In vivo measurements of humeral movement during posterior glenohumeral mobilizations

Nancy R. Talbott, Dexter W. Witt

University of Cincinnati, Oh, USA

Objectives: The purpose of this study was to quantify *in vivo* posterior translational movements occurring in the glenohumeral joint during posterior mobilizations and to determine the intratester reliability of those posterior translational movements.

Methods: Twenty-eight individuals (17 females, 11 males) participated in this study. One physical therapist utilized a Kaltenborn approach to apply three grades of posterior humeral mobilization. A hand held dynamometer was used to quantify the force used during each grade of mobilization. Ultrasound imaging was used to visualize and measure posterior humeral movement. Statistical analysis included descriptive statistics for force and posterior movement, intraclass correlation coefficient (ICC) for intratester reliability of force and posterior movement during each grade of mobilization and paired *t*-tests to compare movement and force between grades of mobilization.

Results: Mean posterior movement (mm) measurements were 3.0, 8.2 and 10.7 for grade I, grade II and grade III mobilizations, respectively. Mean force (Newtons) measurements used during mobilization were 41.7, 121.5 and 209.4 for grade I, grade II and grade III mobilizations, respectively. The ICCs ranged from 0.849 to 0.905 for movement and from 0.717 to 0.889 for force. Force and measurement values were significantly different between grades of mobilization and between dominant and non-dominant arms. Gender was found to be significantly associated with force.

Discussion: Mean movements and mean forces occurring during posterior mobilization increased with increasing grades. Intratester reliability was high for all grades of manual mobilization supporting the use of subjective feedback to determine appropriate force application. Quantification of forces and movements helps to clarify parameters that can serve as a reference for clinical practice.

Keywords: Shoulder joint, Mobilization, Manual therapy, Reliability, Force, Ultrasound imaging

Introduction

Joint mobilization is a manual technique often incorporated into the treatment of individuals with limited or painful glenohumeral joint motion.¹ Although multiple directions of mobilization can be performed in the shoulder, posterior mobilizations have been proposed as techniques that can improve the elevation and the rotation of the glenohumeral joint.²⁻⁴ Carried out by applying a force on the anterior aspect of the proximal humerus in a direction posterior to the associated glenoid fossa, a clinician determines the magnitude of the force and the displacement of a posterior mobilization based on self-perception of resistance and motion. Following the application of these techniques, joint pain may decrease and/or joint range of motion may increase.^{5,6}

Currently, the physiological pathways controlling these responses to mobilization are under investigation. Studies on spinal manipulative and mobilization techniques suggest that effects may not only have a biomechanical effect

but are also because of a neurophysiological component. Although it is unclear if the effects of spinal manual therapy can be generalized to the glenohumeral joint, potential effects may be better understood if a consistent manual stimulus is applied.

One of the challenges, however, in applying a consistent manual stimulus is repeatedly moving a segment the same distance with the same amount of force. If too little force is applied and fails to move the humeral head enough, the desired effect on the targeted tissues, mechanical or neural, may not occur. At the same time, excessive force in the shoulder joint may have implications for patient safety, and the therapist must consider the technique's impact on the tensile strength limits of the heterogeneous tissues in that joint.^{7,8}

To assist in achieving desired results and to clarify the type of manual technique employed, clinicians utilize a system of mobilization grades. One system that is commonly used by clinicians is described by Kaltenborn *et al.*⁹ and includes three grades of mobilization. Grade 1 is defined as a small amplitude movement producing little or no joint separation; grade 2 is a movement that takes up

Correspondence to: Nancy R. Talbott, University of Cincinnati, PO Box 670394, Cincinnati, Ohio 45244, USA. Email: talbotnr@uc.edu

tissue slack and tightens the tissues and grade 3 is a stretching movement that results in connective tissues becoming taut. Despite the frequent use of this grading system in the clinic, quantification of the forces and movements occurring during the three grades of mobilization are lacking in the literature. Studies have been completed that document posterior translation of the humeral head as a force is applied^{10–15} but, for several reasons, these are difficult to compare to the clinical use of posterior glenohumeral mobilization. First, studies that have measured posterior translation have commonly utilized a mechanical device, as opposed to a manual force,^{11,13–16} to produce movement. While these devices can vary the forces used during posterior movements of the humeral head, they are not typically available in the clinic and no manual contact occurs between the examiner and the glenohumeral joint being mobilized. Second, displacement in previous studies was commonly measured externally using an electromagnetic or linear transducer system.^{11,13,15} Again, this type of equipment is uncommon in the clinic and requires considerable calibration and post-processing. In addition, the amount of posterior movement may be confounded by compression of surface tissue and distortion or slipping of the skin markers required when using these systems. Third, the positions of the shoulder used in past studies investigating posterior humeral movement did not always replicate common positions used in the clinic.^{10,13,15,16} Altering humeral position can change tension within the shoulder structures preventing comparisons between laboratory methodology and clinical techniques. Finally and perhaps most critical, posterior humeral displacement documented in past studies was measured during a posterior glenohumeral laxity test, an assessment that differs from the posterior humeral movement that occurs during mobilization.^{12,15,16} Although both would seemingly move the humeral head posterior, the end point for a laxity test and various grades of mobilization would not be expected to be equivalent.

Because the movement and force that occur during the different grades of posterior mobilization have not been objectively quantified, both the validity and reliability of these techniques have been questioned.^{14,17–19} Ultrasound imaging (USI) has been found to be a reliable and valid measurement of glenohumeral translations^{20,21} allowing direct visualization of *in vivo* bony movement during glenohumeral mobilizations. By concurrently measuring the force and posterior translation using USI, an examination of the three grades of mobilization can occur. Based on these results, methods to further understand the mechanisms and effects of mobilization can be developed. In addition, knowledge of forces and translation will provide information that can be used to establish safe ranges of forces and movements when learning and clinically applying posterior glenohumeral mobilizations.

The purpose of this study was to quantify *in vivo* posterior translational movements occurring in the glenohumeral joint during a clinical joint mobilization technique

and to determine the intratester reliability of those posterior translational movements. Specifically, the aims were to (1) quantify the posterior movement of the humeral head during grade 1, grade 2 and grade 3 mobilizations as described by Kaltenborn *et al.*; (2) determine the forces used during the grade 1, grade 2 and grade 3 mobilizations and (3) to calculate the intratester reliability of the forces and the movements associated with the grade 1, grade 2 and grade 3 mobilizations.

Methods

This was a cross-sectional descriptive biomechanical study of healthy participants. The study and the informed consent form were approved by the Institutional Review Board at the University of Cincinnati, Cincinnati, OH, USA. All participants received detailed information about the study and all provided written informed consent. The study is registered at www.clinicaltrials.gov with study identification number NCT02338791.

Participants

Participants were recruited from a population of convenience at the University of Cincinnati's College of Allied Health Sciences, Cincinnati, OH, USA. Following the completion of the informed consent, volunteers were screened by an examiner for inclusion into the study. Volunteers were included if they reported no current or past history of shoulder, neck or arm pain, surgery or injury. Volunteers were excluded from the study if they reported any current or past musculoskeletal or neuromuscular conditions related to the neck, shoulder or arm. Volunteers were also excluded if they reported they were pregnant, did not speak English or had a current or past history of connective tissue disorders. Volunteers who were over the age of 55 years were excluded in order to decrease the potential risk of mobilizing individuals with poorer bone or tissue quality. Volunteers under the age of 18 years were also excluded to eliminate the need for parental consent and potential developmental confounders.

Procedures

Before testing was initiated, height, weight and hand dominance were recorded. Systemic or general hypermobility was assessed through the use of the Beighton mobility scale.²² As described by Beighton *et al.*,²² hypermobility was scored on a scale of 0–9 by assessing mobility of the thumbs, fifth metacarpophalangeal joints, elbows, knees and trunk.

Data collection procedures

Each participant was positioned supine on an adjustable table. With the shoulder exposed, the arm was held in a position of 55° of abduction, 30° of horizontal adduction and neutral rotation as measured by a goniometer. This position reflects the open packed, or rest position, of the glenohumeral joint and is commonly recommended

for joint mobilization and assessment.⁹ The scapula was intrinsically stabilized using the participant's body weight against the table.

To image the movement at the glenohumeral joint, a Biosound MyLab 25 Gold portable ultrasound system (Esaote, Indianapolis, IN, USA) with a 40-mm variable frequency linear transducer was used for imaging. The ultrasound machine had been calibrated with a phantom before the initiation of the study. The ultrasound transducer was oriented horizontally over the anterior aspect of the dominant glenohumeral joint. The transducer was translated medial and lateral until the coracoid process, the lesser tubercle of the humerus and the biceps tendon were visible in the USI display. With the arm in the test position and the transducer in place, the participant was instructed to relax and a rest image was taken (Fig. 1). All imaging was performed by a physical therapist that had completed ~50 hours of musculoskeletal training with sonographers and had been imaging the shoulder region for over 5 years.

A posterior mobilization force was then directed by a second physical therapist through a hand held dynamometer (MicroFET2, Hoggan Health Industries, West Jordan, UT, USA). The therapist had completed a fellowship in manual therapy and was also an orthopaedic clinical specialist with ~25 years in clinical practice. The force was applied to the proximal humerus using the three grades of mobilization described by Kaltenborn *et al.*⁹ Grade 1, a small amplitude movement that produced little or no joint separation; grade 2, a movement that increased the tension in the shoulder till the examiner felt a marked resistance (the first stop) and grade 3, a stretching movement after all tissues were taut in which movement was maximal and resistance to movement had increased rapidly. Images were taken as the therapist verbally indicated reaching a grade 1, a grade 2 and a grade 3 posterior translation. Shoulder position was maintained by the mobilizing therapist. In addition, the therapist responsible for imaging monitored the glenoid and the humerus for changes in position. After a rest of 30 seconds was given, the shoulder was returned

to the open packed position, as measured by a goniometer, and the process was repeated two additional times for a total of three repetitions and 12 images (three images under each of the following conditions: rest, grade 1, grade 2 and grade 3). After an additional rest of 30 seconds, the entire procedure was repeated on the non-dominant shoulder. All forces were recorded by a third examiner who read and silently documented the forces applied by the physical therapist during each mobilization, blinding the mobilizing therapist to the amount of force that was being used between and among mobilization grades.

Glenohumeral measurements

Following completion of mobilization testing, all images were stored and measured by a single examiner utilizing ImageJ software (<http://rsb.info.nih.gov/ij/docs/index.html>). For each image, a vertical line was drawn at the lateral aspect of the coracoid process, a second vertical line was drawn at the lateral aspect of the lesser tubercle of the humerus and the distance between the two vertical lines was measured (Fig. 2). After each measurement was completed, ImageJ recorded the numerical value of that measurement on a spreadsheet. To minimize bias by the measurer, the spreadsheet containing all measurements was not visible on the computer screen during the ongoing measurement, preventing the measurer from looking at the values being recorded or the values that had been previously recorded. In addition, individual files were saved by the Bio sound software using numbers and letters that did not reflect the mobilization grade or trial number, a process that further mitigated measurement bias. All measurements were exported to Microsoft Excel (Microsoft Corporation, Redmond, WA, USA), and the amount of movement for each grade of mobilization was calculated by subtracting the position of the humeral head after a mobilization from the position of the humeral head at rest. Force values for each grade of mobilization were entered into the Excel spreadsheet following the completion of all measurements.

Figure 1 (A) The mobilization test position. The shoulder is placed in 55° of abduction and 30° of horizontal adduction. The hand held dynamometer is positioned on the anterior humerus. The ultrasound transducer is placed horizontally over the anterior glenohumeral joint. (B) The transducer was moved medial and lateral until the biceps tendon, lesser tubercle and coracoid process were visualized in the ultrasound image.

Figure 2 Images taken during a grade 1 mobilization (A), a grade 2 mobilization (B) and a grade 3 mobilization (C). To determine the amount of movement, the distance between the superior aspect of the coracoid process (superior red line) and the lesser tubercle (inferior red line) was measured (green arrow).

Statistical analysis

Descriptive statistics were calculated for participant demographics including age, gender, body mass index (BMI) and Beighton scale. Descriptive statistics were also used to quantify the variables of mean movement during each grade of mobilization and mean force during each grade of mobilization. To determine the intrarater reliability of displacement and force measurements, intraclass correlation coefficients (ICC_{3,3}) were calculated for the movement and the force that occurred during the three trials of a single grade of mobilization. Standard error of measurements (SEMs) for humeral movement and for mobilization force and confidence intervals for each of the ICC values were also calculated.

To further investigate the dependent factors of movement and force, an analysis of variance (ANOVA) was used to investigate the effects of the independent variables of age, grade, Beighton score, dominance, gender and BMI. Paired *t*-tests were used *post hoc* to determine statistical differences between levels of the independent variables when significant main effects were found. Relationships between variables were investigated using correlation coefficients (Pearson correlation coefficients for continuous variables, Point-Biserial correlation coefficients for dichotomous variables and Rank-serial correlation coefficients for ordinal variables). Statistical significance was established *a priori* at $P < 0.05$.

All analyses were completed using SPSS for Windows version 22.0 (SPSS Inc., Chicago, IL, USA).

Results

All 28 participants completed the testing procedures on both arms (Table 1). The ICC values for intrarater

application of grade 1, grade 2 and grade 3 movements ranged from 0.849 to 0.905. The ICC values for intrarater application of grade 1, grade 2 and grade 3 forces ranged from 0.717 to 0.889 (Table 2). Both arms of all participants were pooled for the ICC calculations.

Mean movement of all shoulders was significantly affected by the factors of grade of mobilization and dominance but not by gender, BMI, age or Beighton score (Table 3). The strength of the associations are found in Table 4. Because dominance and grade were significantly associated with posterior movement, further analysis of the effects of grade on movement was conducted separately on the dominant and the non-dominant arm. Mean posterior movement was significantly different between grades in the non-dominant and the dominant arms ($P < 0.001$ for all comparisons). Non-dominant arm movements were significantly greater than dominant arm movements during grade 1 mobilization, grade 2 mobilization and grade 3 mobilization (Table 5).

Mean force of all shoulders was significantly affected by the factors of mobilization, dominance and gender but not by BMI, age or Beighton score (Table 3). The strength of the associations is found in Table 4. Further analysis of the effects of grade on force was conducted separately on the dominant and the non-dominant arms of males and females. Mean force was significantly different between grades of mobilization for the dominant and the non-dominant arms of females and males (Tables 6 and 7). For females, mean forces used during grade 2 and grade 3 mobilizations were significantly greater in the dominant arm than in the non-dominant (Table 6) with no significant differences between arms during grade 1 mobilization. For males, mean force used during grade 3 mobilization was significantly greater in the dominant arm when compared with the non-dominant arm with no significant differences between arms during grade 1 and grade 2 mobilizations (Table 7). The forces used during grade 2 and grade 3 mobilizations of males were significantly greater than females in both the dominant and non-dominant arms. During grade 1 mobilization, force was significantly greater in the non-dominant of males when compared with the females with no significant differences in the forces in the dominant arm.

Table 1 Participant demographic data

Age (years)	28 (2.2), 21–28
Gender	17 females, 11 males
Height (m)	1.7 (0.1), 1.5–1.9
Weight (kg)	72.4 (14.2), 48.6–101.4
BMI (kg/m ²)	24.0 (3.5), 18.9–32.9
Beighton hypermobility score (0–9)	1.9 (2.25), 0–7

Listed as 'mean (SD), range' unless otherwise noted. m: metres; kg: kilograms; BMI: body mass index; SD: standard deviation.

Table 2 Within session reliability of force and movement measurements

	Repetition 1Mean (SD)	Repetition 2Mean (SD)	Repetition 3Mean (SD)	ICC _{3,3} (95% CI)	SEM
Movement (mm)					
Grade 1	2.7 (2.2)	2.8 (2.3)	3.6 (2.5)	0.849 (0.756–0.909)	0.9
Grade 2	8.4 (4.0)	7.9 (3.7)	8.3 (3.8)	0.905 (0.852–0.941)	1.2
Grade 3	10.9 (4.2)	10.6 (3.9)	10.7 (4.1)	0.892 (0.832–0.933)	1.3
Force (N)					
Grade 1	35.7 (9.5)	43.0 (7.9)	46.1 (10.7)	0.717 (0.384–0.856)	5.5
Grade 2	111.7 (25.8)	121.7 (26.4)	130.2 (30.4)	0.840 (0.697–0.912)	11.4
Grade 3	194.9 (40.1)	210.4 (39.4)	221.5 (42.2)	0.889 (0.746–0.945)	13.9

mm: millimetres; SD: standard deviation; ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement, N: Newtons.

Table 3 ANOVA results for movement and force models

Factor	Movement		Force	
	F value	P value	F value	P value
Age	0.252	0.617	0.452	0.502
Gender	0.371	0.543	28.994	<0.001
Dominance	8.188	0.005	24.763	<0.001
BMI	0.263	0.609	0.199	0.656
Beighton score	0.706	0.402	0.187	0.666
Mobilization grade	88.260	<0.001	745.951	<0.001

ANOVA: analysis of variance; BMI: body mass index.

Table 4 Correlation coefficients

	Grade	Gender	Dominance	BMI	Beighton	Age
Force	0.950*	0.390*	–0.365*	–0.035	0.034	–0.053
Movement	0.710*	–0.047	0.216*	0.040	–0.065	–0.039

BMI: body mass index. * $P < 0.05$.

Table 5 Effect of grade and dominance on posterior movement

Mobilization grade	Mean in mm (SD)		t	P value†
	Dominant	Non-dominant		
Grade I	2.31 (1.35)*	3.68 (2.41)†	3.13	0.004
Grade II	7.47 (3.26)*	8.93 (3.65)†	2.46	0.020
Grade III	10.06 (3.33)*	11.39 (4.01)†	2.21	0.036

mm: millimetres; SD: standard deviation.

*Significant differences ($P < 0.001$) in the dominant arm between all grades of mobilization.

†Significant differences ($P < 0.001$) in the non-dominant arm between all grades of mobilization.

‡P values for comparisons between dominant and non-dominant arms at each grade of mobilization.

Table 6 Effect of grade and dominance on mean force in females

Mobilization grade	Mean in N (SD)		t	P value†
	Dominant	Non-dominant		
Grade I	39.6 (4.0)*	38.3 (4.4)†	1.56	0.137
Grade II	120.1 (24.5)*	103.6 (16.5)†	4.36	<0.001
Grade III	218.4 (29.8)*	177.9 (18.7)†	7.95	<0.001

N = Newtons; SD = standard deviation.

*Significant differences ($P < 0.001$) in the dominant arm of females between all grades of mobilization.

†Significant differences ($P < 0.001$) in the non-dominant arm of females between all grades of mobilization.

‡P values for comparisons between dominant and non-dominant arms at each grade of mobilization for females.

Discussion

The specific aims of the study were to quantify humeral movement during three grades of posterior mobilization, to quantify the forces used during those mobilizations and

to determine the reliability of the forces and movements associated with each grade of posterior humeral mobilization. The results establish good intratester reliability of the manual application of posterior humeral mobilization

Table 7 Effect of grade and dominance on mean force in males

Mobilization grade	Mean in N (SD)		<i>t</i>	<i>P</i> value [‡]
	Dominant	Non-dominant		
Grade I	44.5 (9.3) [*]	47.2 (12.0) [†]	0.73	0.482
Grade II	138.8 (19.1) [*]	132.1 (24.9) [†]	0.86	0.409
Grade III	246.0 (36.0) [*]	212.2 (28.0) [†]	2.45	0.034

N: Newtons; SD: standard deviation.

^{*}Significant differences ($P < 0.001$) in the dominant arm of males between all grades of mobilization.

[†]Significant differences ($P < 0.001$) in the non-dominant arm of males between all grades of mobilization.

[‡]*P* values for comparisons between dominant and non-dominant arms at each grade of mobilization for males.

and provide insight into the mean forces and movements during these mobilizations.

The amount of posterior movement that was recorded during the glenohumeral mobilization in this study can be compared to published values that have been made with mechanical devices. Borsa *et al.*¹² reported a mean posterior movement of 5.38mm (SD=2.7mm) in a population of professional baseball pitchers. In that study the shoulder was tested in 90° of shoulder abduction and 60° of external rotation as a force of 15decanewtons (dN) was applied through a mechanical device. In the current study, the mean posterior movement was 8.2mm (SD=3.5) with a force of 121.5N or 12.15dN. Differences are likely to be explained by variations in shoulder position. In the position of 90° of shoulder abduction and 60° of external rotation, shoulder structures are tauter than in the open packed position of 55° of abduction and 30° of horizontal adduction with no ER. Movement, therefore, will reflect the pretension of the tissues with more translation expected in the open packed position. In addition, simply increasing shoulder elevation to 90° of abduction may result in greater posterior translation. Anterior translation has been identified in the early ranges of abduction with posterior translation occurring as the angle of abduction increases.^{23–25} If the humeral head has already translated posteriorly in 90° of abduction, less movement would be expected than if the humerus is in 55° of abduction. Sauers *et al.*¹⁵ also utilized a mechanical device to posteriorly translate the humeral head. In their study, the shoulder was positioned in 20° of elevation of the scapular plane with no rotation and forces between 0 and 15dN were applied. They reported that the posterior movement averaged 10.3mm (SD=3.3) over all force levels (67–134N). This was very similar to the average of 10.7mm (209N during a grade III mobilization) reported in this study. Although different amounts of force were needed to produce similar movements, the differences in shoulder positions could be a contributing factor.

The previously mentioned studies utilized a consistent force and measured displacement as that force was applied.^{10,15,17} Few studies have measured displacement when variable forces were applied. Hsu *et al.*¹⁹ reported mean forces of 18.36–38.76N when 12 experienced physical therapists applied posterior mobilizations to the glenohumeral joint of a fresh cadaver. The forces used in that study were considerably less than the mean forces of

41.7–209.4N recorded in the current study. Comparing forces used to move the humerus of a cadaver with forces used to mobilize normal participants, however, is difficult. The lack of any dynamic stability in a cadaver eliminates the muscular tension that may develop when mobilizing a participant with active muscle control. It has been suggested that an intact neuromuscular system may be a key component of glenohumeral stability^{26,27} and, clinically, individuals with active muscle control often contract or do not completely relax the muscles crossing a joint being mobilized.^{28,29} This could further explain why a greater force was needed to mobilize the participants in this study.

The reliability of both the force and displacement values by a single therapist was clinically acceptable in this study. According to Portney and Watkins,³⁰ coefficients <0.50 represent poor reliability, coefficients between 0.50 and 0.75 suggest moderate reliability and coefficients >0.75 indicate good reliability. The ICCs for movement ranged from 0.849 to 0.902 indicating a single examiner was able to consistently reproduce the same amount of movement for each of the mobilization grades. Hsu *et al.*¹⁹ also reported high intratester ICCs ranging from 0.90 to 0.94 when physical therapists applied grade 2 and grade 3 mobilizations in a dorsal direction. Both studies support the ability of a single therapist to make a consistent assessment of the resistance felt during a mobilization and to distinguish that resistance during different grades of mobilization.

The ICCs for force were also considered good in this study, ranging from 0.717 during a grade I mobilization to 0.889 for a grade III mobilization. These values are slightly lower than those found by Hsu *et al.*^{19,31} and reported by others when mobilizing the knee.³² The lower, yet clinically acceptable, ICCs in this study are largely because of differences between the force applied during the first repetition of mobilization and the greater forces used during the second and third repetitions. Although these differences were not significant, repeatability would be higher if only the second and third measurements were used. In the clinic, an assessment of posterior joint mobility is usually performed before initiating any mobilizations. The methodology employed in the current study did not include such a test. It is conceivable that the examiner used the first repetition to gauge resistance and range. Once the relative amount of motion was perceived, more aggressive

movements were performed during the second and third repetitions. In future studies, it would be reasonable to have a single assessment and then follow the assessment with three measurements.

While age, BMI and Beighton scores did not influence force and movement in this study, arm dominance was significantly associated with both components of posterior mobilization. Greater force was used in the dominant arm compared to the non-dominant arm and the use of that greater force resulted in less movement in the dominant arm than in the non-dominant arm. Although these results differ from studies testing shoulder laxity using instrumented devices in which posterior translations and stiffness values were similar in the right and the left arms,^{14–16} side-to-side differences have been reported by others.^{33,34} The possibility that forces and movements may be different bilaterally and might vary between males and females further supports the need to adapt mobilization techniques to the individual shoulder being treated or assessed. Use of a standard force or a standard displacement even within one individual may not produce the desired clinical effect.

When interpreting the amount of humeral displacement that occurred in this study, consideration should be given to the direction of the posterior force and the potential movement of the scapula during the mobilization. Clinically, a manual posterior mobilization of the glenohumeral joint may not be applied in a pure anterior to posterior direction. Because the glenoid fossa may be tilted slightly anterior or posterior when the arm is at rest,³⁵ a movement guided by the glenoid may include either distraction or compression. Future analyses could be done to quantify posterior as well as medial and lateral movement to quantify total humeral displacement and to analyse each of the components of the force. In addition, in this study, body weight and the surface of the table were used to maintain scapular position. If this was not enough stabilization, the concern would be that the scapula would alter its position during the mobilization. Harryman *et al.*¹⁷ reported that the scapula did externally rotate $\sim 8^\circ$ during the performance of a posterior drawer test for laxity. It is possible that similar scapular rotation occurred. However, if scapular external rotation did occur independent of the humerus, the effect would be a movement of the coracoid process closer to the humerus, resulting in an underestimation of the posterior displacement. In the future, concurrent measurements of scapular and thoracic positioning during mobilization may assist in determining if posterior displacement during mobilization is accompanied by scapular displacement.

The results of this study have implications for performing mobilization clinically and for teaching mobilization techniques. In the clinic, this research provides support for one clinician to be able to utilize the self-perceived feedback obtained during the performance of a grade of mobilization to repetitively displace the humeral head

a consistent distance. Although the ideal parameters for glenohumeral mobilization have not been established and the mechanisms by which mobilization affects any one individual are still being investigated, the results suggest that in a variety of individuals with varying amounts of posterior movement and resistance to that movement, a clinician can manually reproduce similar forces and displacement for different grades of mobilization. While further investigation is needed to clarify the role of force and displacement in producing desired effects, the standardization of the biomechanical stimuli during mobilization may provide a mechanism for repeating a mobilization that has beneficial effects during patient treatment. For the educator working with individuals who are beginning to learn mobilization techniques, this research does not support the use of a single amount of force for a specific grade of movement. Rather, the need to vary forces between individuals is supported. Ultrasound imaging and dynamometry may assist in illustrating this concept and be a method by which students can begin to master the skills needed to control force during the application of glenohumeral mobilization across a variety of individuals.

Several limitations were associated with this study. First, the participants were young and without pathology. Reliability may vary with age and future studies are needed using patients with various impairments. Second, a single examiner with considerable manual therapy experience performed all mobilizations. Reliability may be different based on the clinical experience and manual therapy training of another examiner. Intertester reliability is reportedly poor for mobilization³⁶ and consistent force and displacement by a single examiner may need to be mastered before intertester reliability can improve. Finally, muscle guarding was not concurrently measured in this study. Measuring muscle activity in future studies that are quantifying translations and forces during mobilization could provide insight into the effect of guarding on mobilization.

Conclusion

The results of this pragmatic study assist in identifying the forces and displacements that occur during posterior mobilization of the glenohumeral joint and in determining the reliability of those components. Recognizing the ranges for various grades of mobilization helps to clarify parameters that can serve as a reference for clinical practice. Intratester reliability was high for all grades of manual mobilization, supporting the use of subjective feedback to determine appropriate force application. The variability of both force and movement between individuals suggests that reliable perception of resistance by the clinician is needed for posterior humeral mobilization techniques. Further studies which incorporate measurements of muscle tension and scapular positioning will provide additional information about the application of posterior glenohumeral mobilization.

Disclaimer Statements

Contributors NT and DW were equally responsible for conceiving and designing the study, assuring ethics approval, collecting data, analysing data, interpreting data and writing the article.

Funding This work was supported by the Department of Rehabilitation Sciences, University of Cincinnati.

Conflicts of interest The authors declare no conflict of interest.

Ethics approval This study was approved by the institutional review board at the University of Cincinnati where the study was conducted. All subjects signed the consent form that had been approved by the institutional review board.

References

- 1 Brudvig T, Kulkarni H, Shah S. The effect of therapeutic exercise and mobilization on patients with shoulder dysfunction: a systematic review with meta-analysis. *J Orthop Sports Phys Ther.* 2011;41:734–48.
- 2 Conroy DE, Hayes KW. The effect of joint mobilization as a component of comprehensive treatment for primary shoulder impingement syndrome. *J Orthop Sports Phys Ther.* 1998;28:208–13.
- 3 Nicholson GG. The effects of passive joint mobilization on pain and hypomobility associated with adhesive capsulitis of the shoulder. *J Orthop Sports Phys Ther.* 1985;6(4):238–46.
- 4 Johnson AJ, Godges JJ, Zimmerman GJ, Ounanian LL. The effect of anterior versus posterior glide joint mobilization on external rotation range of motion in patients with shoulder adhesive capsulitis. *J Orthop Sports Phys Ther.* 2007;37(3):88–99.
- 5 Senbursa G, Baltaci G, Atay A. Comparison of conservative treatment with and without manual physical therapy for patients with shoulder impingement syndrome: a prospective, randomized clinical trial. *Knee Surg Sports Traumatol Arthrosc.* 2007;15:915–21.
- 6 Bang MD, Deyle GD. Comparison of supervised exercise with and without manual physical therapy for patients with shoulder impingement syndrome. *J Orthop Sports Phys Ther.* 2000;30:126–37.
- 7 Loew M, Heichel TO, Lehner B. Intraarticular lesions in primary frozen shoulder after manipulation under general anesthesia. *J Shld Elbow Surg.* 2004;14:16–21.
- 8 Muraki T, Aoki M, Uchiyama E, Miyasaka T, Murakami G, Miyamoto S. Strain on the repaired supraspinatus tendon during manual traction and translational glide mobilization on the glenohumeral joint: a cadaveric biomechanics study. *Man Ther.* 2007;12(3):231–9.
- 9 Kaltenborn FM, Evjenth O, Kaltenborn TB, Morgan D, Villowitz E. Manual mobilization of the joints: the kaltenborn method of joint examination and treatment: volume I: the extremities. Oslo, Norway: Olaf Norlis Bokhandel; 2002.
- 10 Borsa PA, Dover GC, Wilk KE, Reinold MM. Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc.* 2006;38:21–6.
- 11 Borsa PA, Sauers EL, Herling DE, Manzour WF. In vivo quantification of capsular end-point in the nonimpaird glenohumeral joint using an instrumented measurement system. *J Orthop Sports Phys Ther.* 2001;31:419–31.
- 12 Borsa PA, Wilk KE, Jacobson JA, Scibek JS, Dover GC, Reinold MM, et al. Correlation of range of motion and glenohumeral translation in professional baseball pitchers. *Am J Sports Med.* 2005;33(9):1392–9.
- 13 Lin HT, Hsu AT, An KN, Chien JR, Kuan TS, Chang GL. Reliability of stiffness measured in glenohumeral joint and its application to assess the effect of end-range mobilization in subjects with adhesive capsulitis. *Man Ther.* 2008;13(4):307–16.
- 14 Pizzari T, Kolt GS, Remedios L. Measurement of anterior to posterior translation of the glenohumeral joint using the KT-1000. *J Orthop Sports Phys Ther.* 1999;10:602–8.
- 15 Sauers EL, Borsa PA, Herling DE, Stanley RD. Instrumented measurement of glenohumeral joint laxity: reliability and normative data. *Knee Surg Sports Traumatol Arthrosc.* 2001;9:34–41.
- 16 Borsa PA, Scibek JS, Jacobson JA, Meister K. Sonographic stress measurement of glenohumeral joint laxity in collegiate swimmers and age-matched controls. *Am J Sports Med.* 2005;33(7):1077–84.
- 17 Harryman DT, Sidles JA, Harris SL, Matsen FA. Laxity of the normal glenohumeral joint: a quantitative in vivo assessment. *J Shoulder Elbow Surg.* 1992;1:66–76.
- 18 Levy AS, Lintner S, Kenter K, Speer KP. Intra- and inter-observer reproducibility of the shoulder laxity examination. *Am J Sports Med.* 1999;27:460–3.
- 19 Hsu AT, Ho L, Chang JH, Chang GL, Hedman T. Characterization of tissue resistance during a dorsally directed translational mobilization of the glenohumeral joint. *Arch Phys Med Rehabil.* 2002;83(3):360–6.
- 20 Borsa PA, Jacobson JA, Scibek JS, Dover GC. Comparison of dynamic sonography to stress radiography for assessing glenohumeral laxity in asymptomatic shoulders. *Am J Sports Med.* 2005;33(5):734–41.
- 21 Court-Payen M, Krarup AL, Skjoldbye B, Lausten GS. Real-time sonography of anterior translation of the shoulder: an anterior approach. *Eur J Ultrasound.* 1999;2:283–7.
- 22 Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis.* 1973;32:413–8.
- 23 Sahara W, Sugamoto K, Murai M, Tanaka H, Yoshikawa H. The three-dimensional motions of glenohumeral joint under semi-loaded condition during arm abduction using vertically open MRI. *Clin Biomech (Bristol, Avon).* 2007;22:304–12.
- 24 Graichen H, Stammberger T, Bonel H, Englmeier K, Reiser M, Eckstein F. Glenohumeral translation during active and passive elevation of the shoulder – a 3D open-MRI study. *J Biomech.* 2000;33:609–13.
- 25 Massimini DF, Boyer PJ, Papanagari R, Gil TJ, Warner JP, Li G. In-vivo glenohumeral translation and ligament elongation during abduction and abduction with internal and external rotation. *J Orthop Surg Res.* 2012;7:29.
- 26 Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med.* 2004;32(2):484–93.
- 27 Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther.* 2009;39:90–104.
- 28 Makhssous M, Lin F, Zhang LQ. Multi-axis passive and active stiffnesses of the glenohumeral joint. *Clin Biomech (Bristol, Avon).* 2004;19:107–15.
- 29 Dhaher YY, Tosumanis AD, Houle TT, Rymer WZ. Neuromuscular reflexes contribute to knee stiffness during valgus loading. *J Neurophysiol.* 2005;93:2698–709.
- 30 Portney LG, Watkins MP. Foundations of clinical research: applications to practice. Upper Saddle River, NJ: Prentice Hall Health; 2000.
- 31 Hsu AT, Chiu JF, Chang JH. Biomechanical analysis of axial distraction mobilization of the glenohumeral joint – a cadaver study. *Man Ther.* 2009;14(4):381–6.
- 32 Silvernail JL, Gill NW, Teyhen DS, Allison SC. Biomechanical measures of knee joint mobilization. *J Man Manip Ther.* 2011;19(3):162–71.
- 33 Lintner SA, Levy A, Kenter K, Speer KP. Glenohumeral translation in the asymptomatic athlete's shoulder and its relationship to other clinically measurable anthropometric variables. *Am J Sports Med.* 1996;24:716–20.
- 34 McFarland EG, Campbell G, McDowell J. Posterior shoulder laxity in asymptomatic athletes. *Am J Sports Med.* 1996;24:468–71.
- 35 Saha AK. Dynamic stability of the glenohumeral joint. *Acta Orthop Scand.* 1971;42:491–505.
- 36 Gorgos KS, Wasyluk NT, Van Lunen BL, Hoch MC. Inter-clinician and intra-clinician reliability of force application during joint mobilization: a systematic review. *Man Ther.* 2014;19:90–6.