Measurement of Scapulohumeral Rhythm using a Dynamic Radiographic Technique: A Validation and Reliability Study

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INTRODUCTION: Understanding shoulder kinematics is critical for diagnosis and treatment of shoulder pathologies. Scapulohumeral rhythm (SHR), defined as the ratio between glenohumeral (GH) and scapulothoracic (ST) contributions to shoulder motion, is a key metric for evaluating shoulder joint function. Current methods of dynamic imaging involving fluoroscopy produces lower image resolution and 3D to 2D registration requires significantly greater time to generate dynamic radiographic data. Dynamic digital radiography (DDR) captures pulsed low-dose radiographs 1.3x of the dose of standard static 2-view shoulder x-rays to create a fluid sequence that enables real-time evaluation of bony movement across range of motion[1]. This study aims to 1) validate manual SHR measurements on DDR against established 3-dimensional (3D) to 2-dimensional (2D) registration technique and 2) establish the most reliable measurement technique by identifying bony landmarks that minimize measurement error.

METHODS: 22 patients who underwent reverse shoulder arthroplasty (RSA) and DDR imaging >6 months postoperatively were included. For the manual measurement approach, PACS (Sectra Medical) was used to measure SHR angles at rest – 30°, 30° - 60°, 60° - 90°, 90° - maximum abduction, and rest – maximum abduction (Figures 1,2). For the 3D to 2D registration technique, surface models of the scapula and humerus, with implants, were generated from computed tomography scans using JointTrack. The models were iteratively superimposed onto scapular and humeral silhouettes on DDR images at the various abduction angles to calculate SHR (Figure 3). To test reliability of various bony landmarks on manual measurement, two readers performed manual measurements on the same DDR frames for each shoulder at every 10 degrees of shoulder abduction, from 0° to 120°. GH angle was calculated from measurement of the angle between the internal border of the humerus and a vertical line. ST angle was calculated from measurements of the angle between a horizontal line and either the lateral border of the scapula, medial border of the scapula, or scapular spine. Data was compared using descriptive statistics, and inter-rater reliability of the manual measurements was assessed with intra-class correlations (ICC).

RESULTS: For the validity portion of the study, paired two-tail t-tests revealed no significant differences in SHR values across all intervals of humerothoracic abduction, indicating strong consistency between the 3D to 2D registration technique and manual measurement on DDR (Table 1). For the reliability portion of the study, each reader manually measured 105 GH angles and 315 ST angles using each measurement method: 105 using the lateral border of the scapula, 105 using the medial border of the scapula, and 105 using the scapular spine. ICCs were statistically significant ($p<0.001$) between the two readers for the GH angles and the ST angles using the lateral border, 0.989 and 0.955, respectively. ICCs for the ST angles using the medial border of the scapula and the scapula spine were 0.544 and 0.142, respectively.

DISCUSSION AND CONCLUSION: SHR measurements obtained manually on DDR images are consistent with those derived from established 3D to 2D model registration in patients who underwent RSA. The lateral border of the scapula is the most reliable skeletal landmark for measurement of ST contribution of SHR, while the chest wall frequently occluded the medial border, and the scapular spine was inconsistently visible due to reliance on ideal patient position. This simple method of SHR measurement on DDR images can be easily integrated in clinical and research workflow where advanced 3D modeling may be too time-consuming. Understanding the contributions of humerus and scapula in shoulder motion, particularly after RSA, is important in informing optimal implant balance for each patient.

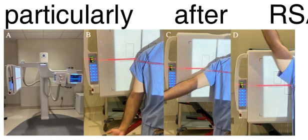

Figure 1. Konica Minolta dynamic digital radiography (DDR) machine (A). Patients are positioned in a Grashey view with their posterior shoulder and scapula contacting the back board of the DDR machine. Patients are instructed to stand upright, stationary, avoid axial rotation, and how to perform the motion including standardizing for forearm supination. Patients begin with their arm at rest and gradually abduct their arm to maximum abduction (B-D)

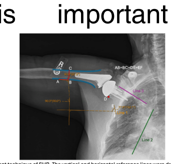

Figure 2. Measurement technique of SHR. The vertical and horizontal reference lines were drawn to over the image. Glenohumeral angles were measured by the angle subtended by the vertical reference line and a line down the medial cortex of the humerus (Line AB). Scapulothoracic angles were measured by the angle subtended by the horizontal reference line and a line parallel to the lateral border of the scapula (Line EF). Lines AB and EF are equal in distance and based on the diameter of the humeral shaft (Line CB).

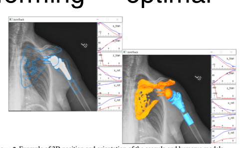

Figure 3. Example of 3D position and orientation of the scapula and humerus models determined using model-image registration technique in JointTrack (University of Florida, Gainesville, FL, USA) and projected onto a DDR image; these 3D poses were iteratively adjusted to match their silhouettes with the silhouettes in the DDR image.

Table 1. Scapulohumeral rhythm measured via 3D-2D registration and manual methods by humerothoracic abduction interval

Intervals of Glenohumeral Abduction	3D-2D Registration	Manual	p-value
Rest - maximum	1.91 ± 0.73	1.88 ± 0.50	0.823
Rest - 30°	2.97 ± 1.45	2.47 ± 2.02	0.236
30° - 60°	1.95 ± 0.56	1.92 ± 0.94	0.898
60° - 90°	1.92 ± 0.82	1.87 ± 0.66	0.673
90° - maximum	1.90 ± 0.51	2.24 ± 0.76	0.256

Values reported as mean ± standard deviation.