

Changes in Abduction and Rotation Range of Motion in Response to Simulated Dorsal and Ventral Translational Mobilization of the Glenohumeral Joint

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APTA is a sponsor of the Decade, an international, multidisciplinary initiative to improve health-related quality of life for people with musculoskeletal disorders.

Background and Purpose. Translational mobilization techniques are frequently used by physical therapists as an intervention for patients with limited ranges of motion (ROMs). However, concrete experimental support for such practice is lacking. The purpose of the study was to evaluate the effect of simulated dorsal and ventral translational mobilization (DTM and VTM) of the glenohumeral joint on abduction and rotational ROMs. **Methods.** Fourteen fresh frozen shoulder specimens from 5 men and 3 women (mean age=77.3 years, SD=10.1, range=62-91) were used for this study. Each specimen underwent 5 repetitions of DTM and VTM in the plane of scapula simulated by a material testing system (MTS) in the resting position (40° of abduction in neutral rotation) and at the end range of abduction with 100 N of force. Abduction and rotation were assessed as the main outcome measures before and after each mobilization procedure performed and monitored by the MTS (abduction, 4 N·m) and by a servomotor attached to the piston of the actuator of the MTS (medial and lateral rotation, 2 N·m). **Results.** There were increases in abduction ROM for both DTM ($\bar{X}=2.10^\circ$, SD=1.76°) and VTM ($\bar{X}=2.06^\circ$, SD=1.96°) at the end-range position. No changes were found in the resting position following the same procedure. Small increases were also found in lateral rotation ROM after VTM in the resting position ($\bar{X}=0.90^\circ$, SD=0.92°, $t=3.65$, $P=.003$) and in medial rotation ROM after DTM ($\bar{X}=0.97^\circ$, SD=1.45°, $t=2.51$, $P=.026$) at the end range of abduction. **Discussion and Conclusion.** The results indicate that both DTM and VTM procedures applied at the end range of abduction improved glenohumeral abduction range of motion. Whether these changes would result in improved function could not be determined because of the use of a cadaver model. [Hsu AT, Hedman T, Chang JH, et al. Changes in abduction and rotation range of motion in response to simulated dorsal and ventral translational mobilization of the glenohumeral joint. *Phys Ther.* 2002;82:544-556.]

Key Words: *In vitro simulation, Joint mobilization, Range of motion, Shoulder.*

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Mobilization techniques such as dorsal, ventral, or inferior glides of the glenohumeral joint are frequently used by physical therapists as an intervention for joints with limited range of motion (ROM) and when impingement syndromes are present.¹⁻¹² Proponents advocate use of gliding movements in what they believe is the direction of limited joint glide in accordance with what is commonly referred to as the "convex-concave rule."¹³⁻¹⁵ This rule states that if a convex surface moves on a fixed concave surface, rolling and gliding movements of the joint surfaces occur in opposite directions, and in the same direction if the configuration is reversed.¹³ According to this rule, a dorsally directed translational mobilization is selected to manage hypomobility in medial rotation, flexion, and horizontal adduction, and a ventrally directed mobilization is selected to manage hypomobility in lateral rotation, horizontal abduction, and

extension.¹³⁻¹⁵ Experimental support for this rule, however, is lacking.

In some studies,¹⁶⁻¹⁸ movement predicted by the convex-concave rule did not occur during active or passive movements, especially at the end range. Howell et al¹⁶ reported that in an active motion toward the cocked stage of throwing when the arm is elevated, extended, and maximally rotated laterally, the center of the humeral head was contained within the glenoid cavity throughout the horizontal movement except when the arm was in maximum extension and lateral rotation. At this moment, the center of the humeral head rested approximately 4 mm posterior to the center of the glenoid cavity in what appears to be a violation of the convex-concave rule.¹⁶ Harryman et al¹⁷ and Itoi et al¹⁸ reported that translation occurred in an anterior direction with glenohumeral flexion and horizontal adduc-

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tion and in a posterior direction with extension and lateral rotation. Anterior translation with flexion could not be prevented by the application of an oppositely directed force.¹⁷ Harryman et al¹⁷ believed these apparent violations of the convex-concave rule to be caused by asymmetrical tightening of the capsule during humeral rotation, resulting in translation of the humeral head in the direction opposite to the tightened capsule (capsular constraint mechanism).¹⁷

In vitro study of glenohumeral stability and simulation of laxity tests following selective cutting of structures can clarify the roles of the glenohumeral capsular ligaments on joint stability.¹⁷⁻²⁹ This method appeared to us to have the potential to provide rationales for translational glenohumeral joint mobilization at different joint positions. These studies¹⁷⁻²⁹ suggest to us that stretching capsular ligaments in a more abducted position will be beneficial in increasing abduction because the inferior glenohumeral ligament complex, we believe, will be resisting further abduction. A few researchers^{1,4-12} have investigated the benefits of glenohumeral joint mobilization in practice. The benefits of specific mobilization movements such as dorsal or ventral glide, however, were not addressed in these studies.

An in vitro simulation of caudally directed mobilization in 20 cadaver glenohumeral joints by using a biaxial material testing system (MTS) led to increases in ROM when the technique was performed at the end range of abduction.³⁰ Mobilization techniques performed in the resting position (40° of abduction in the plane of scapula) were not effective against abduction hypomobility. Hsu and colleagues' findings seem to support the usefulness of the convex-concave rule as the guide for choosing mobilization techniques for increasing ROM.³⁰ Effects on rotation, flexion, and extension ROM, however, were not measured and, therefore, are not known. Use of mobilization at end range to increase ROM was suggested by Edmond,¹⁴ Maitland,³¹ and Wadsworth,³² but they offered no data to suggest that this was more effective than the use of mobilization elsewhere in the ROM. Vermeulen et al,³³ in a multiple-subject case report, described patients as attaining increased ROM in response to end-range mobilization.

In vitro cadaver models when used to study effects of mobilization on joint ROM offer the advantage of allowing invasive procedures and make possible rigid fixation for accurate application of forces/torques and displacements and for measurements of the reactive responses of the joint tissue during simulated maneuvers. This is especially important for the glenohumeral joint because stable fixation of the scapula in vivo is extremely difficult, if not impossible, without use of invasive procedures. We believe that any mobilization procedure that

could not be proven effective with a properly executed fresh cadaver simulation most likely is not worthwhile to apply clinically. We have no data, however, to support this contention, and we also acknowledge that movement of cadaver limbs is quite different from the movement of limbs that occurs in patients. In addition, there are many changes that occur in the soft tissue of cadaver limbs, which further limits direct application of findings to living tissue. This is further compounded by the freezing of tissue. We conducted this study to evaluate the effect of a set of oppositely directed (dorsal and ventral) translational mobilization techniques (DTM and VTM) of the glenohumeral joint on abduction and rotational ROMs in fresh cadaver shoulder specimens.

Method

Specimens

Fourteen fresh frozen cadaver shoulder specimens from 5 men and 3 women (mean age at the time of death = 77.3 years, SD = 10.1, range = 62-91) were used in our study. Disarticulation at the sternoclavicular, scapulothoracic, and elbow joints was done before the study began. Specimens were stored in a freezer (-20°C) until the day before testing. A radiograph (anteroposterior [AP] view) of each specimen was taken and inspected so that specimens with gross abnormalities detectable by the radiographs could be eliminated from the study.

Preparation of Specimens

The specimens were thawed overnight at room temperature in preparation for dissection and testing. In an effort to ensure that the glenohumeral joint capsule was not disrupted by the dissection process, only those soft tissues over the scapula, including skin, subcutaneous tissue, and muscles located at least 8 cm medial to the glenohumeral joint, were removed by an instructor with 7 years of anatomy teaching experience (ATH).

The periosteum was also stripped to expose the medial portion of the scapula. All soft tissues approximately 3 cm distal to the surgical neck of the humerus also were removed. We identified the medial and lateral epicondyles of the humerus, and we used them to define the axis of the elbow joint. A nail 3 mm in diameter and 5 cm in length was aligned parallel to the elbow axis and was driven into the humeral shaft at the level of the deltoid tuberosity to represent the axis of the elbow. The distal portion of the humerus was then sectioned immediately below the deltoid tuberosity. The medial edge of the scapula was fixed in a stainless-steel mold (13 cm in diameter, 7.5 cm in depth) with 2-part polyurethane* mixed at equal percentage by weight. The medial border of the scapula, the tip of the coracoid process, and the

* BJB Enterprises Inc, 14791 Franklin Ave, Tustin, CA 92780.

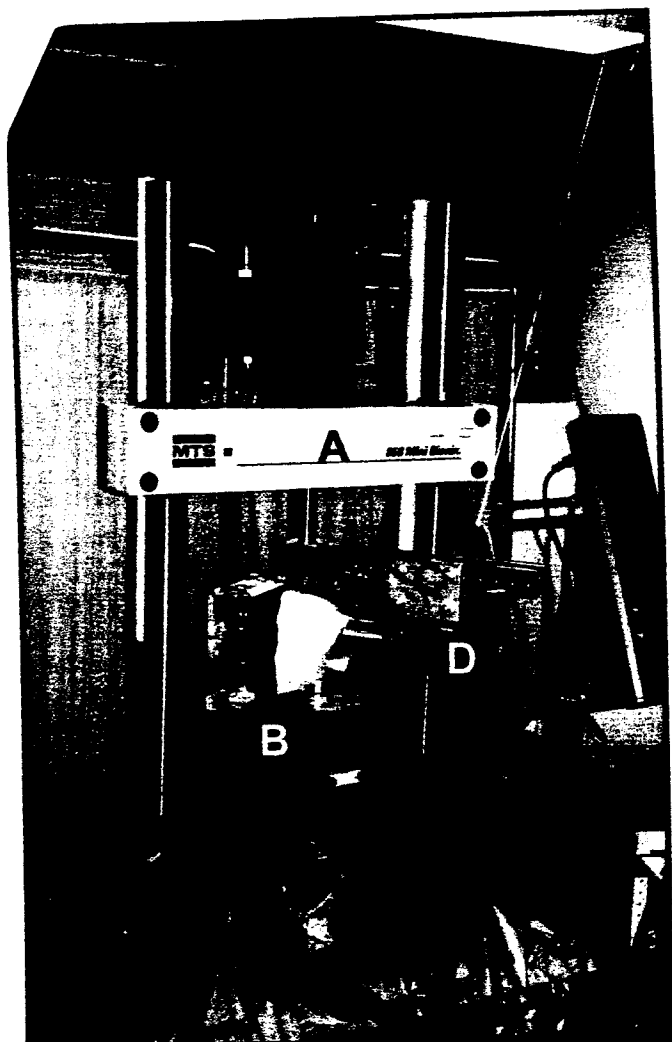


Figure 1. Major instrumentation used in the study. A=material testing system unit, B=X-Y table, C=torque arm, D=servomotor.

lateral angle of the acromion were identified and marked by the investigator (ATH). The plane of the scapula, defined as the plane formed by the medial border of the scapula and the midpoint between the tip of the coracoid process and the lateral angle of the acromion,³⁴ was oriented perpendicular to the base of the scapular mold, with the medial border of the scapula aligned parallel to the base and with the base evenly divided into halves. The distal end of the humerus was placed at the center of a 10-cm-long and 5-cm-internal-diameter cylindrical mold, with the previously driven nail pointing to the lines bisecting the mold into halves and then fixed with polyurethane.

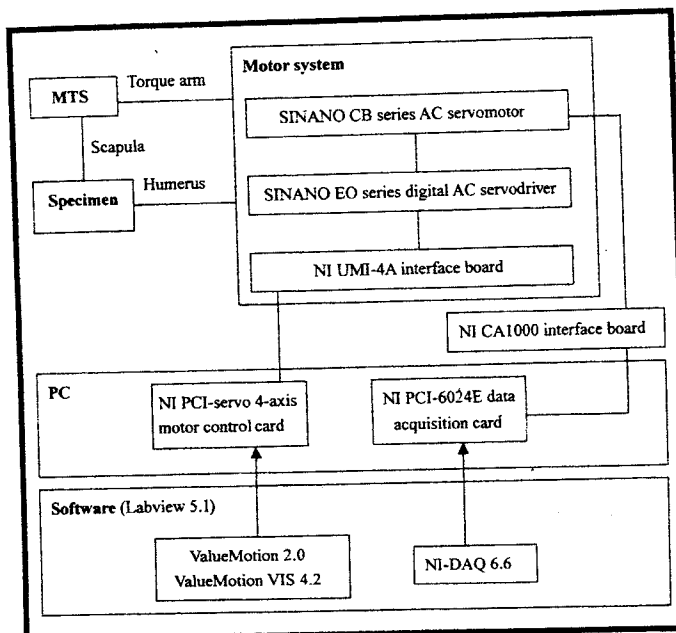


Figure 2. Diagram of experimental setup for testing. Straight lines represent physical connections among components used in the study. Arrows represent control channels. The servomotor is controlled by the motor control card. The torque limit was set and torque output was controlled and recorded by the data acquisition card. MTS=material testing system. NI UMI-4A interface board (model 184966B-01), NI PCI-6024E data acquisition card (model 185415B-02), NI CA1000 interface board, and NI-DAQ 6.6, ValueMotion 2.0, and ValueMotion VIS 4.2 software manufactured by National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759-3504.

Instrumentation

The instrumentation used in the study is shown in Figure 1. A biaxial MTS unit (MTS 858 Mini Bionix[†]) equipped with a custom-made X-Y table was used for experimental simulation. This MTS unit is capable of applying torsion (rotation in the horizontal plane) and tensile (upward) or compressive (downward) forces and displacements controlled by either force (torque) or displacement (angle) limit. The X-Y table was used as the stage for the experiment because it allows displacements in the horizontal plane whenever such movements occur as a result of passive constraints during the evaluation and mobilization procedures in order to eliminate undue stress or strain, and it allows relatively normal arthrokinematics in the glenohumeral joint. A torque arm was designed and made by us for holding the humerus through the mobilization and evaluation procedures. Through this torque arm, the piston rod of the MTS actuator was capable of performing downward and upward displacements (dorsal and ventral glide) of the humerus with a predetermined force limit and torsion (abduction and adduction). A third dimension was added by incorporating a servomotor (SINANO CB

[†] MTS Systems Corp, 14000 Technology Dr, Eden Prairie, MN 55344.

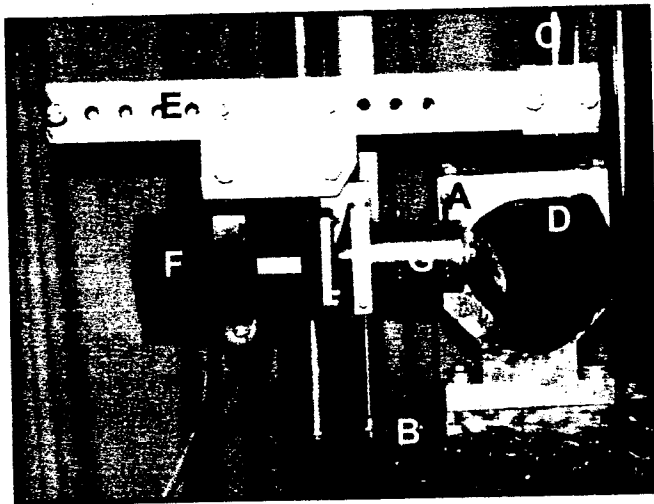


Figure 3. A close-up view of the experimental setup. A=scapular block clamp, B=X-Y table, C=piston of the actuator, D=glenohumeral specimen, E=torque arm, F=servomotor, and G=humeral holder.

series AC servomotor, model 7CB30-2DG7F)[‡] onto the torque arm to perform and record axial (medial and lateral) rotations of the humerus. This servomotor was driven by a digital AC servodriver (SINANO EO series, model E15B-CB301C27F)[‡] and controlled by Labview 5.1 via an NI PCI-servo 4-axis motor control card (184906B-04).[§] A clamp was used to connect the humeral holder to the torque arm to prevent rotation of the humerus during abduction. The clamp was disconnected from the torque arm during the measurement of medial and lateral rotation of the glenohumeral joint. The instrumentation setup diagram is presented in Figure 2.

A 6-camera VICON motion analysis system^{||} was used to test the validity of angle measurement for the servomotor. A 40-cm-long, 5-cm-wide, and 1-cm-thick acrylic plate with 7 retroreflective markers was fixed, at its midpoint, to the shaft of the servomotor. The VICON motion analysis system was used to track the coordinates of each marker and angles of rotation (from -100° to 100° , with increments of 10°) performed by the servomotor. Excellent concurrent validity (intraclass correlation coefficient [ICC (2,1)]=.999) was obtained between angle measurements obtained with the servomotor and the VICON system. Excellent test-retest reliability coefficients also were obtained for angle measurements taken with the servomotor (ICC [2,1]=1.000) and with the MTS (ICC [2,1]=1.000).

[‡] Sinano Electric Co Ltd, 23-11 Sengoku 1-Chome, Bonky-Ku, Tokyo, 112, Japan.

[§] National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759-3504.

^{||} Vicon Motion System Inc, 14 Minns Business Park, West Way, Oxford, OX2 0JB, United Kingdom.

Experimental Setup

The experimental setup is shown in Figure 3. The scapular block was placed on the top plate of the X-Y table by a special clamp custom made by the authors, with the plane of the scapula horizontal and its anterior aspect facing superiorly. The humerus was oriented in a horizontal plane and was parallel with the medial border of the scapula. We defined the neutral position by pressing the humeral head gently into the glenoid fossa until it sat securely in the glenoid fossa and then adjusting the position of the humeral head and shaft until both the shaft of the humerus and the elbow axis were aligned in the plane of the scapula with the shaft of the humerus remaining parallel to its medial border.^{30,34} While holding the humerus in this position, the scapular block was secured to the top plate of the X-Y table with the scapular block clamp. The piston rod of the actuator on the MTS was positioned over the center of the head of the humerus. The torque arm equipped with the servomotor was clamped to the piston rod of the actuator on one end and to the block with the humerus of the specimen on the other. A stainless steel holder connected to the shaft of the servomotor held the block with the humerus in place.

Experimental Procedures

Because the number of specimens available for use in this study was limited, a repeated-measurement design was used. The outcome measures ROM in abduction, medial and lateral rotation of the glenohumeral joint, and the magnitudes of dorsal and ventral displacements of the humerus. The abduction ROM was produced and recorded by the MTS unit with the application of a 4-N·m abduction torque to the glenohumeral joint through the torque arm in the plane of the scapula. The medial and lateral rotation ROMs were assessed by applying a 2-N·m torque in the corresponding direction to the glenohumeral joint by the servomotor installed on the torque arm. The MTS unit also registered linear displacements of the head of the humerus in the dorsal and ventral directions with a 100-N force in each corresponding direction.

The 4-N·m abduction torque was a whole-number derivation (3.56 ± 0.43 N·m) of the abduction torque used by 12 physical therapists, with an average of 13.5 years (SD=4.84) of orthopedic experience, while performing passive abduction ROM on a fresh cadaver glenohumeral specimen mounted on a 6-axis load cell.³⁵ Three ROM measurements were taken to examine the consistency of ROM in response to the same abduction torque. Abduction of the humerus was achieved by a torque applied to the humeral shaft by the torque actuator of the MTS unit through the torque arm at an angular speed of $8^{\circ}/s$. The applied torque would increase in magnitude when resisted by joint tissues until a maxi-

A moment of 4 N·m was achieved, the angular placement was stopped and then reversed to the starting position. The simulated DTM or VTM procedure involved a posteriorly or anteriorly directed force applied by the actuator piston of the MTS in the following manner: the force was increased from 0 to 100 N at a controlled displacement rate of 2 mm/s, was held for 20 seconds, and was moved back to the starting position at the same rate. The 100-N force used in this study was based on the findings of McQuade et al,³⁶ who reported using forces ranging from 101 to 113 N to reach the end point during glenohumeral laxity tests in 21 young subjects with no known pathology.

To date, there are no reports on the differential effects on improving ROM with different durations of force application by therapists during each bout of mobilization in human joints. Research on stretching of hamstring muscles³⁷⁻⁴⁰ and the structures around the hip joint⁴⁰ suggests that longer-duration static stretching is more effective than short-duration stretching³⁹ and that the most effective duration of stretching ranged from 10 to 60 seconds.^{37,38,40,41} Therefore, we used a 20-second holding period during each bout of mobilization to maintain the stretch. To decrease the effect of sequence (whether to apply the DTM or VTM procedure first) on the abduction ROM, the 14 specimens were divided randomly into 2 groups. The DTM procedure was conducted first in the AP group (n=7, mean age=79.0 years, SD=11.1, range=62-91), and the VTM procedure was conducted first in the posteroanterior (PA) group (n=7, mean age=76.3 years, SD=11.8, range=62-91). Given the small number of subjects, the use of a repeated-measurement design could not necessarily result in eliminating the effect of multiple tests and the order in which they were administered.

For AP group specimens, the following procedures were executed.

Procedures performed in the resting position. The testing procedures were started by moving the humerus from the neutral position (0°) to 40 degrees of abduction (the resting position). While holding the humerus in this position, measurements of the position (ROM) in medial and lateral rotation and abduction of the glenohumeral joint were taken in the manner described previously. To test the effect of DTM on glenohumeral abduction, 5 repetitions of the dorsal glide maneuver were applied to the head of the humerus through the torque arm. After the fifth maneuver, the measurements were taken again. This was followed by 5 repetitions of VTM, with measurements taken at the end of the procedure.

Procedures performed in the end-range position. The humerus was then moved to the end range of abduction by the MTS unit with 4 N·m of torque. While holding the humerus in this position, the DTM was performed by the MTS and followed by VTM. Outcome measurements were made before and after DTM, and, finally, after VTM. Experimental procedures for the PA group specimens were essentially the same except that the VTM procedure was always done before the DTM procedure in the resting position as well as in the end-range position.

At the end of the experiment, specimens were dissected further to inspect the shoulder joint visually to determine the presence of observable pathology and to exclude data from specimens that had lost the integrity of its joint or joint capsule. No specimens were excluded.

In an effort to eliminate the effect of minor variations on the abduction torque output, the abduction position was interpolated at the moment when 4 N·m was achieved. Likewise, the measure that allowed us to determine displacement of the humeral head was interpolated at 100 N and the medial and lateral rotation at 2 N·m. For tests performed in the resting position, the differences in ROM measurements obtained before and after DTM (improvement of glenohumeral abduction attributed to the DTM procedure [D_{DTMR}]) and before and after VTM (improvement of glenohumeral abduction attributed to the VTM procedure [D_{VTMR}]) and their corresponding values in the end-range position (D_{DTME} and D_{VTME}) were calculated. These values represent the effects of the mobilization procedure immediately preceding it.

Statistical Analyses

In an effort to determine the effects of mobilization in the different positions, the difference values (before and after) were examined with paired *t* tests against the value of zero. These values were also used in a two-way analysis of variance (ANOVA) for repeated measures to assess the effect of joint position (resting versus end range) and the effect of direction of glide movements (DTM versus VTM) on the ROM of glenohumeral abduction. The same analyses were performed on changes in the medial and lateral rotation angles due to DTM and VTM procedures and on dorsal and ventral displacement. Grouping (AP and PA groups) was the between-subjects variable. A probability value of less than .05 was considered significant. The Statistical Package for the Social Sciences (version 8.0)[#] was used for all statistical analyses.

* SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

Table 1. Peak Dorsal and Ventral Displacement Values (in Millimeters) of the 5 Consecutive Repetitions of the Simulated Glenohumeral Joint Mobilization Executed and Recorded by the Material Testing System with 100 N of Dorsally and Ventrally Directed Forces in the Resting and End-Range Positions

Position ^a	Direction ^b	REP1 ^c			REP2			REP3			REP4			REP5		
		\bar{X}	SD	Range	\bar{X}	SD	Range	\bar{X}	SD	Range	\bar{X}	SD	Range	\bar{X}	SD	Range
Resting	Dorsal	15.25	5.46	6.85-26.27	15.81	5.32	7.33-26.61	16.04	5.27	7.40-26.65	16.22	5.24	7.55-26.83	16.35	5.21	7.59-26.82
	Ventral	25.23	7.30	6.43-35.36	25.99	7.35	6.88-36.19	26.37	7.37	7.11-36.72	26.64	7.39	7.32-37.06	26.84	7.42	7.45-37.32
End range	Dorsal	4.04	1.70	0.76-6.88	4.67	1.75	1.06-7.65	4.96	1.79	1.21-8.04	5.20	1.84	1.32-8.32	5.34	1.86	1.40-8.49
	Ventral	11.65	4.87	4.87-23.45	12.58	4.97	5.36-24.22	13.02	5.01	5.5-14.53	13.35	5.07	5.65-24.97	13.61	5.11	5.70-25.18

^a Position: resting=in resting position of abduction, end range=in end-range position of abduction.

^b Direction: dorsal=dorsal translation, ventral=ventral translation.

^c REP1-REP5=displacement values of the first to fifth repetitions of mobilization.

Results

Amplitude of Ventral and Dorsal Translation During Mobilization

The peak dorsal and ventral displacements calculated for the VTM and DTM procedures are listed in Table 1. There were main effects of joint position ($F=78.52$, $P=.000$) and direction of movement ($F=42.98$, $P=.000$) on values of displacements (Tab. 2). No interaction was found. More displacement ($\bar{X}=11.02$ mm [$SD=5.59$] for DTM, and $\bar{X}=13.23$ mm [$SD=6.04$] for VTM) was allowed in the resting position than in the end-range position and during VTM ($\bar{X}=10.49$ mm [$SD=6.13$] for resting position, and $\bar{X}=8.27$ mm [$SD=5.91$] for end-range position) than during DTM. The increased displacements between successive bouts of DTM or VTM procedures were inversely related to the order of repetition (Fig. 4).

Effect of Dorsal and Ventral Glide on Glenohumeral Abduction

The means, standard deviations, and ranges for glenohumeral abduction ROM before DTM (the initial abduction angle [A_{INR}]), after DTM (A_{DGR}), and after VTM (A_{VGR}) in the resting position and the corresponding variables of the end-range position (A_{INE} , A_{DGE} , and A_{VGE}) are listed in Table 3. No group effects were observed. Changes in abduction ROM attributable to DTM (D_{DGR}) and VTM (D_{VGR}) in the resting position ($\bar{X}=0.17^\circ$ [$SD=0.48^\circ$] and $\bar{X}=0.03^\circ$ [$SD=0.79^\circ$], respectively) and at the end range of abduction (D_{DGE} [$\bar{X}=2.10^\circ$, $SD=1.76^\circ$] and D_{VGE} [$\bar{X}=2.06^\circ$, $SD=1.96^\circ$]) are presented in Table 4. There was an effect of joint position ($F=33.710$, $P=.000$) on the changes in abduction ROM. No effect of direction of gliding movement or interaction between position and direction were noted (Tab. 5).

Effect of Dorsal and Ventral Glide on Glenohumeral Rotation ROM

The ranges of medial rotation measured during various procedures are listed in Table 6, and those of the lateral rotation are listed in Table 7. Two procedures produced small increases in ROM: lateral rotation ROM after the VTM procedure in the resting position ($\bar{X}=0.90^\circ$, $SD=0.92^\circ$, $t=3.65$, $P=.003$) and medial rotation ROM after the DTM procedure in the end-range position ($\bar{X}=0.97^\circ$, $SD=1.45^\circ$, $t=2.51$, $P=.026$). Medial rotation ROM was affected by joint position ($F=61.421$, $P=.000$) and glide direction ($F=4.342$, $P=.024$, Tab. 6). No interaction was found between position and direction. No main effects of joint position or direction of mobilization were found in values of lateral rotation.

Table 2. Primary Results of the Two-Way Analysis of Variance for Repeated Measures on the Effects of Joint Position (Resting Versus End Range) and Direction (Dorsal Versus Ventral) of Displacements^a

Source	df	SS	MS	F	P
Position	1	2058.372	2058.372	78.525	.000
Error (position)	13	340.767	26.213		
Direction	1	1231.443	1231.433	42.976	.000
Error (direction)	13	372.504	28.654		
Position × direction	1	17.214	17.214	2.252	.157
Error (position × direction)	13	99.363	7.643		

^a Values of displacement were measured in millimeters. Displacement values of the 5th repetitions in Table 1 were used for analyses.

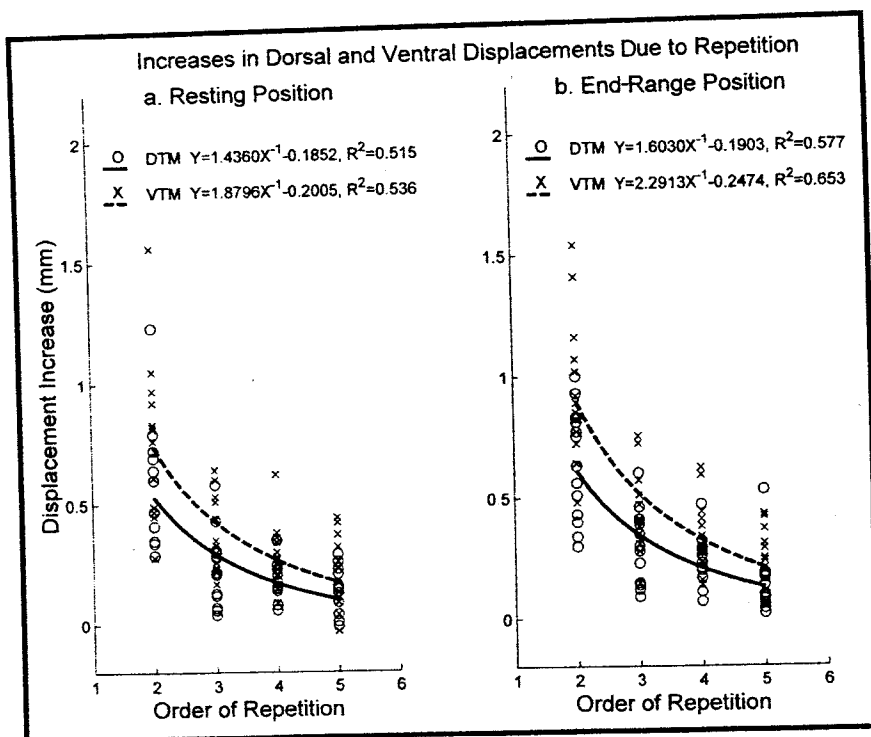


Figure 4. The amount of increase in displacement during dorsal translational mobilization (DTM) (o) and ventral translational mobilization (VTM) (x) in: (a) resting position and (b) end-range position. The amount of increase during the successive repetitions was inversely related to the order of repetition for both DTM (solid lines) and VTM (dashed lines). The amount of displacement corresponds to the order of repetition, indicating the differences in displacement between this repetition and the repetition preceding it.

Discussion

Effects of Dorsal and Ventral Translational Mobilization on Glenohumeral Abduction

In response to DTM and VTM, there was an effect due to of joint position and direction of movement on the amount of translation of the humeral head. More displacement (11.02 mm more for DTM and 13.23 mm more for VTM) occurred in the resting position than in the end-range position. Such a finding could be attrib-

utable to the cradling of the inferior glenohumeral ligament around the humeral head at the end range of abduction.²⁷ More displacement occurred during anterior glide (10.49 mm more for the resting position and 8.27 mm more for the end-range position) than during dorsal glide. Comparison of our findings with those from other studies is difficult because different experimental setups,^{18,23,24,29,42-49} different angles of abduction and rotation,^{18,24,29,42-49} and different magnitudes and directions of translation forces^{18,24,29,42-49} were used, in various studies. The results of our study (Tab. 1) are very similar to those of Black et al,⁴⁸ who reported mean anterior displacements of 27.6 mm (SD=7.5) and 16.9 mm (SD=7.7) in 9 cadaver glenohumeral joints at 45 and 90 degrees of abduction, respectively, in response to a smaller (50-N) anterior force. With the humerus in a neutral position relative to rotation, Debski and colleagues^{23,24} found that anterior displacement of the humeral head was about 5 mm more than that of the posterior displacement in response to an 89 N force in 10 fresh cadaver glenohumeral joints. Pagnani et al,²⁹ Harryman et al,⁴⁶ and Speer et al,⁴⁷ however, reported that anterior and posterior translations were almost the same in magnitude.

In our study, both dorsal and ventral glide (DTM and VTM) procedures when applied at the end-range position were equally effective in increasing glenohumeral abduction. The sequence of testing (regardless of whether DTM or VTM was performed first), in our view, did not affect the outcome. Many factors affect the stability of the head of the humerus: joint surface congruity, joint capsule, labrum, rotator cuff, and

negative intra-articular pressure.¹⁹⁻²⁷ As was noted by Debski et al²³ and Terry et al,⁵⁰ the role of different parts of the glenohumeral joint capsule, due to its continuous nature, leads to a complex distribution of force throughout the capsule in response to displacement of the head of the humerus. Effects of joint position on tensile stress in different portions of the capsule have been studied using simulated laxity tests and selective cutting methods in vitro.^{18,19,23,24,43,45-47} Anterior humeral head transla-

Table 3. Means, Standard Deviations, and Ranges (in Degrees) for Glenohumeral Abduction Range of Motion (ROM)^a Measured During the Procedure Performed in the Study

Group ^b	A _{INR} ^c	A _{DGR}	A _{VGR}	A _{INE}	A _{DGE}	A _{VGE}
AP						
\bar{X}	83.99	84.17	84.34	86.60	88.53	89.64
SD	19.51	19.26	19.49	20.16	20.42	20.41
Range	58.79-116.30	59.22-115.84	59.09-116.27	59.80-117.51	61.17-117.72	62.16-118.26
PA						
\bar{X}	84.55	84.61	84.44	86.60	91.88	89.60
SD	12.61	12.51 ^d	12.60	12.74	13.23 ^d	13.21
Range	56.99-95.88	57.65-96.01	57.22-95.88	59.35-97.51	65.77-107.82	61.99-101.83
Total						
\bar{X}	84.27	84.39	84.39	86.60	90.20	89.62
SD	15.78	15.60	15.77	16.20	16.62	16.51
Range	56.99-116.30	57.65-115.84	57.22-116.27	59.35-117.51	61.17-117.72	61.99-119.26

^a The abduction ROM was achieved by a +N-m abduction torque applied to the glenohumeral joint and recorded by the material testing system unit.
^b Group AP contains specimens with the dorsal glide procedure performed first. Group PA contains specimens with the ventral glide procedure performed first.
^c Values represent the initial abduction ROM measured in the resting position (A_{INR}), after the dorsal glide procedure in the resting position (A_{DGR}), and after the ventral glide procedure in the resting position (A_{VGR}) and ROM measured after the joint was moved to the end-range position (A_{INE}), after the dorsal glide procedure in the end-range position (A_{DGE}), and after the ventral glide procedure in the end-range position (A_{VGE}).
^d The testing sequence was reversed in relation to the variable to its right.

Table 4. Descriptive Statistics for Changes in Glenohumeral Abduction Range of Motion (ROM) (in Degrees) Due to the Effects of Dorsal Glide and Ventral Glide in the Resting and End-Range Positions

Group ^a	D _{DGR} ^b	D _{VGR}	D _{DGE}	D _{VGE}
AP (n=7)				
\bar{X}	0.18	0.17	1.92	1.11
SD	0.61	0.62	1.57	1.03
Range	-0.46 to 1.28	-0.98 to 0.82	0.21 to 4.50	-0.04 to 3.19
PA (n=7)				
\bar{X}	0.17	-0.11	2.27	3.00
SD	0.34	0.96	2.04	2.28
Range	-0.31 to 0.71	-1.86 to 1.33	0.22 to 5.99	0.42 to 7.37
Total (N=14)				
\bar{X}	0.17	0.03	2.10	2.06
SD	0.48	0.79	1.76	1.96
Range	-0.46 to 1.28	-1.86 to 1.33	0.21 to 5.99	-0.04 to 7.37

^a Group AP contains specimens with the dorsal glide procedure performed first. Group PA contains specimens with the ventral glide performed first.
^b Values represent changes in the abduction ROM due to dorsal glide in resting position (D_{DGR}), ventral glide in resting position (D_{VGR}), dorsal glide in end-range position (D_{DGE}), and ventral glide in end-range position (D_{VGE}).

tion was primarily restricted by the coracohumeral and anterior superior glenohumeral ligaments in the neutral position and by the anterior middle and inferior glenohumeral ligaments in the abducted position.^{23,43,45} Like our study, however, these studies were conducted on cadaver specimens; therefore, application to living tissue must be done cautiously. The middle posterior capsule restricted motion for posterior translation of the head in the neutral position, whereas both the middle and inferior capsules were involved in limiting the posterior glide of the head in the abducted position.^{23,43,45} Lateral

rotation in the abducted position stretches the anterior middle and inferior glenohumeral ligaments.^{43,46,47}

Our results are consistent with the findings that laxity tests in the posterior direction primarily stretch the posterior band of the inferior glenohumeral ligament and that anterior translation stretches the anterior band of the inferior glenohumeral ligament when the arm is held near the end range of abduction.^{23,43,45} The anterior and posterior bands and the axillary pouch of the inferior glenohumeral ligament are the primary restraints to the abduction of the glenohumeral joint. Stretching of these capsular ligaments, in our opinion, can lead to improvement in abduction ROM.

Our findings also suggest that DTM and VTM procedures, when performed in the resting position, may not be effective for increasing abduction ROM. Similar results were reported for simulated dorsal and caudal translational mobilization of the glenohumeral joint in fresh cadaver models.^{30,49} In the resting position, the coracohumeral, superior glenohumeral, and middle glenohumeral ligaments are stressed during the anterior laxity test, and the coracohumeral ligament is stretched during the posterior laxity test.^{23,45} Again, we urge caution in using the data because we used cadaver specimens and, in addition, they were from elderly subjects who were over 70 years of