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Three-dimensional glenohumeral arthrokinematics related to internal impingement in throwing athletes: Communication on six clinical cases

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ORIGINAL ARTICLE

Three-dimensional glenohumeral arthrokinematics related to internal impingement in throwing athletes: Communication on six clinical cases

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Abstract

The aim of this study was to undertake a comparative arthrokinematic evaluation of the shoulder of throwers with internal impingement. The participants were six throwing athletes with internal impingement type I. The intra-articular position of the humeral head on the glenoid in the apprehension test pose was evaluated using three-dimensional reconstructions obtained on medical images. Glenohumeral internal rotation deficit, external rotation gain, and the difference in posterior shoulder tightness were assessed goniometrically. No abnormal translation behaviour of the humeral head on the glenoid could be demonstrated, with a posterior positioning of the humeral head in relation to the centre of the glenoid of -6.6 ± 0.9 mm and a superior positioning of $+2.3 \pm 1.5$ mm, despite the presence of a glenohumeral internal rotation deficit between the throwing shoulder and the contralateral shoulder of $-26.3 \pm 7.2°$ and a difference in posterior shoulder tightness of -6.7 ± 2.9 cm. In conclusion, the results do not support the biomechanically based hypotheses relating internal impingement at the end of the late preparatory phase of throwing with an increased posterior-superior or anterior-inferior glenohumeral translation. Instead, the results favour a physiological cause of symptomatic internal impingement.

Keywords: *Internal impingement, arthrokinematics, shoulder, throwing*

Introduction

At the end of the late preparatory phase of throwing, throwing athletes may present posterior shoulder pain due to overload impingement between the greater tubercle and the posterior aspect of the humeral head with the posterior-superior glenoid. Using arthroscopy and MRI arthrography in these throwing athletes, below-surface lesions have been identified on the posterior aspect of the supraspinatus tendon and/or anterior portion of the infraspinatus tendon (called internal impingement) as well as posterior-superior glenoid labrum lesions (type I or II SLAP lesion) together with a thicker labrum, a shallower posterior-inferior capsular recess, and a thicker posterior-inferior capsule (Tuite et al., 2007).

Different hypotheses on the development of internal impingement in throwing athletes have been proposed. The physiological hypothesis relates the lesions of the rotator cuff, labrum, and well-innervated joint capsule to repetitive pinching of these structures between the greater tuberosity and the glenoid rim during the throwing motion, which leads to fraying and subsequently tears (Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). In the more biomechanically oriented hypothesis, a number of authors link symptomatic internal impingement to glenohumeral anterior-inferior subluxation (Davidson, Elattrache, & Jobe, 1995; Edelson & Teitz, 2000; Jobe, 1995; McFarland, Hsu, Neira, & O'Neil, 1999; Paley, Jobe, & Pink, 2000). In this context, Jobe (1995) postulated an anterior-inferior migration of the humeral head on the glenoid at late cocking due to an overstretched anterior-inferior capsuloligamentous complex. On

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the other hand, Myers et al. (2006) found that glenohumeral internal rotation deficit and posterior shoulder tightness, typically present in throwing athletes (Crockett, Gross, & Wilk, 2002), were significantly enhanced in throwers with internal impingement. Burkhart and colleagues (Burkhart, Morgan, & Kibler, 2003) postulated a link between internal impingement and glenohumeral internal rotation deficit. These authors stated that the throwing athlete first develops a tight posterior inferior capsule that shifts the glenohumeral fulcrum in the posterior-superior direction in the late preparatory position. As the shoulder rotates externally around the new fulcrum point, an increased contact of the rotator cuff and posterior labrum is observed (Jazrawi, McCluskey, & Andrews, 2003). These changes intensify what otherwise would be gentle pinching of the labrum, cuff, and joint capsule between the greater tuberosity and glenoid rim, as well as causing twisting shear stress tears of the posterior cuff and labrum. In the theory of Burkhart, the shift of the humeral head on the glenoid is posterior-superior.

The debate about the potential causes of internal impingement revolves around the role of glenohumeral translation (i.e. anterior-inferior vs. posterior-superior). The aim of the current study was to compare the three-dimensional arthrokinematics of elite throwing athletes demonstrating "borderline" internal impingement with previously obtained and published results in asymptomatic and minimal anterior unstable shoulders of a similar population (Baeyens, Van Roy, & De Schepper, 2001; Harryman, Sidles, & Clark, 1990).

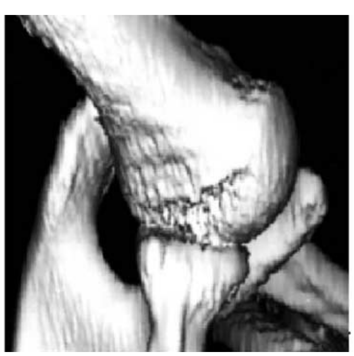
Methods

Participants

Six elite male handball players volunteered for this study (age 26.3 ± 3.7 years, height 1.90 ± 0.05 m, mass 90.3 ± 4.3kg). The participants were 1st league handball players with posterior shoulder pain at the end of the late preparatory phase of throwing that had evolved progressively in the 3 months before clinical examination. Symptoms presented occasionally during strenuous (i.e. high loading) training or during competition. Internal impingement was clinically diagnosed and confirmed by a magnetic resonance gadolinium arthrogram, which demonstrated isolated type I internal fraying of the rotator cuff. Informed written consent was obtained. The study received approval from the ethics committee of the local hospital.

Imaging

Three-dimensional (3D) translation behaviour of the humeral head on the glenoid was assessed by processing fast helical CT-scans (HiSpeed CT/I, General Electrics, USA) obtained with the shoulder passively positioned in 90° abduction and maximal external rotation, which mimics the shoulder at the end of the late preparatory phase of throwing. The helical CT-data were 3D reconstructed into skeletal configurations of the shoulder joint (Figure 1A). Clusters of humeral and scapular sets of anatomical landmark coordinates, which were measured on three consecutive occasions, were used to estimate the global attitude matrix and position vector of the humerus and scapula. The centre of the humeral head was defined as the centre of a sphere delimited by the articular part of the surface of the humeral head. The position vector of this centre of the humeral head was projected on a coordinate system embedded on the glenoid cavity. This glenoid reference frame was built on three landmarks located at the glenoid rim: two landmarks at the superior and inferior angle of the glenoid rim, one landmark in the middle of the anterior part of the glenoid rim. The origin of the glenoid frame was the midpoint between the superior and inferior landmark on the glenoid.

(A)


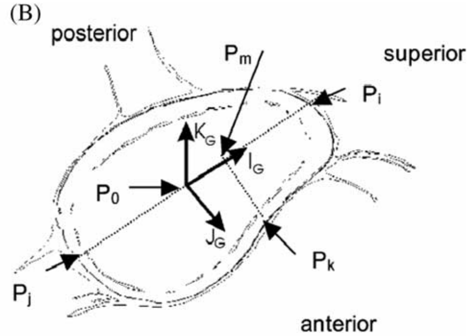
(B)


Figure 1. A 3D reconstruction of the glenohumeral joint in the apprehension test position embedded coordinate system on the glenoid surface with centre P_0 (midpoint between the superior, P_i, and inferior, P_j, angle point on the glenoid rim, i.e. $P_0 = (P_i + P_j)/2$), a superiorly (+) directed Y axis (with unit vector $I_G = (P_i - P_j)/|P_i - P_j|$), a laterally (+) directed Z-axis (with unit vector $K_G = ((P_k - P_0) \times I_G)/ |((P_k - P_0) \times IG)|$), and an anteriorly (+) directed X-axis (with unit vector $J_G = I_G \times K_G$).

The embedded axes were a (positive) superiorly directed Y-axis through the superior and inferior landmarks, a (positive) anteriorly directed X-axis perpendicular to the Y-axis and passing through the anterior landmark, and a (positive) laterally directed Z-axis as the vector product between the X and Y axis (Figure 1B). An error sensitivity analysis revealed that the mean of the error on the detection of the landmarks was 0.37 ± 0.02 mm per coordinate and that the mean of the interpositional differences of the distances between the landmarks was 0.91 ± 0.70 mm (Baeyens et al., 2001)

Range of motion

Goniometric range of motion assessments of external and internal shoulder rotation were based on the descriptions of Norkin and White (2003). Participants lay supine with the shoulder in 90° of abduction and the elbow in 90° flexion, the humerus supported by a towel to level the humerus with the acromial process. External and internal rotation were measured with scapular movement allowed. Three measurements were taken bilaterally and averaged for each limb. External rotation gain was calculated as the difference in measured external rotation between the throwing and contralateral shoulder. Glenohumeral internal rotation deficit was defined as the difference in measured internal rotation between the throwing and contralateral shoulder.

To measure posterior shoulder tightness, the technique described by Tyler and colleagues (Tyler, Nicholas, & Roy, 2000) was used. The participant was positioned on the non-tested side, with both the hips and knees in 90° of flexion, the non-testing arm positioned under the participant's head. A small mark was placed on the medial epicondyle of the arm to be tested. The participant's acromion was aligned perpendicular to the treatment table with the spine in the neutral position. Facing the participant, the experimenter restricted scapular movement by stabilizing the lateral border of the scapula in the retracted position and the participant's humerus at 90° of shoulder abduction and 0° of humeral rotation. The experimenter then passively lowered the arm into horizontal adduction while maintaining neutral humeral rotation and scapular stabilization. Full horizontal adduction was measured at the initiation of scapular motion as the distance between the mark on the medial epicondyle and the surface of the treatment table. Three measurements were taken bilaterally and averaged for each shoulder. Difference in posterior shoulder tightness was calculated as the difference in the measured horizontal adduction between the throwing and contralateral shoulder.

To compare our data with reference data from the literature obtained with the same measurement procedures, two-sample independent *t*-tests were performed after checking the assumptions of normal distribution. Statistical significance was set at $P < 0.05$.

Results

The raw data and descriptive statistics relating to the different variables are presented in Table I.

For the throwers with internal impingement in this study, the 3D medical imaging evaluation of the position of the humeral head on the glenoid gave the following results.

- In the apprehension test position, the centre of the humeral head, with reference to the centre of the embedded coordinate system on the glenoid, was located along the anterior (+)/ posterior (−) axis of the glenoid in a posterior position of -6.6 ± 0.9 mm.
- In the apprehension test position, the centre of the humeral head, with reference to the centre of the embedded coordinate system on the glenoid, was located along the superior (+)/ inferior (−) axis of the glenoid in a superior position of $+2.3 \pm 1.5$ mm.

The goniometric evaluation of the range of motion of the shoulder revealed the following findings:

- With glenohumeral internal rotation deficit (GIRD) defined as the difference in measured internal rotation between the throwing and contralateral shoulder, the participants presented a mean GIRD value of $-26.3 \pm 7.2°$.
- The participants presented a difference in posterior shoulder tightness between the throwing and contralateral shoulder of -6.7 ± 2.9 cm.
- The external rotation gain of the throwing shoulder in terms of the contralateral shoulder was $+19.0 \pm 5.8°$.

Discussion

In the asymptomatic throwing shoulders of handball players, the centre of the humeral head in the apprehension test pose is posteriorly and superiorly positioned on the glenoid (Baeyens et al., 2001; Harryman et al., 1990). With reference to the centre of the glenoid, the magnitude involved is -7.5 ± 1.0 mm posteriorly and $+2.0 \pm 1.6$ mm superiorly (Baeyens et al., 2001). With reference to the centre of the glenoid, the internal impingers in this study presented with a posterior positioning of the humeral head on the glenoid of -6.6 ± 0.9 mm and a superior positioning of $+2.3 \pm 1.5$ mm. Statistical testing revealed no difference ($P < 0.05$) between our data and the data presented in the literature. Hence, using the same measurement procedure, this study demonstrated no differences in superior and posterior positioning of the centre of the humeral head in the late cocking pose between the throwing athletes with internal impingement and the data published on asymptomatic throwing athletes.

In minimal anterior instabilities, the centre of the humeral head has been demonstrated to remain relatively centred on the glenoid (Baeyens et al., 2001; Harryman et al., 1990). As such, for the

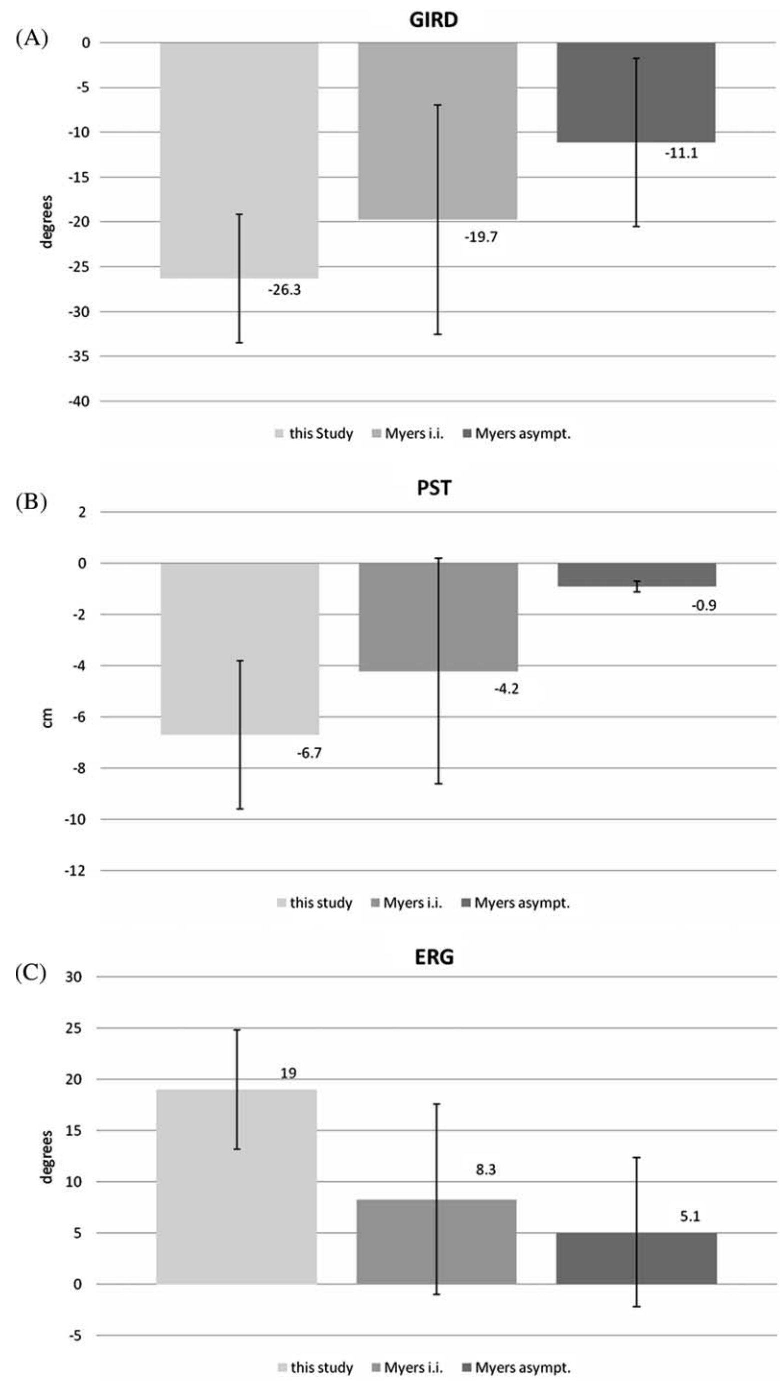


Figure 2. Goniometric data (mean ± s) for (A) glenohumeral internal rotation deficit (GIRD, the difference in measured internal rotation between the throwing and contralateral shoulder, in degrees); (B) Δposterior shoulder tightness (ΔPST, the difference in measured horizontal adduction between the throwing and contralateral shoulder, in cm); and (C) external rotation gain (ERG, the difference in measured external rotation between the throwing and contralateral shoulder, in degrees) between the asymptomatic throwers (Myers asympt.) and throwers with internal impingement (Myers i.i.) in Myers and colleagues' (2006) study and our data for throwers with internal impingement (this study).

Table I. Individual data on the handball players with internal impingement (n = *6)*

	Posterior position (mm)	Superior position (mm)	ΔPosterior shoulder tightness (cm)	GIRD (°)	External rotation gain (°)
Player 1	−5.2	1.3	−8.8	−36	16
Player 2	−6.3	2.1	−2.7	−18	11
Player 3	−7.7	0.4	−6.8	−32	17
Player 4	−6.8	4.2	−3.6	−19	27
Player 5	−7.4	3.6	−7.9	−27	24
Player 6	−6.2	3.9	−10.2	−26	19
Descriptive statistics					
Minimum	−7.7	0.4	−10.2	−36	11
Maximum	−5.2	4.2	−2.7	−18	27
Mean	−6.6	2.6	−6.7	−26.3	19.0
s	0.9	1.5	2.9	7.2	5.8

Note: posterior position = posterior (−) position in the apprehension test pose of the centre of the humeral head relative to the centre of the glenoid cavity (mm); Inferior position = superior (+)/inferior (−) position in the apprehension test pose of the centre of the humeral head relative to the centre of the glenoid cavity (mm); Δposterior shoulder tightness (cm) = the difference in measured horizontal adduction between the throwing and contralateral shoulder; GIRD = glenohumeral internal rotation deficit (degrees), or the difference in measured internal rotation between the throwing and contralateral shoulder; and external rotation gain (degrees) = the difference in measured external rotation between the throwing and contralateral shoulder.

internal impingers investigated in this study, no abnormal glenohumeral translation behaviour could be demonstrated, which could be related to a dysfunction of the anterior part of the inferior glenohumeral ligamentous complex. This finding is supported by the clinical findings of internal impingement without anterior instability (Sonnery-Cottet, Edwards, Noel, & Walch, 2002). These findings do not support the hypothesis initially presented by Jobe (1995), which uniquely relates internal impingement to anterior-inferior subluxation of the humeral head on the glenoid in the late preparatory phase of throwing. However, this does not mean that anterior instability cannot be an aggravating factor or even single cause within the development of internal impingement. These findings show that internal impingement can evolve without anterior instability. In other words, the data relate to internal impingers without anterior instability. Whether anterior instability may induce such an anterior-inferior humeral head translation causing or aggravating internal impingement cannot be excluded. However, it should be noted that several authors have contended that patients with significant anterior subluxation are actually protected against internal impingement. They point out that the positioning of the humerus relative to the glenoid in instability precludes impingement between the greater tuberosity and posterior-superior glenoid (Davidson et al., 1995; Halbrecht, Tirman, & Atkin, 1999; Jobe, 1995; Walch, Boileau, & Noel, 1992).

Grossman et al. (2005) used a cadaver model that mimicked the shoulder position in the late preparatory phase of throwing to demonstrate that posterior shoulder tightness with glenohumeral internal rotation deficit does not allow the humerus to rotate externally into its normal posterior-inferior position but moves posterior-superiorly. Previously, Burkhart et al. (2003) linked a tight posterior inferior capsule with a shift of the centre of the humeral head posterior-superiorly in the late preparatory phase, leading to an increased contact of the rotator cuff and posterior labrum (Jazrawi et al., 2003). Using the same goniometric measurement methods as in the current study, Myers et al. (2006) demonstrated that throwing athletes with internal impingement presented a significantly ($P < 0.05$) greater glenohumeral internal rotation deficit and posterior shoulder tightness ($-19.7 \pm 12.8°$ and -4.2 ± 4.4 cm, respectively) than asymptomatic throwing athletes ($-11.1 \pm 9.4°$ and -0.9 ± 0.2 cm, respectively). In the current study, the internal impingers presented a mean glenohumeral internal rotation deficit of $-26.3 \pm 7.2°$ and a posterior shoulder tightness of -6.7 ± 2.9 cm. Using the same measurement procedure, we found no significant differences in glenohumeral internal rotation deficit or posterior shoulder tightness compared with the internal impingers in Myers and colleagues' (2006) study. And like Myers et al., our data revealed significant differences ($P < 0.05$) in glenohumeral internal rotation deficit and posterior shoulder tightness compared with their asymptomatic throwers. Despite this apparent increase in glenohumeral internal rotation deficit and posterior shoulder tightness for the internal impingers in our study, no difference in posterior or superior positioning of the humeral head on the glenoid was observed between the internal impingers and the asymptomatic throwing shoulders. As such, the data in our study do not support Burkhart and colleagues' (2003) hypothesis.

Myers et al. (2006) observed no significant differences in external rotation gain between the throwers with internal impingement and asymptomatic throwers ($+8.3 \pm 9.2^\circ$ vs. $+5.1 \pm 5.3^\circ$, $P = 0.16$). In the current study, the internal impingers presented an external rotation gain of $19.0 \pm 5.8^\circ$. This external rotation gain was significantly ($P < 0.05$) different from that of the asymptomatic throwers in Myers and colleagues' (2006) study. Furthermore, statistical analysis also revealed the external rotation gain in our sample of throwers with internal impingement to be significantly different ($P < 0.05$) from that of the internal impingers group in Myers and colleagues' study. This finding makes increased external rotation gain a possible aggravating factor within the development of internal impingement in throwers.

Furthermore, Laudner and colleagues (Laudner, Myers, & Pasquale, 2006) demonstrated that throwers with internal impingement exhibit significantly increased sternoclavicular elevation during humeral elevation from 30° to 120°, an increased posterior scapular tilt position, and a more protracted scapula. Whether this compounds the internal impingement remains unclear.

Our results are similar to those of Myer and colleagues' (2006) sample of throwers with internal impingement in terms of glenohumeral internal rotation deficit and posterior shoulder tightness. However, compared with asymptomatic throwing shoulders, no significant differences for the internal impingers in our study were observed regarding superior-posterior or inferior-anterior positioning of the humeral head on the glenoid cavity in the apprehension test position. As such, our data demonstrate the possible occurrence of internal impingement in throwers without the presentation of anterior instability, whereas glenohumeral internal rotation deficit and posterior shoulder tightness were related to internal impingement but not with the hypothesized causal cascade point of view.

Our data favour the physiological hypothesis, which relates the lesions of the rotator cuff, labrum, and well-innervated joint capsule to repetitive pinching of these structures between the greater tuberosity and the glenoid rim during the throwing motion, which leads to fraying and subsequently tears (Myers et al., 2006). Furthermore, cadaver, MRI, and arthroscopic studies have consistently shown that contact of the rotator cuff on the posterior-superior labrum is a normal physiological occurrence (Burkhart, 2006; Burkhart et al., 2003; Edelson & Teitz, 2000; Halbrecht et al., 1999; McFarland et al., 1999). This non-pathologic interposition of the rotator cuff and posterior-superior labrum between the glenoid rim and greater tuberosity, which occurs in throwers and non-throwers alike, has become a well-accepted concept. As such, the answers behind internal impingement as a pathologic condition should be considered in the light of a dysbalance in proprioception with enhanced or decreased muscle force production (Veeger & van der Helm, 2007) and increased loading frequency that is observed in some throwing athletes together with the intrinsic physiological threshold of the supraspinatus/infraspinatus and labrum. Research is required into muscle coordination, strength profiles, and joint reaction forces/joint moments in the shoulder of the throwing athlete that evolves into a cascade of overload.

Conclusion

The findings of the present study do not support the hypothesis of a superior-posterior or anterior-inferior migration of the humeral head on the glenoid causing internal impingement. Instead, the results favour the physiologically oriented hypothesis relating internal impingement to repetitive pinching and progressive overload, which leads to fraying, tears, and pain without actual intra-articular arthrokinematic differences. On the other hand, the results reveal the possibility of external rotation gain as an aggravating factor in the development of internal impingement in throwers. More research in this area is needed.

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