more intense (flat serve, mean: 46%; kick serve, mean: 42%), while superior translation remained low (flat serve, mean: 3%; kick serve, mean: 0%). There was no static posterosuperior shift of glenohumeral contact point.

During abduction, superior translation of the humeral head in relation to the glenoid was observed until 65°, followed by an inferior translation beyond this amplitude (Figure 7). Consequently, the lateral and anterior subacromial spaces decreased until 65° and then increased progressively. At rest, the humeral head was slightly anteriorly translated. When flexion began, posterior translation was noted until 70° followed by a return to a more anterior translation (Figure 8). There was no posterior subluxation at any degree of flexion.

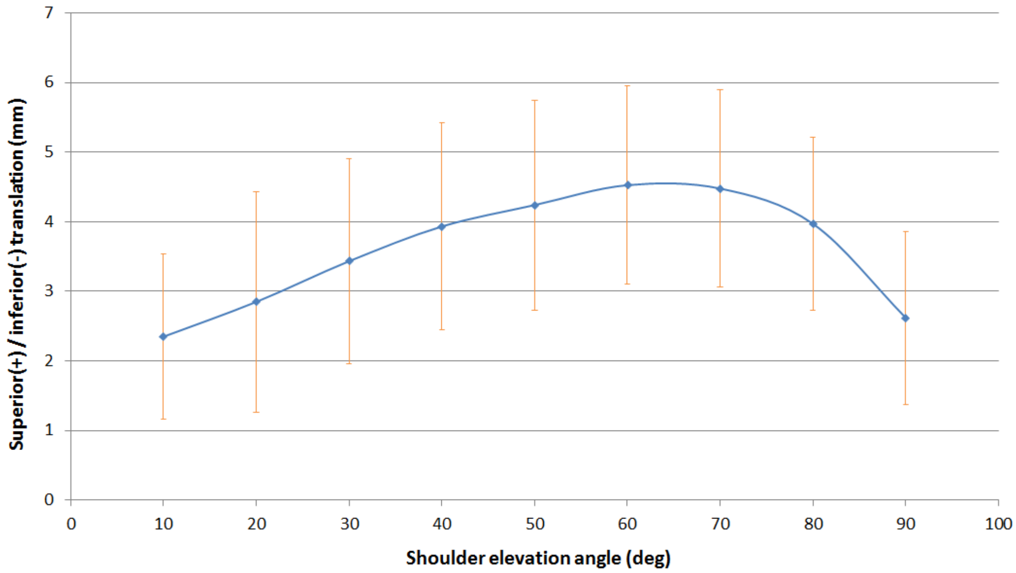

Figure 7: Superior-inferior translations of the humeral head center relative to the glenoid during abduction. Means and standard deviations for all 10 shoulders.

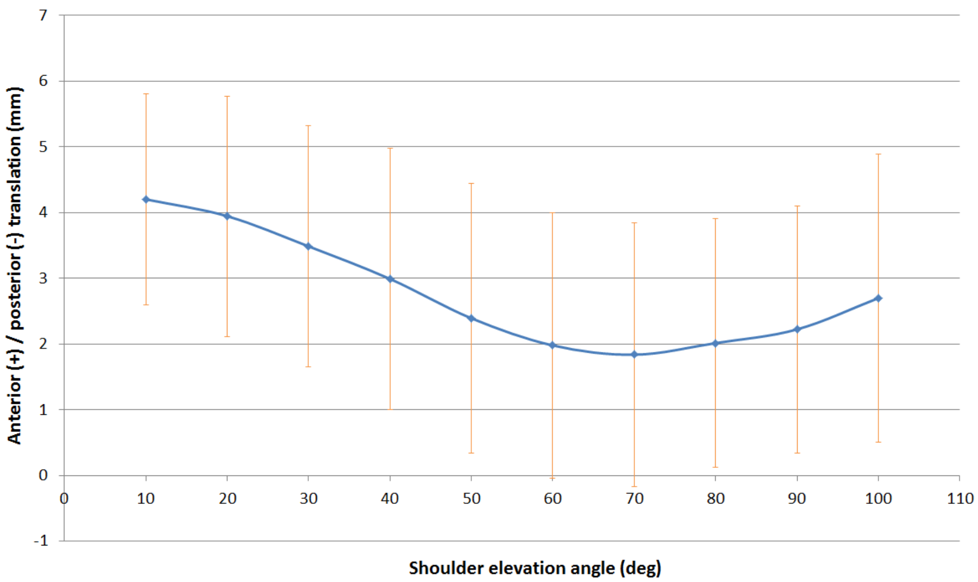

Figure 8: Anterior-posterior translations of the humeral head center relative to the glenoid during flexion. Means and standard deviations for all 10 shoulders.

Also, based on the visual assessment of the 3D simulations, we noticed in six subjects that the arm in abduction was beyond the scapular plane during the cocking stage of serve, resulting in hyperextension.

DISCUSSION

Shoulder pain and pathologic lesions are common in overhead athletes. In the present study, 9 of 10 tennis players presented with radiographic signs of structural lesions that could be related to impingement syndrome that occurred with overhead arm movements. However, the precise causes for these lesions remain unclear. It might result from several factors (e.g., repetitive contact, subtle glenohumeral instability, torsional overload with repetitive hypertwisting, scapular orientation and dyskinesis, etc.). The theory of internal impingement in these athletes, which occurs with the arm in the cocked position of 90° abduction, full external rotation and extension,[26] holds that repeated contact between the rotator cuff insertion and the posterosuperior glenoid rim lead to articular-sided partial thickness rotator cuff tears and superior labral lesions.[5,26] If the contact is physiologic, repetitive contact applied at a rate exceeding tissue repair or torsional and shear stresses[9] may be responsible for rotator cuff or labral damages.

This article evaluated dynamically and in-vivo the different aforementioned causes of lesions in tennis players. As shown by the results of this study, anterosuperior and subacromial impingement remain occasional in this particular population. No shoulder instability could be noted during tennis movements. However, posterosuperior impingement was frequent when serving. Thus, as expected, this shot seems to be the most harmful for the tennis player’s shoulder. Regarding this type of impingement, repetitive contact could be the cause of posterior and posterosuperior labral lesions, as well as PASTA lesions of the posterosuperior cuff.[5,27] Indeed, we were not able, as other authors,[28] to confirm the role in the impingement development from other culprits like (1) static posterosuperior shifts of glenohumeral contact point leading to torsional overload,[9] or (2) instability due to gradual repetitive stretching of the anterior capsuloligamentous structures.[8,26] Nevertheless, this could be explained by the fact that there are many kinds of overhead athletes, and tennis players do not have the same external rotation in abduction and arm speed as do, for example, throwers which have previously been studied. In addition, this could also reflect the efficiency of injury prevention programs that have been established in many tennis clubs (e.g. promotion of compact serve).

Concerning subacromial impingement during abduction, superior translation of the humeral head in relation to the glenoid was observed, followed by inferior translation beyond 65°. Such superior and inferior translation confirms previous observations.[20,29] Consequently, subacromial space decreased until 65° and then increased progressively. Anterior[2] and lateral[3] impingement could hence occur at the beginning of abduction and not at or above 90° like previously believed.[30]

Regarding motion of the glenohumeral joint, the range in internal and external rotation should remain constant between the dominant and the non-dominant arm, with a shift in the external rotation sector of the dominant arm in overhead throwers.[9] We could not confirm the 180° rotation rule in tennis players, as the mean values of the ROM computed in this study were approximately two times smaller than similar measurements found in handball players.[31] We are, therefore, not convinced that a contracted posterior band, evoking the posterior cable to shorten with resultant GIRD, is a theory that can be extrapolated in tennis players. This theory might be specific to baseball players.

Finally, we also evaluated posterior humeral head translation in relation to the glenoid during flexion. An hypothesis of the development of posterior static subluxation described by Walch et al.[32] could be posterior subluxation during normal anterior elevation. At rest, the humeral head was slightly anteriorly translated. When forward flexion began, slight posterior translation was noted until 70° followed by a return to a more anterior translation. There was no posterior subluxation at any degree of flexion. Therefore, since no dynamic or physiologic posterior instability was observed, it is probably not responsible (at term) for static instability in these subjects without hyperlaxity.

We acknowledge the following limitations in our study: (1) the accuracy of the kinematics computation from motion capture data, which was only validated for low velocity movements. Glenohumeral orientation errors were within 4° for each anatomical plane, which is acceptable for clinical use in the study of shoulder pathology. There is potential for difficulty in the calculation of glenohumeral translation from skin markers due to the high mobility of the shoulder. Although the translations could be significant with our model, we demonstrated in the validation work and in this study that the computed translation patterns and amplitudes were in good agreement with published data. To our knowledge, this non-invasive method is the first attempt to calculate both rotations and translations at the glenohumeral joint based on skin markers. (2) The use of bone-to-bone distances to assess impingement which do not take into account precise measurements of the thickness of the impinged soft tissues. One improvement could be to perform a more advanced simulation accounting for the 3D shapes and movements of cartilages, the labrum and the rotator cuff. (3) The findings may not be generalizable. This was a relatively small sample size of primary males in a single sport and skill level, with a narrow age range. (4) The use of 1.5 T MRI, as stronger magnet strengths would enhance image resolution. Moreover, MRI is not a gold standard to demonstrate bony changes. This study may hence underestimate bony lesions such as Bennett exostosis, and (5) as volunteers were not known for any pathology, a criticism could be to have tested healthy players that would prevent extrapolation of results to complaining patients. However, 9 out of the 10 volunteers reported previous symptoms, so we think that they were a good representation. Despite these limitations, we do believe that they did not call into question the results of this study.

CONCLUSION

Tennis players presented frequent radiographic signs of structural lesions that could mainly be related to posterosuperior impingements due to repetitive abnormal motion contacts. This is the first study demonstrating that a dynamic and precise motion analysis of the entire kinematic chain of the shoulder is possible through a non-invasive method of investigation. This premier observation offers novel insights into the analysis of shoulder impingement and instability that could, with future studies, be generalized to other shoulder pathologies and sports. This original method may open new horizons leading to improvement in impingement comprehension.

Practical implications

- Anterior and lateral subacromial and posterosuperior impingements are frequent in overhead athletes.
- Repetitive contact in extreme abduction, extension and external rotation could be the cause of posterior and posterosuperior labral lesions, as well as PASTA lesions of the posterosuperior cuff.
- Coaches and medical staff should consider promotion of compact serve.

- This study has highlighted the benefits of a non-invasive, dynamic and in-vivo evaluation of shoulder pathologies.

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TABLES

TABLE 1

MRI sequences and their imaging parameters

MRI Sequence	Imaging Parameters
Sagittal T1 weighted fast spin echo without fat saturation	Section thickness 3.5 cm; intersection gap 0.5 cm TR/TE 380/11; FOV 16 x 16 cm
Coronal T2 weighted fast spin echo with fat saturation	Section thickness 4 mm; intersection gap 0.5 cm TR/TE 1920/101,6; FOV 16 x 16cm
Sagittal T2 weighted fast spin echo with fat saturation	Section thickness 3.5 cm; intersection gap 0.5 cm TR/TE 5680/103.5; FOV 16 x 16cm
Coronal T1 weighted fast spin echo with fat saturation	Section thickness 4 mm; intersection gap 0.5 cm TR/TE 320/13; FOV 16 x 16cm
Axial T1 weighted fast spin echo with fat saturation	Section thickness 4 mm; intersection gap 0.5 cm TR/TE 640/26,8; FOV 16 x 16 cm
Axial Cosmic® 3D fast gradient echo with fat saturation	Section thickness 1.8 mm; no intersection gap; TR/TE 6.1/3.0; FOV 28 x 28cm
Axial Cosmic® 3D fast gradient echo without fat saturation	Section thickness 4 mm; no intersection gap; TR/TE 5.7/2.8; FOV 28 x 28cm
Axial Lava® 3D fast gradient echo with fat saturation	Section thickness 5.2 mm; no intersection gap; TR/TE 3.7/1.7; FOV 35 x 35cm

TABLE 2

Shoulder range of motion (deg) determined by motion capture during flexion, empty-can abduction and internal-external rotation with 90° abduction according to the two referentials (n = 30; 10 subjects, 3 trials)

Motion	Humerus motion relative to the thorax		Glenohumeral motion	
	Mean ± SD	Range	Mean ± SD	Range
Flexion	144.8 ± 8.0	125 - 157	98.7 ± 9.7	83 - 116
Abduction	139.4 ± 10.9	119 - 161	88.8 ± 11.8	65 - 108
Internal rotation (IR)	44.0 ± 9.8	30 - 70	22.3 ± 11.1	11 - 45
External rotation (ER)	52.6 ± 10.8	36 - 77	58.6 ± 10.3	43 - 79
Total IR-ER	96.6 ± 17.5	74 - 147	80.8 ± 14.9	60 - 107

TABLE 3

Frequency of impingement and minimum humero-acromial, humero-coracoid and humero-glenoid distances (mm) at critical tennis positions (n = 30; 10 subjects, 3 trials)

Distances	Flat serve	Kick serve	Forehand	Backhand
	Frequency Mean ± SD	Frequency Mean ± SD	Frequency Mean ± SD	Frequency Mean ± SD
Lateral humero-acromial	29% 7.5 ± 3.2	42% 6.8 ± 3.7	-	-
Anterior humero-acromial	29% 7.4 ± 2.9	29% 7.0 ± 3.1	-	-
Humero-coracoid	-	-	0% 15.9 ± 1.6	0% 15.0 ± 2.7
Anterosuperior humero-glenoid	-	-	29% 5.5 ± 1.2	0% 6.9 ± 1.3
Posterosuperior humero-glenoid	76% 3.6 ± 1.4	75% 3.3 ± 1.8	-	-

TABLE 4

Pourcentage of subluxation of the glenohumeral joint during tennis serves (n = 30; 10 subjects, 3 trials)

Shot, position	Anterior-posterior subluxation*		Superior-inferior subluxation†	
	Mean ± SD	Range	Mean ± SD	Range
Flat serve, late cocking stage	34% ± 9%	14% - 47%	12% ± 6%	-1% - 21%
Kick serve, late cocking stage	34% ± 6%	22% - 44%	13% ± 9%	0% - 32%
Flat serve, deceleration stage	34% ± 14%	8% - 57%	18% ± 7%	8% - 34%
Kick serve, deceleration stage	37% ± 9%	20% - 56%	19% ± 7%	5% - 32%
Flat serve, finish stage	46% ± 15%	18% - 68%	3% ± 5%	-5% - 14%
Kick serve, finish stage	42% ± 13%	17% - 67%	10% ± 8%	0% - 30%

* A positive value means that the subluxation is anterior, otherwise it is posterior.

† A positive value means that the subluxation is superior, otherwise it is inferior.