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ORIGINAL RESEARCH

ULTRASOUND MEASUREMENTS AND OBJECTIVE FORCES OF GLENOHUMERAL TRANSLATIONS DURING SHOULDER ACCESSORY PASSIVE MOTION TESTING IN HEALTHY INDIVIDUALS

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ABSTRACT

Background: Clinical examination of caspuloligamentous structures of the glenohumeral joint has historically been subjective in nature, as demonstrated by limited intra-rater and inter-rater reproducibility. Musculoskeletal diagnostic ultrasound was utilized to develop a clinically objective measurement technique for glenohumeral inferior and posterolateral translation.

Purpose: The purpose of this study was to measure the accessory passive force required to achieve end range glenohumeral posterolateral and inferior accessory translation, as well as, to quantify the amount of translation of the glenohumeral joint caused by the applied force.

Study Design: Cross-sectional descriptive correlational study

Methods: Twenty-five asymptomatic subjects between the ages of 18 and 30 were recruited via convenience sampling. Posterolateral and inferior shoulder accessory passive translation was assessed and measured using a GE LOGIQe ultrasound, while concurrently using a hand held dynamometer to quantify the passive force applied during assessment. Normative values for force and translation were described as means and standard deviations.

Results: Mean values for posterolateral translation were 6.5 +/- 4.0 mm on the right shoulder and 6.3 +/- 3.5 mm on the left with an associated mean force of 127.1 +/- 55.6 N and 114.4 +/- 50.7 N, respectively. Mean values for inferior translation were 4.8 +/- 1.7 mm on the right shoulder and 5.4 +/- 1.8 mm on the left with an associated mean force of 84.5 +/- 30.5 N and 76.1 +/- 30.1 N, respectively. There was a significant association between inferior translation and inferior force ($r = .51$). No significant association was found between posterolateral translation and posterolateral force. Significant differences were found between dominant and non-dominant shoulders for posterolateral translation, posterolateral force to produce translation, and inferior translation values.

Conclusions: Force data in the posterolateral and inferior direction is consistent with previously reported data for passive accessory motion testing at the shoulder. The results of this study provide data for glenohumeral translations and actual forces applied. Musculoskeletal diagnostic ultrasound can be a clinically relevant way to objectively measure the translation of the glenohumeral joint for assessing accessory passive motion joint translation while performing mobilizations or passive structure testing. This study provides a basis for comparison for healthy shoulder joints.

Level of Evidence: 2b

Keywords: Diagnostic ultrasound, glenohumeral joint translation, handheld dynamometry

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INTRODUCTION

Optimal shoulder function depends on adequate stability and mobility of active and passive joint structures. The rotator cuff acts as the primary active stabilizer by compressing the humeral head in the glenoid fossa.[1,2] The glenoid labrum and capsuloligamentous structures provide the primary passive restraints to excessive glenohumeral (GH) motion.[2,3,4] The objective examination of strength of the active stabilizers has been well established in the literature and can be reliably measured by use of dynamometry, electromyography, and isokinetics.[5] However, clinical examination of caspuloligamentous structures has historically been subjective in nature, as demonstrated by limited intra-rater and inter-rater reproducibility.[6,7,8,9,10,11,12]

Several methods have been used in an attempt to objectify GH translation including computed tomography, stress radiograph, electromagnetic spatial tracking (EST), and linear displacement transducers (LDT).[8,13-20] However, these assessment tools are not readily available in clinical practice for the rehabilitation professional. Musculoskeletal diagnostic ultrasound is a non-invasive, easy to use and portable modality. It has been shown to be a reliable,[11,14,16,17,19] and valid[14,16] modality for assessing GH translation in the anterior, inferior, and posterior direction.

Regardless of imaging modality, a wide range of GH translations have been reported in asymptomatic subjects and athletes.[8,13-21] A portion of the variability is likely due to the varied shoulder testing positions, the magnitude of forces used for GH accessory mobility assessment, and the techniques of measurements. Various testing positions produced differences in end range GH translation distances (Table 1).[3,6,14,15,20,22,23] Several authors have demonstrated a linear relationship between amount of translation and magnitude of force.[6,21,22,24]

Several studies have used predetermined mobilization or passive forces (67-134N) to assess humeral translation,[6,8,13-21,25] but it is unclear whether these forces achieved the end range of GH joint translation. To the authors' knowledge, there are only three studies that have examined the magnitude of force required to attain end range capsular mobility in the shoulder.[13,19,26] No published studies to date have used ultrasound to measure the amount of posterolateral (PL) and inferior joint translation with respect to the magnitude of force applied.

The purpose of this study was to measure the accessory passive force required to achieve end range GH PL and inferior accessory translation. Quantifying the external force applied to the GH joint during accessory passive motion testing to reach end-range is important to clinicians in order to document the degree of translation. It is hypothesized there would be a correlation between GH accessory passive translation distance and magnitude of force applied.

MATERIALS AND METHODS

Subjects

This study used a convenience sample of 25 healthy college-aged students (9 males, 16 females; mean age 26 years; mean height and weight 1.7 m and 72 kg, respectively). Females comprised 64% of the sample and all participants were right hand dominant. Sixteen percent of the participants had participated at a competitive level in an overhead sport for at least one year of competition (Table 2).

Exclusion criteria included a history of upper extremity injury, shoulder surgery, and/or presence of shoulder pain. Participants were measured bilaterally, with each shoulder representing an individual data point. Subjects were provided with detailed information regarding study procedures and any risk associated with the study protocol. The study was approved by the Institutional Review Board at Armstrong State University. All subjects gave written informed consent prior to study participation.

Upon volunteering, subjects completed an intake screening form and a demographic questionnaire to determine eligibility for participation in the study.

Ultrasound Imaging

Subjects were positioned supine on a treatment plinth, with the shoulder positioned in 60° of abduction and neutral GH rotation. Previous research has demonstrated that considerable amounts of GH laxity exists in all directions at 60° of abduction.[3] The direction of GH translation (inferior v. PL) was randomly assigned before each assessment.

Table 1. *Force and Translation Values from other References*				
Reference	Imaging Technique	Upper Extremity Position	Force (N)	Average Translation (mm)
Sauers et al	LDT	20° Abduction	67 89 111 134	Anterior=7.5, Posterior=9.3 Anterior=8.9, Posterior- 10.7 Anterior= 10.2, Posterior= 11.8 Anterior= 11.3, Posterior 12.7
Borsa et al	LDT	20° Abduction	67 89 111 134	Anterior=6.1, Posterior=5.0 Anterior=7.4, Posterior- 6.1 Anterior= 8.7, Posterior= 6.8 Anterior= 9.7, Posterior 6.5
Karup et al	US	0° Abduction	89	Anterior=1.9
Court-Payen et al	US	0° Abduction, Internal Rotation	90	Anterior=1.8
Ellenbecker et al	Stress Radiograph	90° Abduction, 0° ER 90° Abduction, 60° ER	150 150	Anterior= 2.08 Anterior= 1.40
Harryman et al	EST	0° Abduction	NA	Anterior= 7.8
Sauers et al	LDT	20° Abduction	67 89 111 134	Anterior=8.0, Posterior=8.6 Anterior=9.4, Posterior=9.9 Anterior=10.7, Posterior=10.9 Anterior=11.9, Posterior=11.8
Borsa et al	US	90° Abduction, 60° ER	150	Anterior=2.82, Posterior=5.3 Anterior=2.74, Posterior=4.90
Borsa et al	US Stress Radiograph	90° Abduction, 60° ER 90° Abduction, 60° ER	100 100	Posterior =3.97 Posterior=2.96 Anterior= 2.87, Posterior=5.25
Borsa et al	US	90° Abduction, 60° ER	150	Anterior= 2.62, Posterior=5.94 (Throwing shoulder) Anterior= 2.99, Posterior=4.82 (Non-throwing shoulder)
Cheng et al	US Stress Radiograph	90° Abduction, 10° Extension	90	Inferior=4.4 Inferior=4.7
Tibone et al	EST	90° Abduction, 0° ER	Force to End Feel	Dominant Shoulder=9.6 Non-Dominant Shoulder=10.7
Borsa et al	EST	20° Abduction	203 191 181	Anterior=14.5 Posterior=14.0 Inferior=13.9
Talbott et al	US	55° Abduction, 30° Horizontal Adduction, 0° Rotation	41.7 121.5 209.4	Posterior=3.0 Posterior=8.2 Posterior=10.7
LDT=Linear displacement transducer, US= ultrasound, EST= electromagnetic spatial trackers				

Table 2. *Participant Demographics and Baseline Characteristics*	
Participant Demographics and Baseline Characteristics	
Variable	Value
Subjects, n	25
Age, years	26.1 (22-35)
Height	1.7 m
Weight	72 kg
Sex, %	
Male	36
Female	64
Hand dominance, %	
Right hand dominant	100
Left hand dominant	0
Overhead sport, %	
"Yes" to participation	16
"No" to participation	84
M= meters; kg= kilograms; %= percentage of the sample	

Ultrasound imaging was obtained using a GE LOGIQe unit (GE Healthcare, Milwaukee, Wisconsin) with a 3.96-8.41 MHz transducer by an examiner with 16 hours of training with the specific technique used in this study and over three years of experience using ultrasound imaging clinically. Palpation was used to locate the coracoid process and greater tuberosity, according to previously described procedures.[16,18,19] The transducer was placed horizontally over the anterior aspect of the glenohumeral joint, just anterior and inferior to the acromion (Figures 1,2). Two bony landmarks were identified on the ultrasound image: the

Figure 1. *Depiction of ultrasound transducer and HHD positioning during application of inferior force.*

Figure 2. *Depiction of ultrasound transducer and HHD positioning during application of posterolateral force.*

superior surface of the coracoid process and the most superior aspect of the humeral head. Care was taken to include the greater tuberosity to allow consistent landmark identification when measuring translation distance after data collection. After adequate visualization of bony landmarks, a resting image was obtained. Resting images were immediately inspected and repeated if adequate visualization was not achieved.

GH Passive Accessory Motion Testing

After resting images were obtained, a hand held dynamometer (HHD), (Layfayette Manual Muscle Tester Model 01163[R], Layfayette, IN), was placed as close to the GH joint as possible without disrupting the ultrasound transducer. An inferior or PL passive accessory force was performed until a firm capsular end feel was noted by a second examiner with over 40 years of experience of teaching and treating patients using GH joint mobilizations. A PL passive force was utilized due to the orientation of the glenoid fossa. Force was applied through the HHD until a normal, firm capsular end feel was obtained. Each passive accessory motion was completed in approximately one second. At this time, ultrasound landmarks were confirmed again and a second image was captured. Translation forces were blindly recorded by a third examiner. This sequence was repeated three times in each direction on each shoulder, for a total of six pairs of ultrasound images per subject. The mean of the three measurements on each shoulder was used for data analysis.

Measurement

After data collection, the acquired images were reviewed and measured using the ultrasound's built-in measuring tools. For PL translation, a horizontal line was placed on the screen in line with the superior aspect of the coracoid process. The distance between this horizontal line and the most superior aspect of the humeral head was then measured. This value represented the anterior-posterior distance between the greater tuberosity and the coracoid process (Figures 1 and 2). A similar process was undertaken for inferior translation. The superior-inferior distance between the superior aspect of the coracoid process and the superior aspect of the humeral head was measured. The difference in distance between the resting and passive translation images was the amount of total GH translation (Figures 3 and 4). This procedure was repeated for each pair of images. Mean translation distance (three trials of inferior and PL), measured in millimeters (mm), as well as, the mean newtons of force (N) was used for data analysis.

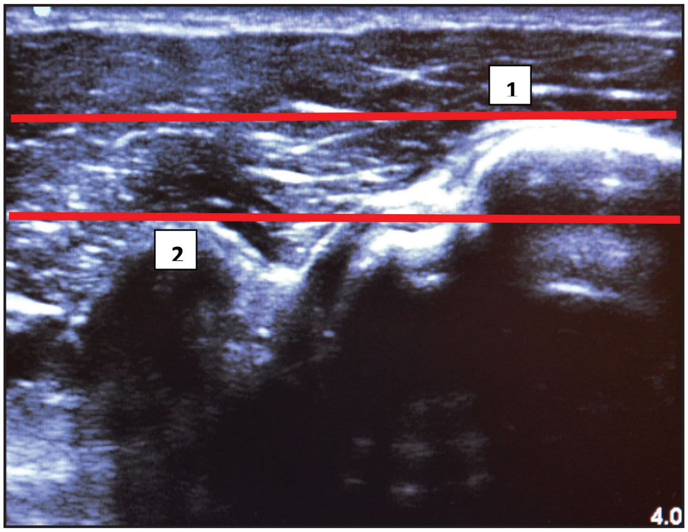

Figure 3. *Image 1. Anterior transverse view of the ultrasound image demonstrating the starting position for posterolateral accessory translation: (1) Superior most aspect of humeral head (2) Superior aspect of coracoid process.*

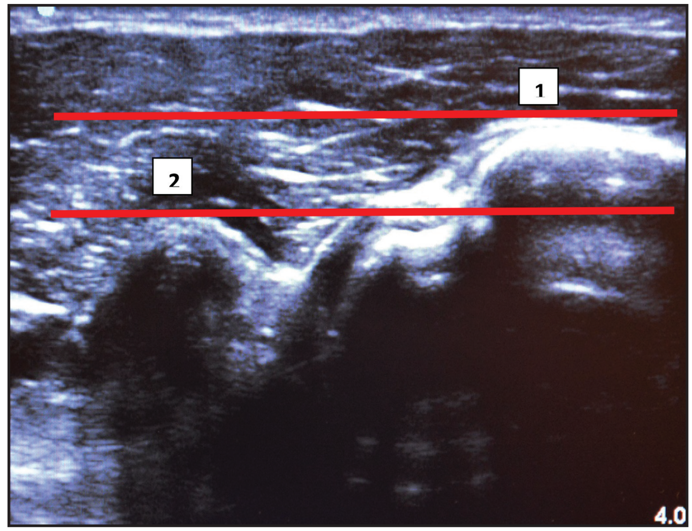

Figure 5. *Image 3. View of the ultrasound image demonstrating the starting position for inferior accessory translation: (1) Superior aspect of humeral tuberosity (2) Superior aspect of coracoid process.*

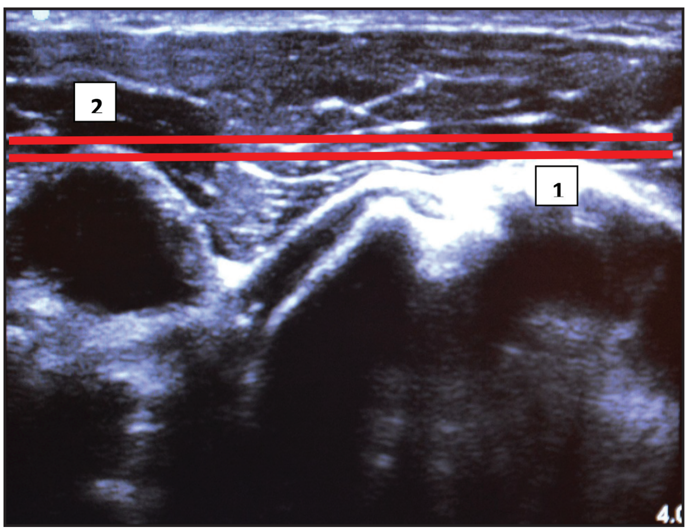

Figure 4. *Image 2. Anterior transverse view of the ultrasound image demonstrating the end position for posterolateral accessory translation: (1) Superior aspect of humeral tuberosity (2) Superior aspect of coracoid process.*

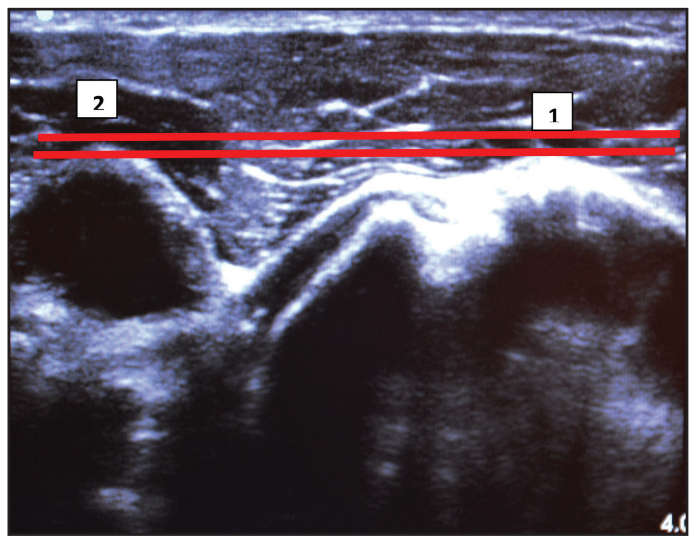

Figure 6. *Image 4. View of the ultrasound image demonstrating the end position for inferior accessory translation: (1) Superior aspect of humeral tuberosity (2) Superior aspect of coracoid process.*

Data analysis

Descriptive statistics were calculated for age, gender, hand dominance, and participation in overhead sports. ICCs (model 2) were calculated to assess intra-rater reliability for PL and inferior force. PL and inferior translation distances were reported as mean values, in millimeters, and standard deviations. Normality was assessed using a Shapiro-Wilk test and histograms. Dependent samples t-tests were conducted to assess differences in translation and force values between gender and dominant versus nondominant shoulders. In the event that data was not normally distributed, a Wilcoxin Signed Rank test was used to assess between group differences. Alpha was set at 0.05. Scatterplots assessed linear relationships between PL and inferior translation with amount of force. Correlations between translatory motion and force were assessed using

Pearson Correlation Coefficients. The following classification was used to interpret the strength of correlation between measures: +/-.1= weak correlation, +/-.3=moderate correlation, +/-.5=strong correlation.[27] All analyses were completed using SPSS version 21.

RESULTS

Analyses yielded coefficient values of 0.78 for PL force and 0.93 for inferior force for intra-rater reliability, indicating good-excellent reliability. The following correlational analyses were examined in this study: inferior translation with inferior force and PL translation with PL force. There was a significant association between inferior translation and inferior force demonstrating a strong correlation ($r=.51$; $p=0.00$). No significant association was found between PL translation with PL force. (Table 7)

The sample means for PL force, translation, and force per translation are presented in Table 3. Table 4 displays sample means for inferior force, translation, and force per translation.

Dependent samples t-tests demonstrated significant differences between dominant and nondominant shoulders for both PL force and translation. (Table 5) There was a significant difference in mean values for force required to produce inferior translation between dominant and nondominant shoulders, with the dominant shoulder requiring greater force to produce inferior translation compared to the nondominant side. Additionally, males required a statistically greater amount of force to glide inferiorly when compared to females. Inferior translation values were statistically similar between males and females and dominant and nondominant shoulders. (Table 6)

DISCUSSION

The purpose of this study was to measure the accessory passive force required to achieve end range GH PL and inferior translation. It was hypothesized there would be a correlation between GH accessory

Table 3. *Mean Values for Posterolateral Force and Translation (Reported as means +/- SD's)*

	Mean Force	Mean Translation	Force/translation
Total Sample	120.7 +/- 52.9 N	6.4 +/- 3.7 mm	19.2 N per 1 mm
Males	120.5 +/- 54.3 N	5.9 +/- 1.4 mm	20.4 N per 1 mm
Females	97.5 +/- 57.1 N	5.9 +/- 5.4 mm	16.5 N per 1 mm
Right shoulder	127.1 +/- 55.6 N	6.5 +/- 4.0 mm	19.5 N per 1 mm
Left shoulder	114.4 +/- 50.7 N	6.3 +/- 3.5 mm	18.1 N per 1 mm

N= newtons of force, mm= millimeters of humeral head translation, force/translation= amount of force per millimeter of movement

Table 4. *Mean Values for Inferior Force and Translation (Reported as means +/-SD's)*

	Mean Force	Mean Translation	Force/translation
Total Sample	80.3 +/- 30.7 N	5.1 +/- 1.7 mm	15.7 N per 1 mm
Males	80.1 +/- 31.8 N	5.3 +/- 1.9 mm	15.1 N per 1 mm
Females	63.4 +/- 29.7 N	4.7 +/- 1.6 mm	13.4 N per 1 mm
Right shoulder	84.5 +/- 30.5 N	4.8 +/- 1.7 mm	17.6 N per 1 mm
Left shoulder	76.1 +/- 30.1 N	5.4 +/- 1.8 mm	14.1 N per 1 mm

N= newtons of force, mm= millimeters of humeral head translation, force/translation= amount of force per millimeter of movement

Table 5. *Between Group Differences for Dominant and Non-Dominant Shoulders*

Variable	t-test statistic	Mean difference	p-value
Posterolateral Force	3.19	12.8 +/- 20.0 N	0.00
Inferior Force	5.54	8.4 +/- 7.5 N	0.00
Posterolateral Translation	0.16	1.4 +/- 4.4 mm	0.88
Inferior Translation	1.4	5.0 +/- 1.8 mm	0.16
N= newtons, mm=millimeters			

Table 6. *Between Group Differences for Gender*

	Gender		
Variable	t-test statistic	Mean difference	p-value
Posterolateral Force	2.17	23.0 +/- 45.0 N	0.04
Inferior Force	3.01	17.6 +/- 24.9 N	0.01
Posterolateral Translation	0.05	0.1 +/- 5.4 mm	0.96
Inferior Translation	1.49	0.6 +/- 1.8 mm	0.16
N=newtons, mm=millimeters			

Table 7. *Correlation Values between Force and Translation*

	Pearson Correlations	
Variables	p-value	Correlation Coefficient (r-value)
Inferior force with Inferior translation	0.00*	0.51
Posterior force with Posterior translation	0.10	0.49
*p value <.05; two-tailed test		

passive translation distance and magnitude of force applied. This hypothesis was partially supported by the results.

The average value for posterolateral translation in the current study was 6.4 mm, when the humerus was positioned at 60° of abduction, which compares favorably to previous work by Borsa et al, who demonstrated mean values ranging from 3.97-5.94 mm in GH positions of 60 and 90° of abduction.[14,15,25] Inferior translation of 5.1 mm found in the current study was consistent with Cheng et al who measured 4.7 mm, however varied from Borsa et al of 13.9 mm of inferior translation.[13,16] This variation was possibly due to Borsa et al using a position of limited shoulder abduction (0-20 degrees) as opposed to the position of 60° of abduction used in the current study, which may have selectively tightened the inferior capsule and inferior GH ligaments which would contribute to the decreased inferior translation.[13] This supposition is supported by findings of Hsu et al who demonstrated a decrease in inferior translation as the GH joint was taken into higher ranges of abduction.[23]

The average PL force used in the current study to achieve full glide was 121 N, measured at 60° of abduction. This value was less than the value of 191N, found in the study by Borsa et al,[13] measured at 20° of abduction, This difference may have been due to Borsa et al utilizing a custom built stress device, whereas the current study used direct manual contact to apply the force to replicate clinical conditions. A custom built stress device may allow force to the GH joint that is not possible with methods used clinically. Talbott et al used a similar testing set up to the current study and found that 209 N of posterior force was used to create a grade III mobilization, defined as the point in posterior shoulder mobilization where all tissues were taut and resistance to movement rapidly increased.[19] These results highlight the overall poor interrater reliability of providers when assessing joint accessory motion. According to a 2014 systematic review, inter-clinician reliability was moderate to poor with force application during mobilization of the cervical, lumbar, and tibiofemoral joint (ICC = -0.04 to 0.70).[22] To date, no studies have demonstrated acceptable levels of interrater reliability for accessory motion testing of the GH joint.[20] Previous authors have demonstrated that posterior translation increases as the GH joint is moved into higher ranges of abduction.[29,30] The average inferior force was 80 N in the present study, which was less than the value of 181 N found by Borsa et al.[25] However, this difference again may be attributed to differences in measurement technique and shoulder position between studies.

No significant correlation was found between the amount of PL force applied and the amount of shoulder PL translation. There are a few possible explanations for the lack of correlation between force applied and translation distance measured. Muscle guarding during GH translation has been described previously,[31,32] and may have been increased during the examination due to the pressure from the HHD on the bicipital groove compressing the underlying soft tissue. The compression may have caused pain and increased muscle guarding. Previous authors have examined the effects of capsuloligamentous stiffness on translation and found a linear relationship, indicating that stiffness or guarding increased as the amount of translation increased.[12,31] The HHD was required to be placed slightly distal on the humerus due to the ultrasound probe positioning needed to concurrently assess the GH joint translation. Moving the site of force application away from the GH joint may have decreased the amount of force imparted on the joint, thus decreasing the amount of total GH translation. Future studies may utilize a curved attachment for the HHD to decrease direct pressure exerted on the biceps groove/tendon. Also, shoulder translations were performed at 60 degrees of abduction, as this is the commonly reported open packed position for the GH joint. Lin et al noted an average open packed position of 23.7 +- 8.4 degrees of abduction when measuring GH joint translation in a group of 15 healthy subjects with an average age of 23.[32] This calls into question the ability to generalize 60 degrees of GH abduction as an open packed position of the shoulder in a group of young healthy subjects, similar to the subjects in the study. Deviation away from a subject's true open packed position would likely limit GH translation due to capsular tightening.

There was a significant correlation between the amount of inferior force applied and the distance of shoulder inferior translation. Therefore, as more force was applied in an inferior direction, a greater amount of translation of the GH joint was observed. This may be due to the location of force application being in a less sensitive area of the shoulder when compared to the area of force application with PL translation.

Although not specifically an aim of the current study, it was noted that a greater amount of force was required to attain the same amount of GH translation in male subjects as compared to female subject. This is in agreement with Talbott et al, who also found a higher force required to achieve grade III posterior translation in the shoulder of male subjects when compared to female subjects. This may be due to increased guarding in male subjects or increased force needed to induce accessory movements due to muscle mass. EMG was not used for assessment of the surrounding musculature, so the exact cause of the increased force required between sexes could not be determined in the current study. The role of muscle contraction during GH translation may be an important area for future research.

Previous authors have found that shoulder translation distances are decreased in pathological shoulders as compared to their uninvolved shoulders.[11,33] Posterior mobilization of the GH joint is a commonly utilized clinical technique to evaluate and improve the accessory motion and positively affect range of motion of internal rotation, flexion, and adduction. Inferior mobilizations are used to evaluate and improve the accessory motion and range of motion for overhead motions.[3,34,35] Harryman et al found that asymptomatic shoulders demonstrated a wide range of translation on clinical testing, with ranges of 19mm (3-22mm) for posterior drawer testing and 10mm (5-15mm) for sulcus testing. The wide range of normal GH joint translation should be considered when evaluating the amount of translation for individual subjects and may limit the generalizability of GH translation studies with small sample sizes. Future research should assess the amount of translation and amount of force during accessory motions on symptomatic subjects. It may also be worthwhile to investigate the relationship between GH joint translation and physiologic passive range of motion in subjects with pathology.

Several limitations should be noted. An experienced clinician performed the application of force, as would be done in a clinical setting, as compared to a custom-built force application device, indicating there could have been a non-uniform rate of force application. Additionally, visualizing bony landmarks with the ultrasound was sometimes difficult due to soft tissue compression that occurred during application of the passive force. Intrarater reliability of the ultrasound measurements of GH translation was not performed prior to the current study. Although this is a limitation, the intrarater and interrater reliability has been well established in the literature (ICC 0.94[7] and 0.89-0.96[4,7] respectfully), as well as the validity of this measure as compared with stress radiography.[14,16] Lastly, since this study only used healthy subjects, the results cannot be generalized to a pathological population.

CONCLUSION

Average PL translation of 6.3 mm and average inferior translation of 6.1mm were found in healthy subjects at 60° of abduction. The average PL force was 120 N and inferior force was 80 N. There were significant differences found between dominant and non-dominant shoulders for PL translation, PL force to produce translation, and inferior translation values. Additionally, males required greater force than females for inferior translation. There were no significant correlations found between PL force and PL translation. However, there was a significant correlation between inferior force and inferior translation. This information can aid in assessment and treatment by providing baseline values for PL and inferior translations directions. The results indicate that musculoskeletal diagnostic ultrasound can be a clinically relevant way to objectively measure the translation of the GH joint for assessing accessory passive motion joint translation while performing mobilizations or passive structure testing.

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