THREE-DIMENSIONAL ARTHROKINEMATIC ANALYSIS OF THE LATE PREPARATORY PHASE OF HANDBALL THROWING

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INTRODUCTION: Dysfunction of the glenohumeral joint in the full cocking phase of throwing is commonly found in handball players. The appending symptoms are related to anterior instability and/or internal impingement. It can be questioned to what extent occult or minor anterior instability and internal impingement are associated with improper intra-articular kinematics. In this context, axillary radiography has been used to examine the in vivo translation of the humeral head on the glenoid in the apprehension test position in subjects with normal shoulders, as well as in those with recurrent anterior dislocations before and after surgical repair and postoperative rehabilitation.[3, 5] However, the complex 3D motion pattern of the shoulder girdle makes 2D recordings susceptible to projection errors. On the other hand, 3D motion recording of the shoulder girdle is hampered by large bone to skin displacements, making skin-attached markers unreliable to record clavicular or scapular motions. Alternatively, 3D Euler/Cardanic rotations during shoulder elevation have been reliably recorded by the introduction of roentgenstereo-photogrammetry after implantation of tantalium markers in the bones,[2] 3D linkage systems[7] or electromagnetic devices.[1] MRI has been used to demonstrate glenohumeral relationships in asymptomatic volunteers during internal and external rotation of the arm.[6] However, an in vivo 3D intra-articular kinematical analysis of the shoulder joint has not been published as yet. This paper presents the error sensitivity analysis of an in vivo 3D intra-articular kinematics approach based on medical imaging and the finite helical axis concept. Using this methodology, the first clinical data of this kind are presented on the late preparatory phase of handball throwing in 2 minor anterior unstable shoulders and 1 internal impinger, as compared to 3 non-symptomatic handball players.

METHODS AND MATERIALS:

Step 1: CT data acquisition and 3D reconstruction. Helical CT scanning provided the medical imaging data for 3D reconstruction of the bony configurations of the shoulder joint, threshold around 160 Hounsfield units (Fig. 1). In order to minimize, in a 512x512 matrix, the image pixel size to 0.5 mm, the maximum display field of view was limited to 25 cm. This medical imaging data was acquired in a step-by-step procedure, starting from a standardized pose with the shoulder in 90° abduction and 90° external rotation (Pose 2). Pose 1 aimed at the shoulder in 90° abduction and neutral rotation. From a clinical point of view, full cocking was assessed on an individual basis in pose 3.

Step 2: Primary kinematical analysis. Based on the distribution of the anatomical landmarks, primary joint kinematical analysis was assessed by means of Veldpaus et al.'s approach[8]. The estimates of the rotation matrix and the translation vector were made clinically accessible by use of the finite helical axis parameters (shift **t**,

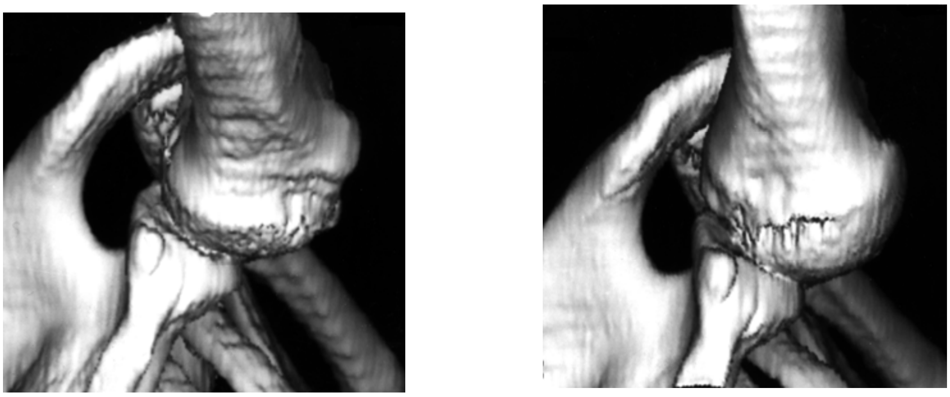

Fig. 1 3D bone reconstruction: anterior-inferior views of the glenohumeral relationships in poses 1 and 3 (normal test case)

rotation angle θ, direction vector **n** and position vector **s**). Summarized for the glenohumeral analysis, measurement error distribution was isotropic with an accuracy of 0.37±0.02 mm per coordinate. The positive scalar │1-s│ from the estimated matrix sR (s>0, $R^TR=\mathbf{I}$) had a value of 6.9±1.5 pro mille. The errors in the spatial parameters were estimated using Woltring's model.[10] The estimates for the position vector demonstrated high standard deviations. Its kinematical impact was therefore assessed graphically in the finite field of relative motion, which will be discussed infra.

N=6	σ_n (°)	σ_θ (°)	σ_θ (%)	σ_t (mm)	$\sigma_{s\perp n}$ (mm)
Gh_{12}	2.60±1.13	0.39±0.10	0.8±0.5	0.38±0.12	2.70±1.17
Gh_{23}	2.08±0.82	0.46±0.10	3.7±1.4	0.55±0.24	1.79±0.98

Table 1 σ : averaged standard errors (±SD) of the estimated spatial parameters; GH_{ij} : glenohumeral, pose j related to pose i.

Step 3: Intra-articular kinematical analysis. In a further step, virtual dis-articulation of the glenohumeral joint made it possible to embed a reference frame on the articular surface of the glenoid, built on three polar landmarks providing the unity vectors: $\mathbf{I_G}$ superiorly directed, $\mathbf{J_G}$ anteriorly directed and $\mathbf{K_G}$ laterally directed (see Fig. 2). Subsequently, the relative glenohumeral finite helical axis parameters **n**, θ and **t** were decomposed on this local frame of the glenoid, with:

$$\mathbf{n} = n_I\mathbf{I_G} + n_J\mathbf{J_G} + n_K\mathbf{K_G}, \quad \theta = \theta_I\mathbf{I_G} + \theta_J\mathbf{J_G} + \theta_K\mathbf{K_G}, \quad \mathbf{t} = t_I\mathbf{I_G} + t_J\mathbf{J_G} + t_K\mathbf{K_G}.$$

θ_I was termed glenohumeral intra-articular horizontal abduction (-)/ adduction (+),θ_J abduction (-)/adduction (+), and θ_K external (+) / internal (-) rotation.
The position vector **s** was assessed in the finite field of relative motion (defined as the set of the relative finite planes of motion, perpendicularly situated about the

relative finite helical axis). In this finite field of relative motion, the articular surface profiles for the subsequent poses were detectable because the error in the estimation of the direction vector was negligibly small. Furthermore, the negligible small error in the estimation of the rotation angle legitimized its combination with a

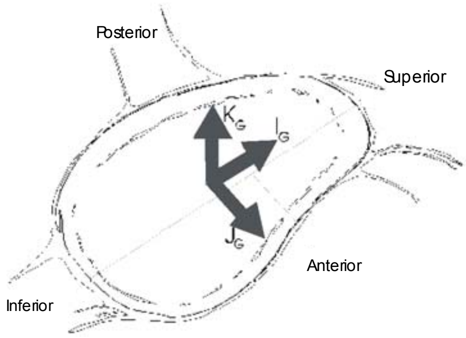

Fig. 2 Local frame embedded on the glenoid.

rigid body constraint on the humeral head's subsequent profiles, after relative rotation and shift along the relative finite helical axis. Subsequently, the position vector of the relative finite helical axis was estimated and decomposed on a technical frame oriented with its X axis parallel to the articular surface of the glenoid, centered in the center of the fitted curvature of the articular profile of the humeral head, and normalized to the radius of this curvature.

RESULTS: From position 2 to position 3, the normal shoulders did not rotate in the external/internal plane (n_{KG} -0.06±0.11° and θ_{KG} 0.71±0.68°). In contrast, a large external rotation component together with a large rotation magnitude was found in the minor unstable shoulders (n_{KG} 0.82 and 0.82; θ_{KG} 9.89° and 20.46° respectively) as well as the internal impinger. The test case with internal impingement demonstrated a higher angle of the humeral shaft with the sagittal plane of the glenoid and a smaller angle between the humeral shaft and the frontal plane, indicating an improper positioning of the scapula.

Evaluation of the position vector in the asymptomatic and internal impingement shoulders revealed that from position 2 to position 3 the relative finite helical axis was positioned off centered on the humeral head by an enlarged contribution of roll. For the minor anterior unstable shoulders an off-centered position was due to an enlarged impaction component.

The 3D displacement of the geometrical center of the humeral head on the glenoid was deduced from its measured coordinates in position 2. In the full cocking position, the humeral head of the normal and internal impingement shoulders translated into a posteriorly localized position on the glenoid (J_G -7.25±0.87mm). In contrast, the humeral head in both test cases with anterior instability translated up to a centralized position on the glenoid.

DISCUSSION: Glenohumeral anterior instability can be present in a variety of ways, ranging from a vague sense of shoulder dysfunction to frank dislocation.

Compared with asymptomatic shoulders, minor anterior instability at full cocking is related to two arthrokinematic dysfunctions: a centralized instead of a posteriorized position of the humeral head on the local anterior/posterior axis of the glenoid and an enlarged qualitative and quantitative contribution of the intra-articular external rotation component. These results can be related to the conclusions from in vitro biomechanical research which state that towards full cocking the anterior part of the inferior glenohumeral ligament is the primary stabilizer limiting anterior translation of the humeral head on the glenoid, together with its limiting function on glenohumeral external rotation.[9] In the literature, internal impingement has been associated with excessive external rotation, with or without anterior glenohumeral instability.[4] Towards full cocking, the test case with internal impingement was arthrokinematically characterized by an accentuated and increased glenohumeral external rotation and a dysfunction in scapular setting, however, with a normal posterior translation of the humeral head on the glenoid.

The purpose of the study was to identify the reconstruction problems of joint structures and their immediate relevance for the clinician through the implementation of a classic biomechanical methodology. This methodology will be expanded in a topographical model approach and a methodology study concerning contact areal displacement analysis. Future research will concentrate on the pathomechanics of joint dysfunctions and the arthrokinematical effects of surgical intervention.

REFERENCES:

An, K.-N., Browne, O., Korinek, S. et al. (1991). Three-Dimensional Kinematics of Glenohumeral Elevation. *J. Orthop. Res.* **9**, 143-149.

Högfors, C., Peterson, B., Sigholm, G. et al. (1991). Biomechanical Model of the Shoulder Joint: II. The Shoulder Rhythm. *J. Biomech.* **24**, 699-709.

Howell, S. M., Galinat, B. J., Renzi, A. J. et al. (1988). Normal and Abnormal Mechanics of the Glenohumeral Joint in the Horizontal Plane. *J. Bone Joint Surg.* **70A**, 227-232.

Jobe, C. M. (1997). Superior Glenoid Impingement. *Orthop. Clin. North Am.* **28**, 137-143.

Paletta, G. A., Warner, J. J. P., Warren, R. F. et al. (1997). Shoulder Kinematics with Two Plane X-Ray Evaluation in Patients with Anterior Instability or Rotator Cuff Tearing. *J. Shoulder Elbow Surg.* **6**, 516-527.

Rhoad, R. C., Klimkiewicz, J. J., Williams, G. R. et al. (1998). A New in Vivo Technique for Three-Dimensional Shoulder Kinematics Analysis. *Skeletal Radiol.* **27**, 92-97.

van der Helm, F. C. T. (1991). The Shoulder Girdle: A Dynamic Approach. Doctoral Thesis. Delft: Technische Universiteit.

Veldpaus, F. E., Woltring, H. J., Dortmans, L. M. (1988). A Least Squares Algorithm for Equiform Transformation From Spatial Marker Coordinates. *J. Biomech.* **21**, 45-54.

Wilk, K. E., Arrigo, C. A., Andrews, J. R. (1997). Current Concepts: The Stabilizing Structures of the Glenohumeral Joint. *J. Orthop. Sports Phys. Ther.* **25**, 364-379.

Woltring, H. J., Huiskes, R., de Lange, A. (1985). Finite Centroid and Helical Axis Estimation from Noisy Landmark Measurements in the Study of Human Joint Kinematics. *J. Biomech*. **18**, 379-389.