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Reliability of scapular positioning measurement procedure using the Palpation Meter (PALM)

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Abstract

Background and objectives Observation and measurement of the static position of the scapula is important for investigating both shoulder and neck pathology. Measurement of scapular position is complex and lacks a clinically useful instrument. The objective of this study was to investigate the reliability of the Palpation Meter (PALM) for measuring scapular position when the glenohumeral joint is held in various positions.

Methods Thirty normal subjects were recruited for a test–retest reliability study. Three raters conducted measurements on two different occasions to estimate intra- and inter-rater reliability. The scapular positions evaluated in this study were: (1) the horizontal distance between the scapula and the spine in the scapular resting position and during elevation of the arm in the scapular plane; and (2) the vertical distance between C_7 and the acromion (C_7–A). Intraclass correlation coefficient (ICC), standard error of measurement (SEM) and Bland and Altman limits of agreement were calculated.

Results Reliability values for measurements of the horizontal distance between the scapula and the spine were generally good for both intra-rater (ICC 0.81 to 0.89; SEM 0.56 to 1.17 cm) and inter-rater (ICC 0.67 to 0.89; SEM 0.59 to 0.98 cm) evaluation. Reliability values of measurement of depression of the acromion were also good for both intra-rater (ICC 0.72 to 0.78; SEM 0.66 to 0.79) and inter-rater (ICC 0.76; SEM 0.64) evaluation. No systematic bias was observed with Bland and Altman analysis.

Conclusions The PALM is a reliable tool for the measurement of scapular positioning in a healthy sample. Future studies should be conducted to further investigate the clinometric properties of the PALM in patient populations before its clinical usefulness for measuring scapular position can be established.

Keywords: Scapula; Reproducibility of Results; Body Weights and Measures; PALM; Palpation Meter

Introduction

Observation and measurement of the static position of the scapula is important for investigating both shoulder and neck pathology, which are the second and the third most common sites of musculoskeletal pain [1–4]. Together, they are the most common sites of musculoskeletal disorders, which are the most expensive form of work disability [3–5]. Direct and indirect annual expenses due to all musculoskeletal disorders amount to approximately $26 billion Canadian dollars for the Canadian population (direct costs of CAD$7.5 billion and indirect costs of CAD$18.1 billion), and approximately $38 billion Euros for the German population (direct costs of EUR$25 billion and indirect costs of EUR$13.3 billion) [5,6].

Many techniques and tools have been reported for measuring scapular position [7–13]. However, these techniques/tools are limited to measuring only one of the scapular static positions, or have limited clinical use because they are expensive, time consuming or lack sufficient rigor in their measurement properties [14].

An instrument that could possibly overcome the shortcomings of these techniques/tools is the Palpation Meter (PALM). The PALM has been used to measure pelvic crest height dif-

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ference and has shown to be a valid and reliable instrument [15]. It can also be used to measure scapular medial/lateral displacement and acromion depression, among other measurements (i.e. scapula upward rotation). However, reliability (the degree to which a measurement is considered consistent and reproducible) of the PALM to measure scapular position has not been tested. Reliability is a necessary condition for a measurement to be considered valid or responsive to change, and is essential to determine whether a measurement is valid (truly represents what is being measured) and if it can detect clinically important changes before and following rehabilitation interventions (responsiveness) [16]. Therefore, the purpose of the present study was to evaluate intra- and inter-rater reliability of the PALM for measuring scapular lateral displacement in the scapular resting position and elevation of the arms in the scapular plane (scaption), and for measuring acromion depression in the scapular resting position.

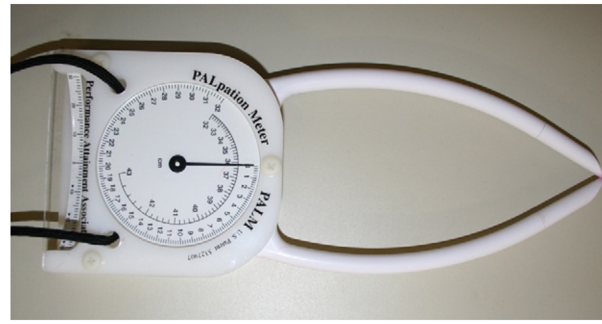

Fig. 1. Palpation Meter.

Methods

Participants

A convenience sample of 30 healthy participants (15 females and 15 males) was recruited. Subjects were recruited continually until 30 subjects were found. Sample size was calculated *a priori* and was estimated so that the study had 80% power with an alpha level of 0.05 for intraclass correlation coefficient (ICC) 0 = 0.7 and ICC 1 = 0.85 with three raters [17]. To be included in this study, participants had to be healthy with no known shoulder pathology, and between the ages of 18 and 40 years to ensure full musculoskeletal development and to avoid joint degenerative changes associated with ageing since both may affect normal biomechanics [18–20]. Participants were excluded if they presented with or had a history of shoulder girdle pain or pathology; cervical radiculopathy with radiating pain to the shoulder; thoracic outlet syndrome; surgery or trauma to the thoracic spine, rib cage, shoulder girdle or cervical spine; scoliosis or hyperkyphosis; any congenital defect of the scapula (e.g. Sprengel's deformity); any neuromuscular disorder such as palsy of the shoulder muscles due to nerve injuries (e.g. long thoracic nerve, suprascapular nerve, axillary nerve); leg length discrepancy; and body mass index (BMI) greater than normal values (i.e. $>25\,kg/m^2$ in females and $>27\,kg/m^2$ in males) [21].

This study received ethical approval from the University of Alberta Health Research Ethics Board prior to data collection. The subjects were fully informed about the nature of the experiment before their agreement to participate.

Raters

Three physical therapists measured the scapular position of the participants. All raters in the present study received approximately 10 hours of training about the study methods, had special training in musculoskeletal rehabilitation, and had a minimum of 1 year of clinical practice in outpatient orthopaedics.

Study design

To investigate intra-rater reliability, all three investigators measured each of the 30 participants in two sessions conducted 1 week apart (each participant was measured six times). The time allowed between sessions was used to prevent the inflation of reliability estimates by recall [22]. The measurements taken in Session 2 were used to determine inter-rater reliability [23].

Instrumentation

Reliability estimates were conducted using the PALM (Performance Attainment Associates, St. Paul, MN, USA) (Fig. 1). The PALM calculator was used for measurement of the vertical distance between body structures. The PALM calculator is a slide ruler that uses the values obtained from the caliper and inclinometer to calculate the vertical distance between the body structures under investigation. The device costs approximately USD$200.

Randomisation

Randomisation using a random-number table was conducted to decide the sequence of examiners measuring each participant during data collection, and to decide which shoulder (dominant or non-dominant) was measured for each participant. The order of arm position measurement (resting scapular position, 90° of scaption and full scaption) was not randomised. The reason for this decision was that the proposed procedure was meant to be used in this sequence in both research and clinical settings. The logical rationale is that patients would start from the easiest position which requires the least range of movement and progress to the most challenging position which requires the greatest range of movement.

Preparation of participants

Prior to the measurement procedure, subjects were asked to report their level of shoulder activity evaluated by the shoulder activity scale [24]. Then, participants were asked to expose their upper thoracic region by wearing a sports bra if female, or taking off their shirt if male. They were also asked to remove their shoes to eliminate potential discrepancies in posture caused by the shoes. Participants were asked to assume a natural and relaxed position while standing on a reference grid which was used to mark the position of their feet. This reference grid was used in the next session to standardise the position of the participant's feet in both sessions.

Measurements

To determine the horizontal distance of the scapula from the spine, two measurements were taken: the horizontal distance from the root of the spine of the scapula to the thoracic spine (Line A–B in Fig. 2), and from the inferior angle of the scapula to the thoracic spine (Line C–D in Fig. 2).

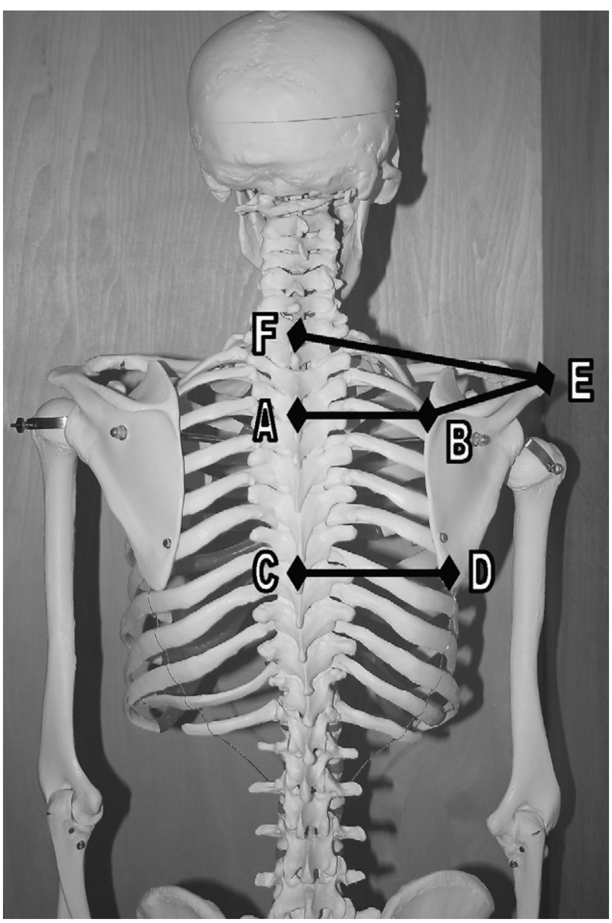

Fig. 2. Anatomical landmarks used for the measurement of scapular protraction and depression. Root of the spine of the scapula (B), corresponding mark on the vertebral column (A), inferior angle of the scapula (D), corresponding mark on the vertebral column (C), postero-inferior angle of the acromion (E), and seventh cervical vertebrae (F).

To determine a normalised value for the horizontal distance of the scapula from the spine, the distance from the posterior angle of the acromion to the root of the spine of the scapula (Line B–E in Fig. 2) was divided by Line C–D; the only normalised measurement in the study. Since the scapula in men is significantly larger than that in women and the taller the person is, the larger the scapula, dividing the distance between scapula and spine by the scapula size is important for reaching a more realistic mean value [7,25,26]. The DiVeta procedure is commonly used to report this normalised value, and involves dividing the distance between the third thoracic vertebra and the acromion by the scapula size [7,27–30]. However, it was decided not to use this procedure since it involves identification of the third thoracic vertebra through palpation, and this could have been an extra source of error to the procedure. It was hoped that decreasing potential sources of error would result in a more reliable measurement procedure.

The last measurement was the vertical distance from the postero-inferior angle of the acromion to C_7 (Line E–F in Fig. 2). Acromion depression was measured in this study because a depressed acromion in the scapular resting position means either depression of the scapula, downward rotation of the scapula or both; all have been associated with shoulder/neck pain and pathology [31]. To define this value, the measured distance between these two landmarks and the measured inclination were combined using the PALM calculator. The spinous process of C_7 was identified by identifying $C_{6.}$ During flexion/extension of the cervical spine, movement is felt in the spinous process of C_6 but not in the spinous process of C_7 [2]. It was decided to measure acromion depression using the spinous process of C_7 and the posterior angle of the acromion due to the simplicity of identifying these structures through palpation.

The examiners used the PALM to measure the previously mentioned distances. The end of one arm of the caliper was positioned over one of the landmarks, and the end of the other arm was positioned over another landmark. The PALM inclinometer had to be level for measurement of the horizontal distance between the scapula and the thoracic spine. The inclinometer value was used to calculate the vertical distance between the scapula and $C_{7.}$ The inclinometer value was ignored for measurement of the distance from the posterior angle of the acromion to the root of the spine of the scapula, since only the distance in centimetres was relevant for this measurement.

Measurement procedure in the scapular resting position

To measure the scapular resting position, the examiners drew a vertical line over the spinous processes of the thoracic spine, which was used to measure the horizontal distance between the scapula and the spine. The line began superior to the scapula and ended inferiorly. The examiners then palpated and identified the inferior angle and the root of the spine of the scapula, the spinous process of C_7 and the postero-inferior angle of the acromion. A line-point grease pencil was used to mark the identified structures. Skin surface palpation has been reported to be a valid method to determine scapular position [32].

After identifying the necessary landmarks, the following verbal instructions were given to the participants: 'Stand facing straight ahead; and allow your hands, shoulders, arms and lower extremities to assume the positions they normally would while you stand in a relaxed way'. No further attempt was made to standardise position since normal posture differs from person to person, and complex methods to standardise posture while standing could compromise the participants' capability to assume a natural relaxed position [9].

Measurement procedure during arm elevation

The procedure used for measuring the scapular position in its resting position was repeated for measuring the scapular position during arm elevation, with the following exceptions: identification of the spinous process of C_7, and the postero-inferior angle of the acromion. These structures were only used for the measurement of acromion depression, which was not measured during scaption. The palpation procedure for identification of landmarks, as previously explained, was reconducted at 90° of scaption and complete scaption.

For measurements of scapular position at 90° of scaption and complete scaption, participants stood on the same reference grid used during measurements in the scapular resting position. The scapular plane was considered 40° anteriorly from the frontal plane [33–35]. Reference poles were used to guide the participant's arm through the scapular plane (Fig. 3). A goniometer was used to determine 90° of scaption [36]. For measurements at the end of the scaption range of motion, the following verbal instructions were given to each participant: 'Elevate your arm along the poles as high as you can with your thumb up, trying not to move your spine'. Participants were asked to keep their thumbs up during arm elevation to control for glenohumeral rotation. Raters observed the participant's trunk during arm elevation and re-inforced instructions to avoid trunk movement if trunk movement was noticed.

Statistical analysis

Statistical Package for the Social Sciences (SPSS) Version 15.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Descriptive statistics were used to describe the population. Mean and standard deviation (SD) were reported for demographic information, BMI and scapular measurements.

ICC was used to generate reliability coefficients for intra- and inter-rater scapular measurements. ICC was calculated using a two-way mixed effects model, single measure reliability [ICC (3,1)] with absolute agreement and alpha level set at 0.05. A 95% confidence interval was calculated to evaluate the precision of the reliability estimate.

Fig. 3. Reference poles used to guide the participant's arm through the scapular plane.

A rigid criterion was not used to assess reliability coefficients since its use is highly debatable [16,37]. Instead, it is suggested that absolute reliability should be reported to supplement relative reliability (ICC). Relative reliability refers to the position of a measurement value in relation to the other measurement values in test–retest situations. Perfect relative reliability occurs when all measurements keep the same positions in relation to the other measurements from test to retest. Spurious high values of relative reliability occur if all measurements substantially vary their absolute value from test to retest without changing their position within the group of measurements. This problem occurs since reliability estimates such as the ICC are dependent on the heterogeneity of the sample under investigation. More heterogeneous samples result in a relatively lower ICC compared with less heterogeneous samples, even when the error variance is the same. Therefore, it is important to evaluate absolute reliability. Absolute reliability indicates how much variation occurs on test–retest, and gives objective values for the evaluation of this variation. In this way, clinicians or researchers can know in absolute values how much variability in the scores can be expected due to measurement errors. Therefore, the standard error of measurement (SEM) was calculated to report absolute reliability. SEM was calculated using the following formula: $SEM = SD\ (1 - ICC)^{1/2}$.

In order to investigate whether systematic biases between raters occurred, and quantify how much measurements differed between raters, Bland and Altman's limits of agreement were calculated for each measurement [38].

Table 1
Mean, standard deviation (SD) and range of demographic data for participants.

Demographics	Mean (SD)	Range
Age (years)	26.5 ± 3.79	21 to 36
Height (m)	1.72 ± 0.08	1.55 to 1.94
Weight (kg)	68.8 ± 11.17	47.5 to 102.0
BMI (kg/m^2)	23.3 ± 2.76	17.9 to 27.0

Table 2
Shoulder activity level of participants as measured by the shoulder activity scale.

Activity level	*n*
Low	9
Average	19
High	2

Results

Sample characteristics

Thirty-five participants were screened, and 30 were recruited for the study (15 males and 15 females). Five participants were excluded from the study for the following reasons: three participants reported a history of shoulder pain and/or instability, and two participants presented trunk asymmetry during Adam's forward bending test. The study sample mainly consisted of students from the University of Alberta. Measurements of the dominant shoulder were taken in 15 participants. Tables 1 and 2 show the characteristics of the participants involved in this study.

Agreement among raters

The mean of the absolute values of the measurements was similar between raters. The distance from the inferior angle of the scapula to the spine increased constantly with arm elevation, whereas the distance between the root of the spine of the scapula and the spine remained similar for different arm positions. Table 3 shows the mean value of each measurement taken by each rater, intra- and inter-rater ICC values and their respective confidence intervals, along with the SEM.

Two Bland and Altman plots representative of intra- and inter-rater reliability of the measurements are presented in Figs. 4 and 5. They show the average of measurement values

Table 3
Mean, standard deviation (SD), intraclass correlation coefficient [ICC; 95% confidence interval (CI)] and standard error of measurement (SEM). 1 = Rater 1; 2 = Rater 2; 3 = Rater 3. Mean and SD of measurements are presented in centimetres.

Position	Measurement	Mean (SD)	Intra-rater ICC (95% CI)	Intra-rater SEM (cm)	Inter-rater ICC (95% CI)	Inter-rater SEM (cm)
Neutral	Inferior angle	1 = 8.5 (1.7)	1 = 0.83 (0.67 to 0.91)	1 = 0.69	0.89 (0.81 to 0.94)	0.59
		2 = 8.5 (1.7)	2 = 0.89 (0.79 to 0.95)	2 = 0.56		
		3 = 8.6 (1.7)	3 = 0.83 (0.69 to 0.91)	3 = 0.70		
	Root of the spine of the scapula	1 = 8.0 (1.4)	1 = 0.77 (0.57 to 0.89)	1 = 0.69	0.77 (0.62 to 0.87)	0.69
		2 = 7.9 (1.4)	2 = 0.78 (0.59 to 0.89)	2 = 0.68		
		3 = 8.0 (1.4)	3 = 0.81 (0.65 to 0.91)	3 = 0.63		
	Normalised distance	1 = 1.6 (0.3)	1 = 0.75 (0.54 to 0.87)	1 = 0.15	0.75 (0.56 to 0.87)	0.19
		2 = 1.7 (0.4)	2 = 0.85 (0.70 to 0.92)	2 = 0.15		
		3 = 1.6 (0.3)	3 = 0.69 (0.44 to 0.84)	3 = 0.18		
	Vertical distance	1 = 7.3 (1.5)	1 = 0.72 (0.49 to 0.86)	1 = 0.79	0.76 (0.61 to 0.87)	0.64
		2 = 6.9 (1.4)	2 = 0.78 (0.59 to 0.89)	2 = 0.66		
		3 = 6.9 (1.3)	3 = 0.74 (0.53 to 0.87)	3 = 0.67		
90° of scaption	Inferior angle	1 = 11.1 (2.1)	1 = 0.69 (0.45 to 0.84)	1 = 1.17	0.74 (0.56 to 0.86)	0.98
		2 = 11.4 (1.8)	2 = 0.70 (0.45 to 0.84)	2 = 0.99		
		3 = 12.0 (1.7)	3 = 0.89 (0.79 to 0.95)	3 = 0.56		
	Root of the spine of the scapula	1 = 7.6 (1.6)	1 = 0.86 (0.73 to 0.93)	1 = 0.61	0.74 (0.59 to 0.87)	0.84
		2 = 7.9 (1.6)	2 = 0.86 (0.65 to 0.94)	2 = 0.60		
		3 = 8.0 (1.7)	3 = 0.78 (0.59 to 0.89)	3 = 0.79		
Full scaption	Inferior angle	1 = 16.5 (1.9)	1 = 0.88 (0.76 to 0.94)	1 = 0.68	0.85 (0.75 to 0.92)	0.74
		2 = 16.7 (1.8)	2 = 0.71 (0.48 to 0.85)	2 = 0.98		
		3 = 16.5 (1.8)	3 = 0.86 (0.72 to 0.93)	3 = 0.70		
	Root of the spine of the scapula	1 = 8.4 (1.3)	1 = 0.73 (0.50 to 0.86)	1 = 0.70	0.67 (0.49 to 0.81)	0.87
		2 = 8.1 (1.5)	2 = 0.73 (0.50 to 0.86)	2 = 0.79		
		3 = 8.0 (1.7)	3 = 0.85 (0.70 to 0.92)	3 = 0.68		

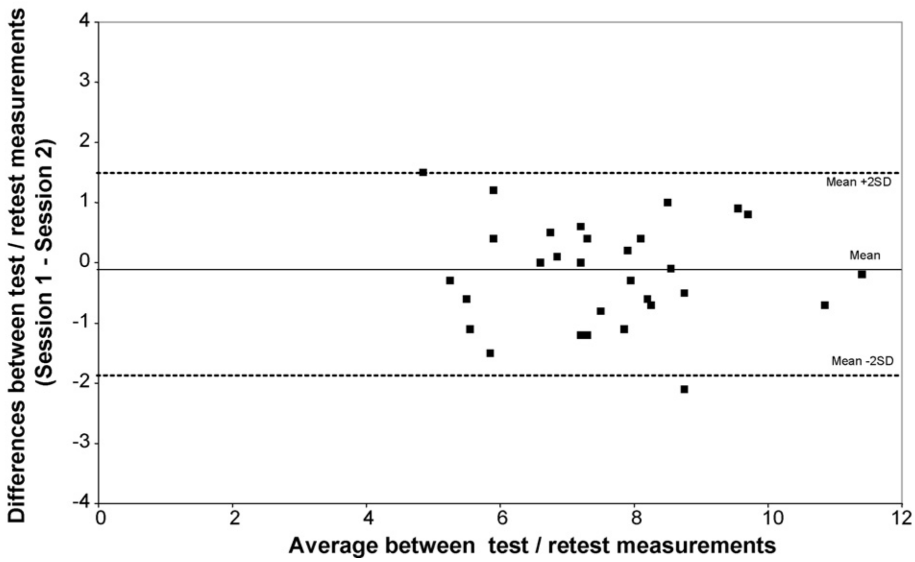

Fig. 4. Bland and Altman plot showing the average of measurement values obtained by a single rater in test/retest plotted against the difference between the two measurements. Plot presents measurements of the distance from the root of the spine of the scapula to the thoracic spine with 90° of scaption.

obtained by a single rater (Fig. 4) or two raters (Fig. 5) plotted against the difference between the two measurements. The mean difference between measurements was below 1 cm for 21 (70%) participants for measurements obtained either by a single rater (intra-rater) or two raters (inter-rater). Limits of agreement were −1.88 and 1.54 cm for intra-rater measurement and −2.15 and 1.79 cm for inter-rater measurement, which further supports good agreement between one rater measuring on two occasions, and two raters measuring on the same occasion.

Discussion

In general, the ICC values reported in this study demonstrated good to excellent reliability as the lower value of the 95% confidence intervals was above 0.4 [39]. All of the SEMs reported in this study are below 0.8 cm, which may be low enough to be clinically important since a single intervention aiming at improving scapular positioning may cause changes of 1.4 cm in scapular lateral displacement and 1.7 cm in scapula elevation in the resting position of the

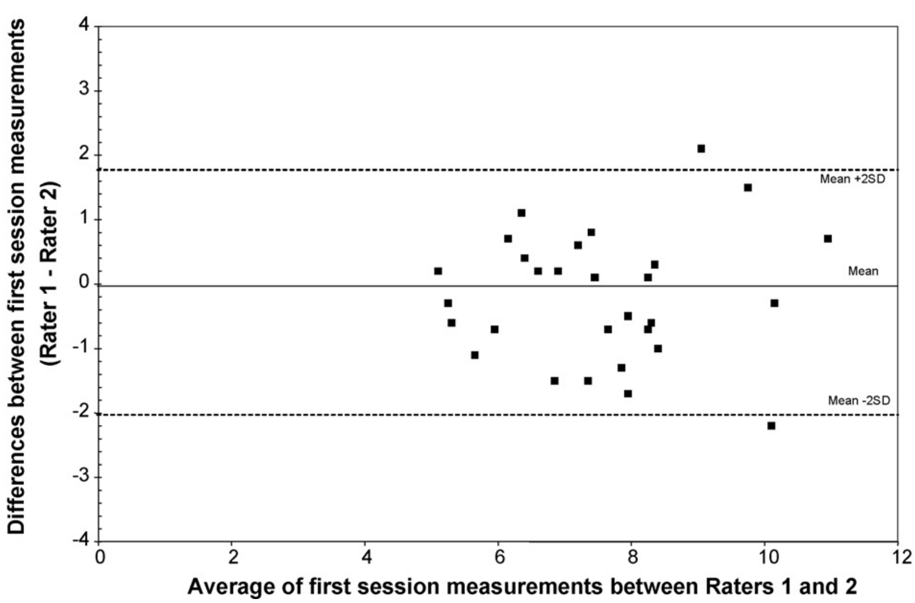

Fig. 5. Bland and Altman plot showing the average of measurement values obtained by two different raters plotted against the difference between the measurements of both raters. Plot presents measurements of the distance from the root of the spine of the scapula to the thoracic spine with 90° of scaption.

Table 4
Reliability values for the Palpation Meter (PALM) and other instruments for the measurement of the distance between inferior angle of the scapula and spine.

Study	Intra-rater ICC	Intra-rater SEM (cm)	Inter-rater ICC	Inter-rater SEM (cm)	Measurement tool
da Costa [this study]	0.89	0.56	0.89	0.59	PALM
Gibson 1995 [28]	0.94	0.44	0.69	1.20	Piece of string
T'Jonck 1996 [29]	0.93	0.18	0.78	0.57	Tape measure
Crotty 2000 [30]	0.98	0.27	0.87	0.75	Inelastic white fabric
Plafcan 2000 [41]	0.88	0.44	0.80	0.56	Scapular measurement instrument
Odom 2001 [11]	0.75	0.61	0.67	0.79	Piece of string
Lewis 2005 [40]	0.98	0.30	–	–	Measurement of photographs
McKenna 2004 [42]	–	–	0.87	0.53	Tape measure

ICC, intraclass correlation coefficient; SEM, standard error of measurement.

shoulder [40]. The mean difference of measurements within and between all three raters was generally low and did not follow a specific pattern, indicating that there was no systematic bias, such as one rater scoring consistently higher or lower than the other. The limits of agreement indicate that on 95% of occasions, the maximum difference found between two measurements of a single rater will be less than 1.89 cm and between two different raters will be less than 2.16 cm.

Comparison of ICC and SEM of the PALM with other instruments

To better understand the clinical relevance of the results presented in this study, they were only compared with results of studies that reported both ICC and SEM of clinical measurements [37]. Tables 4 and 5 depict reliability values of studies used for comparison [11,28–30,40–42].

Judging by the SEM in Tables 4 and 5, intra-rater reliability does not seem to differ between the PALM and other tools for measuring the distance from the scapula to the spine. However, the PALM seemed to have better inter-rater reliability for measuring the distance from the scapula to the spine than other tools, although comparison across studies was limited due to different measurement procedures (i.e. use of different landmarks and measurements taken in different planes of arm elevation). Interestingly, reliability of the tape measure reported by previous studies is similar to reliability of the PALM. This is a relevant remark since tape measures are considerably cheaper than the PALM. However, such analysis must be carefully conducted and interpreted, as issues with the study design and statistical analysis of those studies using tape measures to determine scapular position may have led to spurious high values of reliability.

Since the present study used a different method for calculating the normalised values of the distance between the scapula and spine and of acromion depression, no studies were found to compare ICC and SEM with the values reported in the present study.

Methodological issues

Probable important reasons for differences in reliability values for the measurement of the scapular position obtained from different studies are memory effect, learning effect, different rater expertise among studies, and different methods for ICC calculation.

Memory effect was a frequent problem observed in previous studies looking at scapular position measurement procedures. Conducting intra-rater measurements with only a few minutes between test and retest may have resulted in high ICC values and low SEM values in these studies [43]. This information may have limited clinical utility since it is not common for a clinician to conduct measurements of scapular position within minutes of a previous measurement in the clinical setting. In this study, a week was chosen to be the time between tests in order to overcome this limitation. One week was considered to be appropriate to avoid a memory effect and significant changes in the participant's shoulder posture, but to still have clinical importance.

Also, there was a significant learning effect among the raters of the present study. Although it was decided *a priori* that inter-rater reliability would be estimated using the measurements of the retest, the inter-rater ICC of the first test was calculated to analyse whether an apparent difference existed. Inter-rater ICC values of the first test were markedly lower compared with inter-rater ICC values of the retest. This may have occurred due to an improvement in the raters' skills to conduct the measurements, more specifically to identify the necessary landmarks through palpation. Although all raters in the present study received

Table 5
Reliability values for the Palpation Meter (PALM) and other instruments for the measurement between root of the spine of the scapula and spine.

Reference	Intra-rater ICC	Intra-rater SEM (cm)	Inter-rater ICC	Inter-rater SEM (cm)	Measurement tool
da Costa [this study]	0.81	0.63	0.77	0.69	PALM
T'Jonck 1996 [29]	0.99	0.12	0.79	0.57	Tape measure
Plafcan 2000 [41]	0.86	0.43	0.61	0.72	Scapular measurement instrument
McKenna 2004 [42]	–	–	0.74	0.59	Tape measure

ICC, intraclass correlation coefficient; SEM, standard error of measurement.

about 10 hours of training dealing with the study methods prior to collecting the study's data, and were physical therapists with special training in musculoskeletal rehabilitation, a learning effect is likely to have occurred since none of them had significant clinical experience with the measurement of scapular position using the PALM. Therefore, a clinician who wishes to use this technique to measure scapular position interchangeably with other clinicians' measurements should be aware that the inter-rater ICC values resulting from this procedure were only achieved after some training.

Furthermore, years of clinical experience with the shoulder girdle of the raters involved in this study was much lower compared with the raters of the studies that did report this information. It was observed that palpation of the landmarks used for scapular position measurement, such as the inferior angle and root of the spine of the scapula during arm elevation, requires considerable training and expertise for optimal identification. It is expected that ICC values decrease and SEM values increase with elevation of the arm due to the difficulty of palpation through contracted muscles. In the present study, a decrease in ICC and an increase in SEM with arm elevation was observed. The most significant decreases in reliability that occurred with arm elevation were the inferior angle of the scapula at 90° of elevation, and the root of the spine of the scapula at complete arm elevation. Plafcan *et al.* reported that raters had difficulty locating scapular landmarks during arm elevation, and they believed that this issue resulted in lower reliability of their procedure [41]. Thus, limited shoulder palpation expertise may also have had a significant negative influence in the ICC and SEM values reported in the present study.

Finally, another factor that could have influenced the reliability values between studies is the use of different methods to calculate ICC. In the present study design (raters as a fixed effect, measurements were not averaged and absolute agreement was desired), the most conservative way of calculating ICC was used. This could have resulted in more consistent but lower ICC and larger SEM values for both intra- and inter-rater reliability. The studies used for comparison had similar study designs, and thus should also have used the most conservative approach to calculate ICC. However, most of these previous studies did not give full details of how ICC was calculated, which limits comparisons with the results of the present study.

Strengths and limitations

The strengths of the present study include the design and statistical analysis used to measure reliability, as previously discussed. A limitation but also a strength of the present study was the trade-off between internal and external validity due to limited shoulder joint expertise of the raters involved in this study. This limitation impaired the observation of the optimal reliability of this procedure (decreased internal validity). On the other hand, it allows generalisation of the results to clinicians who do not have many years of clinical experience with the shoulder joint (increased external validity). Thus, it is expected that non-expert clinicians can achieve similar levels of reliability when conducting the measurements of scapular position proposed in the present study.

Two factors could limit the clinical generalisability of the present study: the inclusion of only those individuals who did not have present or history of shoulder pathology, as well as subjects who did not exceed normative BMI values. These factors do not allow direct generalisation of the findings of this study to individuals who do not possess these characteristics, as reliability may be lower for individuals with shoulder/neck pain and individuals with above normative values of BMI. Moreover, it is important to stress that reference poles were used to guide scaption, and that the use of a vertical structure (such as the doorway) may be important to reproduce the measurement reliability reported in this study.

Future studies and practical applicability

It is not sound at this stage to conclude which tool or method is optimal for measuring scapular position in the clinical setting. Given the scarcity of reliable and valid tools for measuring scapular position, it is important to conduct further studies to investigate the clinical utility of the PALM to measure scapular position due to the promising results found in this study.

Nevertheless, considering the methodological flaws of other studies that investigated the reliability of clinical tools used for the measurement of medial/lateral displacement and depression/elevation of the acromion, the PALM seems to be one of the clinical tools with the strongest evidence of reliability. Thus, future studies should test intra- and inter-rater reliability of different scapular position measurement tools commonly used in clinical settings, taking into consideration the methodological issues highlighted in the present study, so that a better comparison can be made between the PALM and other measurement tools. Moreover, future studies should be conducted to investigate other important measurement properties of the PALM, such as concurrent validity (e.g. comparing PALM with measurements taken in radiographs) and responsiveness to change (e.g. before and after treatment or comparing control with shoulder pathology groups).

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