Journal of Biomechanics 43 (2010) 771–774

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Measuring humeral head translation using fluoroscopy: A validation study

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ARTICLE INFO

Article history:
Accepted 16 October 2009

Keywords:
Glenohumeral Kinematics
2-D measurement
Fluoroscopy
Humeral head
Superior translation

ABSTRACT

Numerous techniques have been employed to monitor humeral head translation due to its involvement with several shoulder pathologies. However, most of the techniques were not validated. The objective of this study is to compare the accuracy of manual digitization and contour registration in measuring superior translation of the humeral head. Eight pairs of cadaver scapulae and humerii bones were harvested for this study. Each scapula and humerus was secured in a customized jig that allowed for control of humeral head translations and a vise that permitted rotations of the scapula about three axes. Fluoroscopy was used to take images of the shoulder bones. Scapular orientation was manipulated in different positions while the humerus was at 90° of humeral elevation in the scapular plane. Humeral head translation was measured using the two methods and was compared to the known translation. Additionally, accuracy of the contour registration method to measure 2-D scapular rotations was assessed. The range for the root mean square (RMS) error for manual digitization method was 0.27 mm - 0.43 mm and the contour registration method had a RMS error ranging from 0.18 mm - 0.40 mm. In addition, the RMS error for the scapular angle rotation using the contour registration method was 2.4°. Both methods showed acceptable errors. However, on average, the contour registration method showed lesser measurement error compared to the manual digitization method. In addition, the contour registration method was able to show good accuracy in measuring rotation that is useful in 2-D image analysis.

1. Introduction

Shoulder impingement syndrome and rotator cuff tears are among the most common chronic shoulder injuries in the general population (Flatow et al., 1994; Soslowsky et al., 1997; Ludewig and Cook, 2002; Wong et al., 2003). Superior translation of the humeral head is believed to be one of the causes of shoulder impingement syndrome (Sharkey and Marder, 1995; Deutsch et al., 1996; Wong et al., 2003).

The majority of the research investigating translations of the humeral head during shoulder abduction have utilized x-rays (Poppen and Walker, 1976; Deutsch et al., 1996; Paletta et al., 1997; Yamaguchi et al., 2000). Numerous techniques have been utilized to quantify humeral head translation during shoulder elevation, ranging from manual digitization of key landmarks to computer-assisted contour recognition (Poppen and Walker, 1976; Graichen et al., 2000; Pfirrmann et al., 2002; Bey et al., 2006; Hallstrom and Karrholm, 2006). With the exception of Bey and colleagues (2006), to our knowledge, none of these methods have been validated against a gold standard. In the present study, two methods were used to quantify humeral head translation. Both methods were based on digitized landmarks on the humeral head and glenoid. The first method was based on Poppen and Walker (1976) and is termed Manual Digitization (MD) in the current study. The second method was developed by Crisco et al. (1995), named Contour Registration (CR) in the current study, and quantifies translation through image contour registration. The purpose of the current study was to compare the accuracy of these two different methods in measuring superior translation of the humeral head.

2. Methods

2.1. Specimens and Instrumentation

Eight glenohumeral joints were obtained from four cadavers (74 ± 14 years old), two females and two males. The scapula and the humerus were harvested and the majority of soft tissues were removed. The bones were stabilized on a shoulder jig that was situated 40 cm away from the image intensifier (Fig. 1). This device allowed the scapula to be manipulated with three degrees of rotational freedom (i.e. upward/downward rotation, anterior/posterior tilting, and internal/external rotation). The humerus was secured to a translation device with an accuracy of 0.1 mm in order to displace it superiorly. A calibration object with a known length was positioned on the superior aspect of the subscapular fossa to

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doi:10.1016/j.jbiomech.2009.10.034

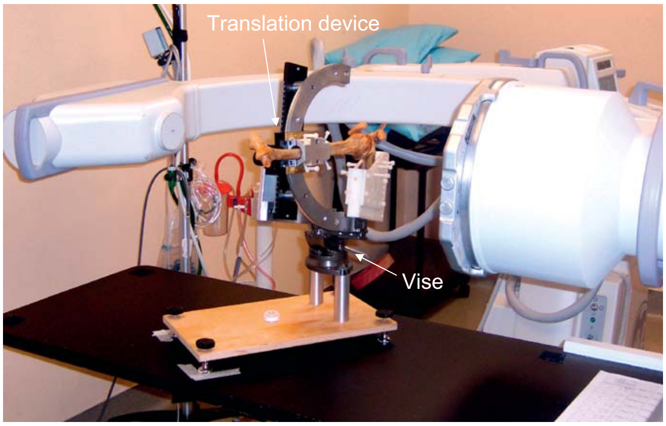

Fig. 1. Shoulder jig used to secure the scapula and humerus positioned in the middle of the fluoroscopy unit.

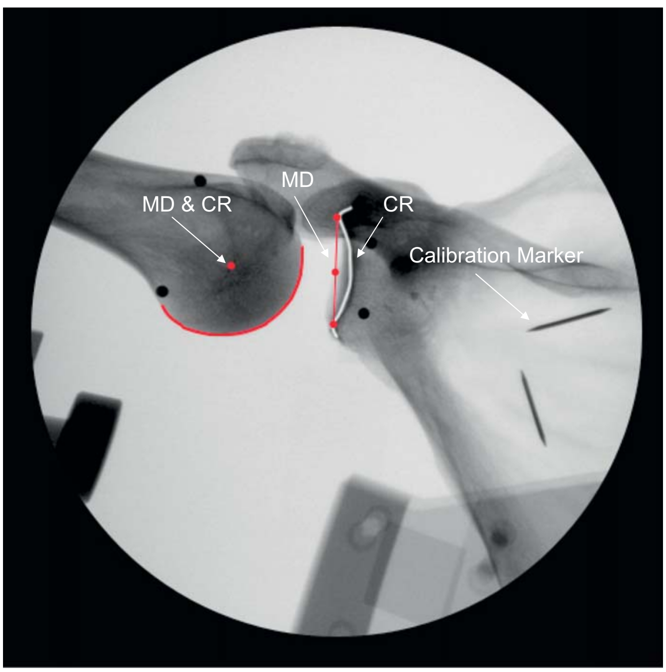

Fig. 2. Digital image with points and digitized contours used for both MD and CR methods.

help in scaling the digital image (Fig. 2). The superior humeral head translation was recorded using a GE (OEC) 9800 fluoroscopy unit (Fig. 1) set at the standard automatic mode (49–51 kVp, 0.49–0.54 mA).

2.2. Protocol

The bone pairs were situated so that the anterior surface of the scapula was perpendicular to the beam of the fluoroscope in order to reduce projection error. Data were collected at four humeral angles: 30°, 60°, 90°, and 120° of elevation in the scapular plane. For each specimen, the scapula was placed in a predetermined neutral position set to mimic the orientation of the scapula *in-vivo* (McClure et al., 2006) while the humerus was positioned at the aforementioned humeral elevation angles (Table 1). In addition, at 90° of humeral elevation (Table 1), the scapula was manipulated into different degrees of rotation, one standard deviation from the neutral position, while maintaining the other degrees of rotation in neutral (McClure et al., 2006). Fluoroscopic images were taken at a neutral position and again after 2.0 mm (A) and 4.0 mm (B) of superior translation for each set of humeral and scapular angles, which are within the range reported in the literature (Poppen and Walker, 1976; Deutsch et al., 1996; Bezer et al., 2005; Graichen et al., 2005).

Table 1
Scapular orientation angle used for the study at specific humeral elevation angle-based on McClure et al. (2006).

	Humeral elevation (°)	Scapular orientation (°) Posterior tilt	Upward rotation	Internal rotation
Neutral	30	3	1	25
	60	6	5	26
	90	7	15	25
	120	10	28	22
± 1 Standard deviation	90	0	15	25
	90	14	15	25
	90	7	2	25
	90	7	28	25
	90	7	15	17
	90	7	15	33

2.3. Image analysis

The images were first analyzed by digitizing points on the humeral head and the glenoid using edge detection software, Space (Lewis Center for Neuroimaging, University of Oregon, Eugene, http://lcni.uoregon.edu/%7Emark/Space_program.html). The humeral head coordinates were then used to calculate the geometric center of the humeral head by using a curve fitting, non-linear regression analysis to fit a circle to the humeral head coordinate data, and then calculating the center point (Fig. 2) using a customized LabVIEW (National Instruments Corporation, Austin, TX) program. Since the scapula was positioned on the jig by aligning the scapular spine and not the vertical axis of the glenoid, humeral translation was defined as net translation of the humeral head, using both x and y components. Humeral head net translation was calculated using two methods. The first method (MD) involved digitizing points on the superior and inferior aspect of the glenoid and finding the center of a line connecting the two points. The center of the line served as the origin of the glenoid coordinate system (Poppen and Walker, 1976; Deutsch et al., 1996). The net translation was then calculated using the geometric center of the humeral head with respect to the glenoid coordinate system between images. The second method (CR) entailed digitizing points on the entire glenoid face and employing the image contour registration procedure described by Crisco et al. (1995). Using the geometric center of the humeral head and the transformation matrix that was generated based on the contour registration between images; the net translation of the humerus was calculated. Root mean square (RMS) errors were calculated between the measured translation and the actual translation. Additionally, a two-way mixed model Intraclass Correlation Coefficient (ICC) was used to assess the intrarater reliability of the CR and MD methods on two separate days.

Further image analysis at 90° of humeral elevation was performed to assess the validity of the image contour registration method in calculating scapular rotational angles (Crisco et al., 1995). Images were rotated by 10° using Photoshop CS2 (Adobe, San Jose, CA). Using the CR method, the angle between the initial position and rotated image was calculated. Additionally, the angle between the upward (UR) and downward (DR) scapular rotation was calculated. The resulting angle was then compared to the known value of the scapular angle between UR and DR, which was 26°. The scapular angle was based on the position of the scapula (Table 1), one standard deviation from neutral, when the humerus was at 90° of elevation (McClure et al., 2006).

3. Results

The ICC value for the CR and the MD methods were 0.81 and 0.80, respectively. For the MD,neutral scapular position had a RMS error of 0.28 mm (14%) and 0.34 mm (17%) for translations A and B respectively. The CR method in neutral scapular position had a RMS error of 0.22 mm (11%) and 0.23 mm (12%) (Table 2). MD had the greatest error when the scapula was upwardly rotated (0.41 mm) during the first translation and posteriorly tilted (0.43 mm) at the second translation. The CR had the greatest error when the scapula was externally rotated (0.30 mm and 0.40 mm).

Method MD showed lesser error at 30° and 60° of humeral elevation (Fig. 3). For the scapular angle calculation, only the CR

Table 2
Superior translation root mean square (RMS) error of the two methods compared to the actual translation.

Scapular orientation	RMS error (mm)			
	Contour registration		Manual digitization	
	A	B	A	B
Neutral	0.23	0.22	0.34	0.28
Anterior tilt	0.23	0.21	0.37	0.33
Posterior tilt	0.19	0.17	0.38	0.43
Upward rotation	0.22	0.25	0.41	0.34
Downward rotation	0.18	0.28	0.32	0.36
Internal rotation	0.27	0.34	0.27	0.35
External rotation	0.29	0.40	0.27	0.28

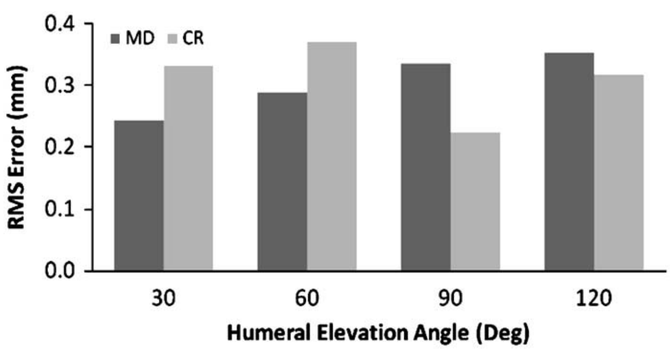

Fig. 3. Superior translation RMS error between the two methods during neutral scapular position at 30°, 60°, 90°, and 120° of humeral elevation.

method was used as it can measure rotational angles. The RMS error between scapular UR and DR was 2.4°. The RMS error between known scapular angle and rotated image was 0.7°.

4. Discussion

Both methods showed reasonably low errors in measuring humeral head translation. The image contour registration method of Crisco et al. (1995) had lower measurement error compared to the technique used by Poppen and Walker (1976) in measuring superior humeral head translation in the present study. One of the advantages of the CR technique compared to MD was that it allowed more points to be digitized on the glenoid that could provide an accurate representation of the surface geometry. In addition, the subjective nature of digitizing two points on the glenoid face used for the MD method was avoided, which could add to the error associated with the measurement. The CR method was also able to take into account any rotational motion of the glenoid during the trials which could be beneficial in an *in-vivo* study.

For the present study, the projection error was controlled by insuring that the anterior surface of the scapula was directly perpendicular to the beam of the fluoroscope during all the scapular neutral positions. One of the major concerns with the use of two dimensional (2-D) medical imaging (i.e. single plane radiograph) is the potential for out of plane motion (Dennis et al., 2005; Bey et al., 2006). The results of the present study showed that when the scapula was not positioned perpendicular to the fluoroscope, the RMS error increased. The MD method had the highest error when the scapula was placed in a posteriorly tilted position compared to neutral. This higher measurement error may be due to the fact that the distance between the superior and inferior glenoid changed because the superior portion of the glenoid was farther away from the fluoroscope compared to the inferior portion which could influence the origin of the image.

The image contour registration method of Crisco et al. (1995) reported translation errors of 1.21 mm when they translated the femoral bone by 2.06 mm. In a recent study, Bey and colleagues (2006) validated a new 3-D model-based tracking technique using biplane x-ray measuring glenohumeral joint kinematics. Our mean RMS errors of 0.34 mm for MD and 0.23 mm for CR compare favorably to their previously reported error of approximately ± 0.5 mm (Bey et al., 2006). However, when compared to Crisco et al. (1995), both methods showed better accuracy. There are several limitations that need to be addressed for the current study. First, the study was performed in-vitro with no soft tissues intact and only the bones were utilized. As a result, the digital x-ray images analyzed in the present study might have a better quality compared to images taken in-vivo. Using the CR method in-vivo might create problems when digitizing the glenoid contour due to poor image quality. In addition, since glenohumeral kinematics is a 3-D motion and the current study is using a 2-D imaging technique to monitor humeral motion, out of plane movement is a concern.

5. Conclusion

The present study showed good accuracy for both techniques in measuring superior translation of the humeral head. However, we believe the CR method is a better technique to utilize especially in-vivo because it gives a better representation of the glenoid contour needed to measure humeral head translation. In addition, it avoids the subjective nature of digitizing points in the glenoid that is used to define the coordinate system in the MD technique.

Conflict of interest statement

There are no conflict of interest releated to the work submitted in this manuscript.

Acknowledgements

We would like to thank Dianne Raponi and Annie Fetcher for assisting in the data collection, Mark Dow for developing the Space software, and Pain consultants of Oregon for the use of their fluoroscopy machine. Partial funding for this project was provided by a grant from NIOSH: 5R01OH008288.

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