Three-Dimensional Freehand Ultrasound to Measure Scapular Kinematics and Relationship to Shoulder Pain in Manual Wheelchair Users

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ABSTRACT

The objective of this study was to use three-dimensional freehand ultrasound to measure scapular kinematics and to determine how scapular motion relates to subject characteristics, clinical exam scores, shoulder pain, and years of wheelchair use among manual wheelchair users (MWUs). A total of 44 subjects, 22 MWUs and 22 able-bodied controls (AB), were imaged in four positions of interest (arm at rest and humeral elevation in the sagittal, frontal, and scapular planes). Significant predictors for scapular position included body mass index ($p \leq 0.05$), ultrasound exam score ($p \leq 0.049$), trunk flexion at rest ($p \leq 0.012$), internal rotation at rest ($p \leq 0.019$), downward rotation at rest ($p \leq 0.037$), and posterior tilting at rest ($p \leq 0.032$). Understanding scapular kinematics and its relationship to subject characteristics could prove to be essential to improving preventative care for shoulder injuries among MWUs.

BACKGROUND

The prevalence of shoulder pain among wheelchair users is 31-73% (Bayley, 1987), which is higher than the general population. Shoulder pain and pathology are generally not the result of isolated episodes and have been linked to changes in scapular movement. Previous studies have shown that early intervention is associated with faster recovery (Van der Windt, 1996). Thus, in this study, we place emphasis on characterizing abnormal scapular movement by measuring scapular kinematics and analyzing its relationship with subject characteristics.

Existing methods to evaluate scapular movement are invasive, expensive, require exposure to radiation, or suffer skin-based motion artifacts. Ultrasound (US) combined with motion tracking, or freehand US (FUS), could enable three-dimensional (3D) reconstruction of scapular movement and has the potential to overcome the aforementioned limitations. In a previous study, we evaluated the reliability of FUS in measuring static scapular position in different planes of arm elevation and found substantial to excellent reliability with intraclass correlation coefficients (ICC) ranging from 0.62 to 0.95 and a low standard error of measurement ranging 0.16 – 1.33°.

The overall goal of this study was to use 3D FUS to determine what subject characteristics could be used to predict scapular kinematics. We evaluated the relationship between scapular position and subject age, body mass index (BMI), clinical exam scores, reported shoulder pain, and resting trunk and scapular positions. Additionally, among MWUs, we investigated whether scapular position was related to years of wheelchair use and/or reported pain during activities of daily living. We also conducted a secondary analysis where we dichotomized subject by the following characteristics: physical exam shoulder scale (PESS), ultrasound shoulder pathology rating scale (USPRS), years since injury, age, and BMI, to determine if there was a relation to scapular rotation.

METHODS

<u>Participants</u>

This study included MWUs and AB controls who were gender and age matched within ±5 years. Subjects were eligible to participate in this study if they were over the age of 18, spoke English, and able to raise their arm above their head. To be eligible for the study MWUs also had to use a wheelchair as their primary means of mobility (>80% of mobility). Subjects were excluded from this study if they had a history of fractures or dislocations in the shoulder from which they had not fully recovered, had upper extremity impairment, weakness or spasticity that prevented smooth movement, or if they could not complete reach tasks while seated with support straps around the trunk. Testing occurred both at the National Veteran's Wheelchair Games and the Human Engineering Research Laboratories. This study was approved by the local Institutional Review Board. Consent of each subject was obtained prior to data collection.

<u>Questionnaires</u>

Subjects were asked to complete basic intake forms and pain questionnaires. The basic intake form asked about subject age, ethnicity, height, weight, dominant handedness and if any shoulder pain was experienced in the last 7 days. If the participant was a MWU, we also asked questions on type and date of injury or diagnosis. A short questionnaire regarding history of shoulder pain and upper extremity surgical history was also administered. The Wheelchair Users Shoulder Pain Index (WUSPI), which asks about pain during daily activities, was also administered to MWUs.

Clinical Evaluation

All participants completed physical and US exams of the upper extremity to investigate shoulder pathology. The dominant shoulder was examined as we anticipated finding more pathology on the dominant side. The physical exam (PESS) consisted of palpation over the bicipital groove/biceps tendon, acromioclavicular (AC) joint, as well as the Neer test, Hawkin's-Kennedy test, painful arc, Jobe's test, resisted external rotation, and O'Brien's test for the labrum and AC joint (Brose, 2008). The ultrasound exam (USPRS) included static evaluation of bony surfaces and tendons of the rotator cuff as well as dynamic evaluation of impingement (Brose, 2008).

Freehand Three-Dimensional Ultrasound System

US imaging was completed using a Philips HD11XE US machine[1], an Epiphan Frame Grabber[2], and a custom orthogonal attachment, equipped with Vicon markers, fitted to the US probe. Additional markers were placed on the trunk and dominant arm to measure movement during trials. Movement was recorded using Vicon Nexus software and 10 cameras[3].

Ultrasound Imaging of the Scapula

One operator performed all US scanning. The depth of the US imaging was set to 4cm for all participants. Participants were imaged multiple times in each of the four positions of interest which consisted of the arm by the participant's side at rest and humeral elevation to 90° in the sagittal, frontal, and scapular planes (40° anterior to the frontal plane). The subject held each position for one minute during scanning.

Data Processing

US videos were read into Matlab and written to individual image files. The scapular border was manually identified as an x-y coordinate in each US image. A series of transformations were applied to the 2D point identified in each US image at the scapular border to determine the location of this point in 3D space (Worobey, 2014). Once the location of the scapular border was determined for each of the US images collected during the trial, the points were pooled to create a 3D reconstruction of the scapular border.

Scapular and humeral position were determined with respect to the trunk. The scapular local coordinate system was determined with our z-axis as a linear regression of the points making up the spine of the scapula, the x-axis as perpendicular to a plane fit to all of the points in our 3D scapular reconstruction, and the y-axis as their cross-product. Rotations were determined using a YXZ rotation sequence with the first rotation representing internal/external rotation (IR/ER), the second as upward/downward rotation (UR/DR), and the third as anterior/posterior tilting (AT/PT). ISB standards were used to determine trunk and humeral coordinate systems (Wu, 2005).

Statistical Analysis

To investigate the relationship between pathology and scapular position in the combined group of controls and wheelchair users, multiple regressions were performed to predict each of the scapular rotations based on USPRS score, PESS score, age, BMI, trunk flexion, and resting scapular position. Predictor variables for both models were tested for multicollinearity. All statistical analyses were completed with SPSS[4] with the significance level set apriori at 0.05.

After conducting the multiple regression analyses, we found that pain and pathology were not significant predictors of scapular position in the majority of analyses. Therefore, we conducted a secondary analysis where we dichotomized the following subject characteristics and used paired comparisons to determine if there was a relation to scapular rotation: PESS to pain and no pain (0, >0), USPRS to above and below the median score (<=5, >5), years since injury (<=10 years, >10 years), age to above and below the mean (<=50 years, >50 years), and BMI to overweight or not overweight (>=25 kg/m^2, <25 kg/m^2) .

RESULTS

Twenty-two AB and 22 MWUs participated in this study. Demographic information for all participants, as well as a summary of median (MED) and interquartile (IQR) ranges for clinical exam scores, can be found in Table 1. Three MWUs had wheelchairs equipped with power assist wheels. Among MWUs, diagnoses/injuries included paraplegia (n=9), tetraplegia (n=6), multiple sclerosis (n=3), bilateral below knee amputation (n=1), guillian barre syndrome (n=1), extensive leg fractures resulting in nerve damage (n=1), and traumatic brain injury (n=1).

Table 1: Demographic Variables (± stdev) and Median & Interquartile Ranges for PESS, USPRS, WUSPI

n = 44	**AB**	**MWU**
Gender	13 male, 9 female	13 male, 9 female
Age (years)	50.5±11.6	50.6±12.2
BMI (m/kg^2)	24.22±2.87	24.56±4.85
WC use (years)	N/A	16.3±9.4
MED/IQR **PESS**	2.0 / 0.5-3.0	2.0 / 0.0-4.0
MED/IQR **USPRS**	3.5 / 1.0-5.8	6.5 / 4.0-8.0
MED/IQR **WUSPI**	N/A	2.5 / 0.0-17.4

A description of average group values and standard deviations for each scapular rotation in the different testing planes can be found below in Table 2.

Table 2: Mean ± Standard Deviation of Scapular Rotation for MWU and AB for All Testing Positions

Plane	***Scapular Rotations***

	IR/ER		UR/DR		AT/PT	
	MWU	**AB**	**MWU**	**AB**	**MWU**	**AB**
Rest	32.3 ±1.4°	31.6 ±1.3°	-5.3 ±2.0°	-0.5 ±2.5°	-14.0 ±1.3°	-12.4 ±1.2°
Sag.	34.1 ±2.5°	34.9 ±3.6°	-37.0 ±3.6°	-36.4 ±3.6°	1.1 ±2.8°	3.1 ±1.8°
Front.	23.1 ±2.5°	21.8 ±1.8°	-40.0 ±4.8°	+40.8 ±3.6°	1.2 ±3.5°	4.3 ±1.4°
Scap.	30.8 ±1.9°	28.8 ±2.0°	-37.7 ±3.3°	-37.0 ±3.7°	-1.4 ±1.8°	2.8 ±1.8°

Predicting Scapular Kinematics based on Subject Characteristics

We found greater BMI was correlated to greater anterior tilting at rest (R=0.348, p=0.021) and higher USPRS scores were correlated with increased age (R=0.543, p<0.001). Increased trunk extension (TE) at rest was correlated to higher USPRS scores (R=0.137, p=0.036), downward rotation at rest (R=0.377, p=0.012), and anterior tilting at rest (R=0.371, p=0.013). Among wheelchair users, WUSPI and PESS scores were correlated (R=0.574, p=0.005) and greater years of wheelchair use was correlated with downward rotation at rest (R=0.477, p=0.025).

A summary of the relationship between scapular rotations in all testing planes and significant predictor variables (p<0.005) can be found in Table 3.

Table 3: Relation between Scapular Rotations and Predictor Variables (+ indicates positive, - indicates negative relation)

Plane & Scapular Rotation		**Predictor Variable**					
		TF at Rest	IR at Rest	DR at Rest	PT at Rest	BMI	USPRS
Rest	IR						
	DR	-					
	PT	+				+	
Sag.	IR	+	+		-		-
	DR			+			
	PT		-		+		
Front.	IR	+	+		-		
	DR			+			
	PT		-		+		
Scap.	IR	+	+		-		
	DR			+			
	PT		-		+	-	

Abbreviations: TF = trunk flexion, IR = internal rotation, DR = downward rotation, PT = posterior tilting

While not significantly different after applying the correction for multiple comparisons, we found a trend towards more posterior tilting for males in the frontal and scapular plane testing positions (p=0.042-0.0580). We also found trends towards more upward rotation and posterior tilting among those under 50 years of age in the rest testing position (p=0.039).

For our secondary analysis of dichotomized variables, we found significantly less upward rotation with PESS >0 in all testing positions (p=0.009-0.034). We also found significantly less upward rotation in the frontal and scapular plane testing positions with USPRS >5 (p=0.009-0.025). Additionally, we found significantly more internal rotation among those using a wheelchair for greater than 10 years in all testing positions (p=0.004-0.021). Significantly more posterior tilting was present in all testing positions among those with a BMI less than 25 kg/m^2 (p=0.001-0.015).

DISCUSSION

The results of the multiple regression analyses found correlations between BMI, PESS, USPRS and years of wheelchair use with scapular kinematics, variables that have not been previously evaluated simultaneously. For scapular rotations at rest, individuals with higher BMI displayed decreased posterior tilting. Individuals with greater trunk flexion had greater upward rotation and less posterior tilting at rest. Our results align with Finley et al who found greater upward rotation and decreased posterior tilting of the scapula when the arm was at rest among subjects who sat upright compared to those who slouched (Finley, 2003). These slouched postures mimic the seating position of wheelchair users, characterized to include thoracic kyphosis and rounded shoulders, and have been related to muscle imbalance and shoulder pain (Curtis, 1999); (Burnham, 1993).

Many of the predictions found for internal rotation, upward rotation, and posterior tilting across the elevated testing positions (sagittal, frontal, and scapular) were predicted by positions at rest. These relationships indicate that a more 'impinged' position during scapular elevation was predicted by a more 'impinged' position at rest.

The results of our secondary analysis using paired comparisons revealed that the USPRS score was significantly correlated to the difference in posterior tilting between elevated and rest positions for the sagittal and scapular planes (R=-0.343,p=0.023 and R=0.349,p=0.020). This correlation suggests that increased pathology is related to less posterior tilting with humeral elevation, which is in agreement with other studies (Ludewig, 2000); (McClure, 2006). BMI was significantly correlated to increased anterior tilting in all testing positions (R: 0.348-0.483, p: 0.001-0.021). This relation suggests that an increase in weight adversely affects scapular tilting. Among MWUs, those using a wheelchair for more than 10 years demonstrated greater internal rotation in all testing positions. This finding is in accordance with characteristic seating posture of wheelchair users that includes rounded shoulders (Curtis, 1999); Burnham (1993). The increase in internal rotation can be harmful as it may put the head of the humerus closer to the anterior aspect of the acromion (Cook, 2002).

Limitations

This study had a relatively small sample (n = 22) of MWUs and AB individuals. BMI also has an effect on US imaging as quality can decrease with increased adipose tissue or muscle above the scapula. Future study should conduct multiple comparisons to further validate results.

CONCLUSION

This is the first study that combines subjects from different population pools (able-bodied and wheelchair users) and attempts to use resting postures and subject characteristics to predict scapular kinematics when the arm is elevated. Many of the relationships found between resting postures and scapular position or rotation relate to body posture when the subject is seated at rest. The seating position of wheelchair users can negatively affect their shoulder position. Likewise, body weight is an important factor to be addressed as it too can adversely affect scapular kinematics. It is possible that encouraging better scapular positioning at rest may in turn improve scapular kinematics during activities of daily living, increase shoulder stability, and hopefully reduce the prevalence of shoulder pain.

Evaluating scapular motion is integral for the advancement of interventions to reduce injury risk and treatments. Future studies using these results may be used towards a better understanding of scapular kinematic patterns for wheelchair users and people with shoulder injuries or pathologies.

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FOOTNOTES

[1] Philips Medical Systems, Bothell, WA

[2] Epiphan Systems, Ottawa, ON, Canada

[3] Vicon Motion Systems, Los Angeles, CA

[4] IBM SPSS Statistics Software, version 20 (Armonk, NY: IBM Corp.)