

Measurement of Anterior-to-Posterior Translation of the Glenohumeral Joint Using the KT-1000

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Study Design: Single-group repeated measures.

Objectives: To adapt an existing arthrometer to allow simple quantification of glenohumeral translation and to assess the arthrometer's reliability.

Background: The measurement of glenohumeral translation is an integral part of the clinical examination of the shoulder. However, no objective and reliable measure for glenohumeral translation has been reported.

Methods and Measures: The KT-1000 Knee Ligament Arthrometer was used to measure the amount of anterior-to-posterior (AP) translation of the humeral head at the glenohumeral joints of 28 (16 women and 12 men) nonimpaired undergraduate university students (age 22.1 ± 2.9 years). Two assessments were made (20 minutes apart), by a single tester, of the dominant and nondominant shoulders of each participant.

Results: Anterior-to-posterior translation varied from 10 to 32 mm (20.9 ± 4.9). The test-retest reliability of the KT-1000 when measuring the nondominant shoulders was good (ICC [intraclass correlation coefficient] 0.76), and it was moderate (ICC = 0.67) when measuring the dominant shoulders. The reliability findings were influenced by large amounts of random error. Analysis by ANOVA showed that compared to women (dominant shoulder, 22.6 ± 4.6 mm; nondominant, 23.8 ± 4.2 mm), men showed significantly less glenohumeral translation (dominant, 17.1 ± 3.7 mm; nondominant, 18.3 ± 3.7 mm).

Conclusions: The KT-1000 arthrometer has the potential to provide therapists with a clinically viable method of measuring glenohumeral translation. *J Orthop Sports Phys Ther* 1999;29:602-608.

Key Words: assessment, objective measure, shoulder joint

The glenohumeral joint has been described as the most mobile and potentially unstable joint in the body.⁷ Shoulder dysfunction is commonly associated with an increase or decrease in laxity of the joint, thus establishing the examination of translatory motion as an essential component of clinical assessment.¹⁴ The assessment of joint laxity is used to evaluate joint pathology, diagnose joint disorders, identify deviations from normal joint mechanics, and assist in the selection of treatment techniques.²⁵ The amount of joint laxity is also used as an indicator of an individual's predisposition to musculoskeletal and joint injury⁹ and of development of glenohumeral instability.¹⁰ Despite the recommended use of glenohumeral laxity as a sign of shoulder pathology, the measurement of shoulder laxity is subjective and unreliable.²⁹

The anterior and posterior drawer tests, the apprehension test, and the sulcus sign are manual tests of the glenohumeral joint that are used to document the amount of passive translation available in the shoulder and to repro-

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The protocol for this study was approved by the Faculty of Health Sciences Ethics Committee at La Trobe University, Victoria, Australia.

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duce symptoms of instability.^{4,14} Although these tests provide the therapist with an indication of the amount of movement available and of the quality of shoulder movement, there are problems associated with the clinical testing procedures. For example, tests for laxity of the capsule and ligaments of the glenohumeral joint require the examiner to recognize the amount of force being applied to the joint, estimate the movement occurring at the joint, and consciously compare the response of the joint to the response that would be expected in a nonimpaired shoulder joint.¹⁹ The subjective nature of this process makes it potentially unreliable and susceptible to large amounts of error within and between examiners. Several researchers identified inconsistencies between tester perception of laxity when performing manual laxity tests at the glenohumeral joint and at other joints throughout the body.^{6,19,24,27} This appears to support the suggestion of McFarland et al²⁹ that the manual grading systems commonly used in clinical settings to quantify glenohumeral laxity rely on subjective interpretation of the amount of movement detected and are often not discriminating enough, given the large variations in shoulder translation. It is therefore clear that quantitative measures of joint translation are necessary for accurate and reliable assessment of joint laxity.¹³

Instruments such as the KT-1000 knee ligament arthrometer (MEDmetric Corporation, San Diego, Calif), Acufex Knee Signature System (Orthopaedic Systems Inc, Hayward, Calif), Genucom Knee Analysis System (FARO Medical Technologies Inc, Montreal, Quebec, Canada), Styker Knee Laxity Tester (Styker Corp, Kalamazoo, Mich), and the Dyonics Dynamic Cruciate Tester (DCT Dyonics, Andover, Mass) are commercially available for clinically quantifying laxity at the knee joint.^{1,2,16} However, no such instrument exists for measuring laxity at the shoulder joint. Recent studies have, however, reported the use of test instruments to objectively measure the translation available at the glenohumeral joint in the laboratory setting.^{13,18,26,31} For example, Harryman et al¹³ used electromagnetic spatial trackers to provide a reliable measure of glenohumeral translation. Although this technique allows accurate measurement of the available laxity, its application in the clinical setting is cumbersome because the procedure requires the use of extensive equipment (electromagnetic position sensors, a magnetic field transmitter, and a computer) and also involves invasive attachment of the position sensors to the deltoid tuberosity and scapula. Fluoroscopic evaluation, ultrasound techniques, radiography, and magnetic resonance imaging have also been used to assess translation of the glenohumeral joint.^{11,17,31} While these techniques are useful for laboratory assessment of the shoulder, they are clearly not practical for quantifying glenohumeral laxity in a clinical environment.

Recently, Jorgensen and Bak¹⁸ addressed the need for a simple and accurate measure of glenohumeral-joint translation. They¹⁸ examined the test-retest reliability of the Donjoy Knee Laxity Tester as a measure of translation at the shoulder joint in a combined sample of pathological and nonimpaired subjects. Although the investigators reported excellent test-retest reliability (intraclass correlation coefficient [ICC] = 0.996), the validity of their findings must be interpreted with caution. Specifically, consideration should be given to the large discrepancies between the mean findings for glenohumeral translation of Jorgensen and Bak¹⁸ (2.1 ± 1.7 mm) compared with those reported in investigations of nonimpaired subjects, such as that of Harryman et al¹³ (anterior translation = 7.8 ± 4.0 mm; posterior translation = 7.9 ± 5.6 mm), who used electromagnetic spatial trackers, and Papilion and Shall³¹ (anterior translation = 14.9 mm, standard deviation not reported; posterior translation = 33.7 mm, standard deviation not reported), who used fluoroscopic evaluation.

Despite the possible limitations of the Donjoy Knee Laxity Tester, the use of a portable, noninvasive arthrometer appears to be an innovative and viable concept that deserves further investigation. The construction of a glenohumeral arthrometer or the adaptation of a knee ligament arthrometer to test and quantify glenohumeral-joint laxity would have many benefits in both the clinical and research settings. In the clinical setting, a glenohumeral arthrometer could be used to identify excessive laxity and thus facilitate the prevention of shoulder instability by early implementation of appropriate management strategies. Further, such an instrument could assist with the selection of appropriate treatment regimes and in evaluation of the effects of intervention. In the research setting, the development of a glenohumeral arthrometer could be used to further investigate the relationship between joint laxity and injury. Laxity between dominant and nondominant shoulders, between stable and unstable shoulders, between different age groups, and between men and women could be measured using this device. It is important, however, to first establish the reliability of the instrument before it is utilized in clinical settings to measure glenohumeral-joint laxity.

The aim of this study therefore was to assess the reliability of the KT-1000 Knee Ligament Arthrometer in measuring translation at the glenohumeral joint. It should be noted that the KT-1000 Knee Ligament Arthrometer has been found to be reliable and accurate for measuring measuring knee laxity.^{1,2,8,34,35} We also examined the relationship between gender and glenohumeral-joint laxity.

METHODS AND MEASURES

Participants were 28 (16 women and 12 men) volunteer undergraduate physiotherapy students with

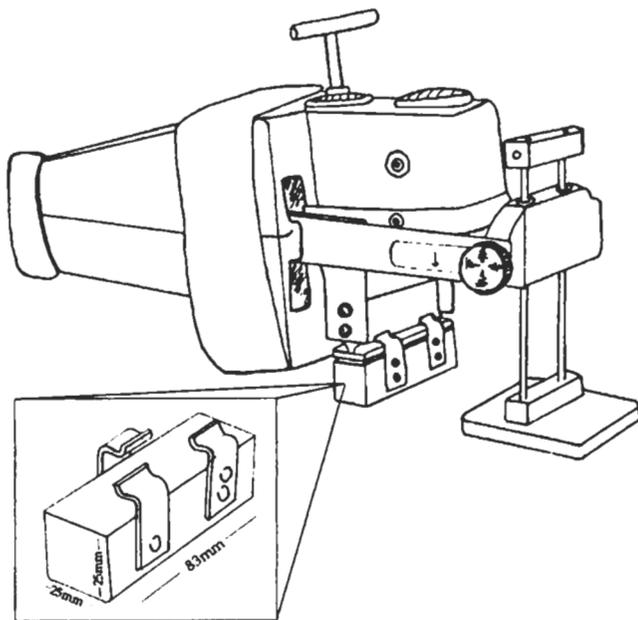


FIGURE 1. The KT-1000 with wooden block attached to the proximal sensor pad to measure translation at the glenohumeral joint.

no history of shoulder pathology. The participants' ages varied from 19 to 34 years (22.1 ± 2.9). Informed consent was obtained from all participants and rights of subjects were protected. The project was approved by the Faculty of Health Sciences Ethics Committee at La Trobe University, Victoria, Australia.

The KT-1000 Knee Ligament Arthrometer (MED-metric), used to measure glenohumeral translation, was modified to ensure that the horizontal sensor bars could be parallel at the beginning of each test: a removable wooden sensor pad was designed and assembled to attach to the proximal sensor pad to increase its depth (Figure 1).

Testing was undertaken with the participants in a prone position with their shoulders exposed and the arm to be tested abducted to 90° (neutral in the coronal plane) and resting on a table positioned beside the plinth. The opposite arm was relaxed on the plinth, and the participant's head was rotated away from the side being tested.

The KT-1000 was positioned on the arm with the proximal sensor pad close to the joint line and equidistant between the acromion and axilla. The distal sensor pad was positioned on a towel placed over the scapula. Velcro straps were fastened around the arm to stabilize the arthrometer (Figure 2). The shoulder girdle was stabilized with pressure exerted by the tester's hand over the scapula and the distal sensor pad of the KT-1000. In this position, the hand of the tester was close to the joint line and exerted adequate pressure to ensure minimal shoulder girdle movement.

The testing protocol was based on that developed

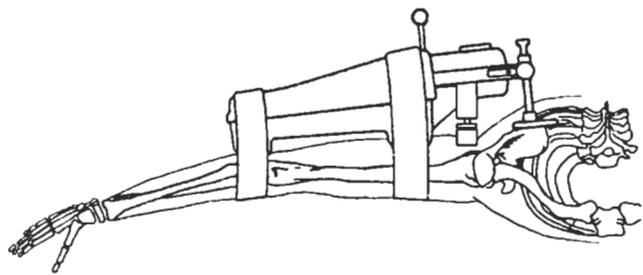


FIGURE 2. Positioning of the KT-1000 to measure anterior-to-posterior translation at the glenohumeral joint. Note that the purpose of this Figure is to indicate the position of the arm and the position of the KT-1000 relative to the arm. It is not an accurate representation of the plane of the scapula or the plane of the translational movement. The position of the arm was chosen ultimately to allow stable and comfortable placement of the KT-1000 on the arm.

by Daniel⁸ for the measurement of translation at the knee joint. Maintaining the constant pressure on the distal pad to stabilize the arthrometer and the shoulder girdle, the horizontal sensor bars were positioned in parallel and the arthrometer dial was set to zero. To calibrate the arthrometer, 3 anteriorly directed forces of 67 N (15 lb), indicated by an audio signal of the KT-1000, were placed through the force handle and released. In line with the KT-1000 instruction manual, the arthrometer was considered zeroed when upon release of the force handle, the dial consistently returned to 0 ± 0.5 mm. With the arm in this position, the anterior translation of the humeral head when the anterior force was applied was negligible in all subjects. It was the aim to standardize the starting position with the humeral head in a maximum anterior position and to obtain a true reading of anterior-to-posterior (AP) glenohumeral translation.

The participants were instructed to relax, and 2 familiarization tests were performed. The tests involved a posteriorly directed force of 67 N (15 lb) being applied to the arthrometer handle. Directly following the posterior pulling force, an anteriorly directed pushing force of 67 N (15 lb) was applied. The amount of displacement measured when the posterior force was applied was recorded only if on release of the anterior force, the needle returned to 0 ± 0.5 mm on the dial. The measurement was considered invalid if the needle on the dial did not return to 0 ± 0.5 mm, as this is an indication that muscle activity is occurring and relaxation has not been achieved.³ The 3 test trials were then performed and recorded in the same manner as the familiarization tests. Of the 3 measurements, the greatest amount of displacement achieved was recorded for statistical analysis. This was based on the argument that maximum relaxation of the participant coincided with the greatest laxity measurement. The entire procedure, including the familiarization tests, was then repeated on the opposite shoulder. The sequence of testing

TABLE 1. Means and standard deviations of humeral head anterior-to-posterior translation.

Group	Mean (mm)*	Standard deviation (mm)
Dominant test 1	20.2	5.0
Dominant test 2	20.1	4.7
Nondominant test 1	21.5	4.8
Nondominant test 2	22.0	4.9

* Represents the mean for the 28 subjects of the trial (of 3 trials) generating the greatest amount of displacement.

was alternated with each participant. Overall, half of the participants had their dominant shoulder tested first, while the other half had their nondominant shoulder tested first. Shoulder dominance was identified through participant self-reporting of preferred arm for throwing a ball and preferred hand for writing. The tester was not blind to the results of each test. The tester recorded the measurements after the 3 trials on the shoulder were complete.

Following the testing of both shoulders, participants rested for 20 minutes, during which time they were asked to be seated with minimal shoulder movement. After the break, the entire procedure was repeated, including participant and arthrometer repositioning, calibration of the KT-1000, familiarization tests, and 3 test trials. All measurements were taken by the 1 tester, who undertook approximately 8 hours of training with the KT-1000 prior to testing.

RESULTS

Reliability

The reliability of the test-retest data was analyzed using the ICC (2,1). The ICC (2,1) uses a single-factor (test-retest), repeated-measures ANOVA to divide the total variance into between subjects and error components. The equation for the ICC is $ICC(2,1) = \frac{BMS - EMS}{(BMS + (k - 1)EMS) + [k(RMS - EMS)/n]}$, where BMS is the between-subjects mean square, RMS is the between-raters mean square, EMS is the error mean square, *n* is the number of subjects, and *k* is the number of factors. The ICC obtained for the dominant shoulder demonstrated moderate reliability (0.67), while the nondominant shoulder ICC finding of 0.76 indicated good reliability.³³

The means and standard deviations of humeral head AP translation for the dominant and nondominant shoulders can be seen in Table 1. The changes between test 1 and test 2 were examined using the 95% confidence intervals. Table 2 shows the mean difference (systematic error), the standard deviation of change scores (random error), and the upper and lower limits of the 95% confidence intervals.

The mean difference (systematic error) values reflect the average of the difference scores between

TABLE 2. Mean difference, standard deviation of observed change scores, and 95% confidence interval limits.

	Mean difference (mm)	Standard deviation of change (mm)	95% Confidence interval	
			Lower limit	Upper limit
Dominant	-0.179	3.98	-8.0	7.6
Nondominant	0.518	3.36	-6.1	7.1

test 1 and test 2. Analysis by paired *t* test showed no significant difference between scores from test 1 to test 2 for the dominant shoulders ($t_{27} = 0.24, P = .81$) or the nondominant shoulders ($t_{27} = -0.82, P = .42$), indicating that no systematic error occurred between test sessions in either shoulder. The standard deviation of observed change scores (random error) was reasonably large for both the dominant and nondominant shoulders.

Sex and Side Comparisons of Shoulder Laxity

To compare the AP translation findings between men and women and between dominant and nondominant shoulders (Table 3), a 2-way ANOVA was used. Sex and side were the factors that were entered into a 2 × 2 ANOVA design. The main effect for gender was significant ($F_{1,52} = 24.1, P = .0001$), indicating that men had significantly less glenohumeral translation than women (Table 3). The main effect of side, however, was not significant ($F_{1,52} = 1.2, P = .28$), and there was no interaction effect ($F_{1,52} = .001, P = .98$).

DISCUSSION

The findings from our study showed that when using 67 N of force, the KT-1000 had moderate to good reliability in testing AP translation at the glenohumeral joint in nonimpaired participants. It is difficult to compare the current reliability findings with those of other studies because of the unique and exploratory nature of this investigation. A search of the literature failed to find any previously published research that reported on the use of the KT-1000 in assessing glenohumeral translation. However, several studies have reported on the clinical reliability of the KT-1000 when testing translation at the knee.^{12,30} For

TABLE 3. Means and standard deviations of anterior-to-posterior translation for the dominant and nondominant shoulders of men and women.

Group	Mean (mm)	Standard deviation (mm)
Men (<i>n</i> = 12)—dominant shoulder	17.1	3.7
Men (<i>n</i> = 12)—nondominant shoulder	18.3	3.7
Women (<i>n</i> = 16)—dominant shoulder	22.6	4.6
Women (<i>n</i> = 16)—nondominant shoulder	23.8	4.2

TABLE 4. Summary of studies that have reported measurements of glenohumeral translation.

Investigators	Instrument	Force used	Participants	Laxity findings (mm)
Pizzari et al (current investigation)	KT-1000 Knee Ligament Arthrometer	67 N	28 nonimpaired participants (22.1 ± 2.9 years)	Anterior-to-posterior: mean = 21.0 (SD = 4.9)
Jorgensen and Bak ¹⁸	Donjoy Knee Laxity Tester	89 N	10 nonimpaired participants (mean age, 25; SD not reported)	Anterior-to-posterior: mean = 2.1 (SD = 1.7)
			10 participants hypermobility (mean age, 24; SD not reported)	Anterior-to-posterior: mean = 11.9 (SD = 6.4)
Papilion and Shall ¹¹	Fluoroscopic evaluation	Not reported	Nonimpaired participants 40 years-and under group (actual number in group was not reported; mean age, 28; SD not reported)	Anterior: mean = 14.9 (SD not reported)
				Posterior: mean = 33.7 (SD not reported)
Harryman et al ¹³	Electromagnetic sensors	Not reported	8 nonimpaired participants (mean age, 34; SD not reported)	Anterior: mean = 7.8 (SD = 4.0)
				Posterior: mean = 7.9 (SD = 5.6)

example, both Hanten and Pace¹² and Myrer et al³⁰ reported high reliability (ICC = 0.84–0.95) when investigating knee joint anterior translation.

The obvious difference between previous studies and our investigation is that we used the KT-1000 to test shoulder laxity. Testing on the shoulder required modification of the KT-1000 and a change in the position of the examiner relative to the participant and the instrument. The investigators^{12,30} testing the reliability of the KT-1000 at the knee joint used 89 N (20 lb) of force to displace the articular surfaces of the joint, whereas in our study, only 67 N (15 lb) was used. It should be noted that the reliability, validity, and sensitivity of the KT-1000 at the knee joint has been shown to improve with force levels greater than 67 N (15 lb).^{3,15} However, because of the exploratory nature of this study and because of previous reports that the glenohumeral joint is the most unstable joint in the body,⁷ we selected a relatively low level of force (67 N [15 lb]) to test glenohumeral-joint translation.

The 95% confidence intervals using the systematic and random-error values provides a valuable frame of reference for interpreting changes between tests of the KT-1000. The 95% confidence interval provides the limits within which one can be 95% confident that change is due to error. Change beyond these limits implies that there has been some significant change that cannot be explained by measurement error alone. The limits of error variance for this study were quite large, suggesting that for the dominant shoulder, an increase between test 1 and test 2 of greater than 7.6 mm or a decrease between tests 1 and 2 of greater than 8.0 mm indicates that an effect has occurred and that the change is not due to error. Clinically, however, such large confidence interval limits are probably inappropriate. For example, if treating a client for reduced shoulder

mobility, the KT-1000 would need to detect an increase of 7.6 mm or larger to ensure that the intervention was efficacious. The large random-error values contributed to the wide limit range. Improving the reliability of the KT-1000 for measurements at the shoulder could help to reduce the random-error values and establish more feasible limits of error variance. This could be achieved by increasing the standardization of the test procedure (eg, standardizing the degree of rotation of the arm), by increasing the level of force used during the test, or by using electromyography on surrounding muscles to ensure optimum muscle relaxation.

In the current investigation, women displayed significantly greater AP translation compared with men. This finding supports the earlier report of McFarland et al,²⁸ who found that men had significantly less inferior translation at the shoulder and were less likely to be subluxated posteriorly during laxity testing than women. Unfortunately, however, McFarland et al²⁸ did not report the actual values of translation but quantified translation using a grading system (Grade I = less than 10 mm, Grade II = 10–15 mm, and Grade III = greater than 15 mm). Further support for gender differences was indicated by Larsson et al²² in their study of 660 subjects (360 men and 300 women), in which they identified that hypermobility is predominantly a female characteristic. Several other investigators have reported that joint hypermobility throughout the body has been observed to occur more frequently in women than men.^{5,20,23} Although these reports do not focus directly on the glenohumeral joint, the belief that generalized ligamentous laxity throughout the body is associated with increased shoulder laxity is supported in the literature.^{21,32,36}

It is interesting to note the considerable variations in laxity at the glenohumeral joint that were demon-

strated in our findings and in previous research (Table 4). There are many possible reasons for the variation of measures across different studies. For example, the test instruments, the position of the shoulders, and the amount of force displacing the articulating surfaces have varied among studies (Table 4); in addition, the sample populations have been heterogeneous, and 1 study³¹ used anesthesia to assist with measurement (Table 4). If valid comparisons are to be made between studies, a more standardized approach to this line of research is required.

Notwithstanding the findings of the present investigation of moderate to good reliability of the KT-1000 in measuring AP glenohumeral translation, some potential limitations should be noted. These include possible inconsistencies in positioning the KT-1000, stabilizing the distal sensor pad, controlling for muscle relaxation, and establishing a consistent starting position of the humeral head. For example, even minimal rotation of the arthrometer over the humerus altered the zeroed reading on the dial, thus affecting the standardization of the arthrometer starting position.

Another important consideration is the ability to generalize our findings to some patients with shoulder dysfunction. For example, the position of the arm during testing may exclude some people from undergoing examination. That is, a person with greatly reduced glenohumeral-joint range of movement or with pain through range may not be able to reach this position.

A final consideration relates to the 67 N (15 lb) of force used in the study. As stated earlier, it could be that this force was not adequate to gain sufficient translational movement of the humeral head. It has been shown at the knee joint that increasing the level of force when using the KT-1000 results in greater translational measurement being recorded and in greater reliability of measurements, compared with when lower levels of force are used.^{3,15} Increasing the level of force at the shoulder could achieve a more valid reflection of the total AP translation of the humeral head; however, within the bounds of this initial investigation it was decided to use a low (conservative) level of force.

Our investigation has identified the need for further study of the reliability of testing glenohumeral translation using the KT-1000. Such research should focus on increasing the standardization of test procedure and on investigating different levels of force in testing the glenohumeral joint.

Aside from the intratherapist reliability findings that we reported, the intertherapist reliability of using the KT-1000 on the shoulder should be examined. Further, comparison of the KT-1000 with other methods of quantifying glenohumeral translation (eg, electromagnetic sensors) would be an important

consideration in examining the validity of the KT-1000 for measuring glenohumeral-joint laxity.

The findings of this study have identified a potentially appropriate instrument for the measurement of AP glenohumeral translation in both clinical and laboratory settings.

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