Title:

Tracking the Scapula using the Scapula Locator with and without Feedback from Pressure-sensors: a Comparative Study

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Abstract

Background: The scapula locator method has associated intra-observer and inter-observer errors caused by the dependency on the observer to locate the scapular landmarks. The potential effect of the pressures applied by the observer on the measured scapular kinematics when this method is used has also been overlooked so far. The aim of this study was to investigate the effect of using feedback on the pressures applied on the scapula using the locator on the intra-observer and inter-observer reliabilities of the method as well as on the kinematics obtained using this method.

Methods: Three observers tracked the scapular motion of the dominant shoulder of each subject using the locator with no reference to pressure-feedback for three trials of bilateral elevation in the scapular plane and using the locator with pressure-feedback for three other trials. Variations between the measurements obtained were used to calculate the intra-observer errors and variations between the measurements obtained by the three observers for the same subject were used to calculate inter-observer errors. Repeated-measures ANOVA tests were used to look at differences between the two methods in terms of intra-observer and inter-observer errors and scapular kinematics.

Findings: Using pressure-feedback reduced the intra-observer errors but had no effect on the inter-observer errors. Different scapular kinematics was measured using the two methods.

Interpretations: Pressure-feedback improves the reliability of the scapula locator method. Differences in the scapular kinematics suggest that unregulated pressures have an effect on the physiological scapular motion.

1. Introduction

The thick layer of soft-tissue covering the scapula makes it difficult to determine the bone's position during motion. This has led to the development of a number of scapular measurement techniques. Non-invasive techniques include the use of an acromion sensor, but it has been shown to have high errors above 100° of elevation (Karduna et al., 2001; van Andel et al., 2009). Other non-ionising imaging techniques have been recently used; however they restrict subjects to certain orientations and are yet to be validated (Hill et al., 2007). The scapula locator method was developed to reduce the problem of soft-tissue deformation and is commonly used in clinical studies (Kontaxis and Johnson, 2008; Price et al., 2001). However, the manual handling of the locator by an observer means that the method is associated with intra-observer and inter-observer errors (de Groot, 1997; Meskers et al., 1998).

Furthermore, there is no information on the effect of external forces applied on the scapula on the shoulder kinematics. Therefore the effect of the unregulated pressures applied using the locator on the scapular movement is unknown. Recently a new scapula locator has been developed which allows the observer to maintain regulated range of low pressures on the landmarks using feedback from pressure-sensors whilst tracking the scapular movement (Shaheen, 2010).

The aim of this study is to investigate whether feedback on the pressures applied on the contact points with the scapular landmarks improves the intra-observer and inter-observer reliabilities of the scapula locator and whether the unregulated pressures applied using the locator have an effect on the measured kinematics.

2. **Methods**

Instrumentation

An optical motion system (Vicon, Oxford) was used to track markers attached to the humerus, thorax and scapula locator. The locator has three pressure sensors (Interlink Electronics, Camarillo) attached to the tips of the probes in contact with the acromial angle (AA), inferior angle (AI) and root of the scapular spine (TS). Feedback from the pressure-sensors was displayed on a computer screen (Figure 1).

Study population

14 male subjects with mean age of 29.4 ± 11.1 years, fully functional shoulders as assessed by the Oxford Shoulder Score (Dawson et al., 2009) and no history of shoulder pain participated in the study.

Data capture

Subjects performed bilateral elevations in the scapular plane at a velocity of approximately 10°/s with the help of a metronome. An observer tracked the movement of the scapula using the locator without reference to the pressure-sensors feedback (Method NF) for the first three trials. For three other elevations the observer used the locator with feedback from the pressure-sensors to track the scapula whilst aiming to maintain regulated range of low pressures of approximately 1-3 N of force on the landmarks (Method F). This was repeated by two other observers for the same subject. All observers received the same training on how to palpate and track the scapula prior to the start of the experiment.

In order to avoid the interaction of the two methods if observers learn to regulate the pressures with Method F and transfer this learning when using Method NF; all observers used Method NF for the first three elevations and Method F for the latter three. A preliminary study has already shown that six consecutive trials using the same method (either NF or F) do not produce improvement due to practise alone (Shaheen, 2010).

For 13 out of the 14 subjects the experiment was completed over two sessions instead of one. For this reason, only the measurements obtained by two observers in a single session were used to calculate inter-observer variations, therefore avoiding the inclusion of inter-session errors.

Data analysis

Anatomical co-ordinate frames for the thorax, humerus and scapula were defined (Wu et al., 2005). Glenohumeral and humerothoracic rotations were calculated using Euler rotations in the sequence of x-z'-y'' (abduction, flexion, axial rotation) and scapulothoracic rotations in the sequence of y-x'-z'' (internal, upward, tilt).

The intra-observer errors are the standard deviation between the trials of each observer measuring the same subject and the inter-observer errors are the standard deviation between the mean measurements of the two observers measuring the same subject in the same session.

A repeated-measures ANOVA test was used to compare the scapulothoracic intra-observer variations, inter-observer variations and kinematics between the two methods at humerothoracic abduction angles of 30 - 140° at 10° intervals. Where an interaction between the method and abduction angle was significant, factorial ANOVA tests were used to determine if differences between the methods lay in low (< 90°) or high (≥ 90°) elevations.

3. **Results**

Mean intra-observer variations for internal, upward rotations scapular tilt (abduction angles ≥ 90°) are significantly smaller for Method F (Table 1). No difference was found in the inter-observer variations between the methods (Table 1). Method NF was found to measure more internal rotation and anterior tilt than Method F in high abduction angles (Table 2, Figure 2).

4. Discussion

Intra-observer and Inter-observer Reliability

The internal rotation and tilt intra-observer and inter-observer errors of the two methods were found to increase with elevation (Figure 2). This is likely to be influenced by the increase in the difficulty of palpation at higher elevations and because the landmarks are only palpated once at the start and tracked for the rest of the motion; causing an accumulation of errors. Nonetheless, the mean intra-observer and inter-observer errors were still comparable or smaller than those reported when using the locator statically (Barnett et al., 1999; Meskers et al., 1998).

Although the difference between the errors of the two methods is relatively small, using the locator with feedback is found to reduce the intra-observer errors by means ranging from 15 - 20% for the three scapulothoracic rotations. For the internal rotation and tilt this error reduction increases with humeral elevation and ranges from 0.3 – 1.8° (Figure 2). These values can be of significance particularly when compared to the full range-of-motion of these rotations. Despite the large range-of-motion of the upward rotation the feedback only reduces the errors by approximately 0.5° over the whole range of abduction and is therefore less significant.

The use of the pressure-sensors feedback to reduce intra-observer errors is strongly recommended in measurements of movements occurring at high elevation angles. But the additional cost of attaching pressure-sensors to the locator may not result in an added advantage if measurements within the functional range (< 90°) only are being measured.

The inter-observer errors were not reduced with pressure feedback; suggesting that observers introduce a consistent error to the measurements. In future studies, the use of a single observer to obtain the measurements is recommended.

Kinematics

The measured scapular internal and upward rotations of the two methods are largely comparable to previous studies but the tilt measured in this study is more anterior than in other studies (Meskers et al., 1998, Meskers et al., 2007). This is likely to be caused by inter-individual differences (de Groot, 1997), and also because of the small subject groups employed by all these studies which means that they are not representative of the same overall population.

Differences in the scapular kinematics between the two methods at high abduction angles can be explained from studying the operation of the observers. For the measurements of right shoulders in this study, observers use their fingers to track the movement of AA and AI and they tilt the locator until the last probe is in contact with TS. When the palpation of the landmarks becomes more difficult at high abductions, observers rely on the feedback to track TS. But when there is no feedback, observers tend to either put too little pressure on the third probe causing it to come on and off the landmark, or too much pressure to ensure that the probe is always in contact with TS, with the latter being the more common technique. Most observers applying high pressure on TS also apply a high pressure on AA; this could have been influenced by the fact that all observers were right-handed and used their right-hand to both track AA and tilt the locator to be in contact with TS. If high pressures had an effect on the physiological shoulder motion, the high pressure on AA would be expected to internally rotate the scapula, and the relatively lower pressure on AI would anteriorly tilt the scapula; which is what is observed in Method NF.

This is the first time evidence is given to suggest that external forces can affect the scapular physiological motion, though these differences are small. The differences in the measured kinematics may have been influenced by the different measurement techniques employed with the two methods and by the variations between the same subject's movements i.e. motor noise (de Groot 1997).

5. **Conclusions**

Using the scapula locator with pressure feedback improves the intra-observer reliability. Differences in the measured kinematics between the two locator methods suggests that unregulated pressures on the scapula alter the physiological scapular motion although this difference may be influenced by other factors related to technique and motor noise.

Acknowledgements

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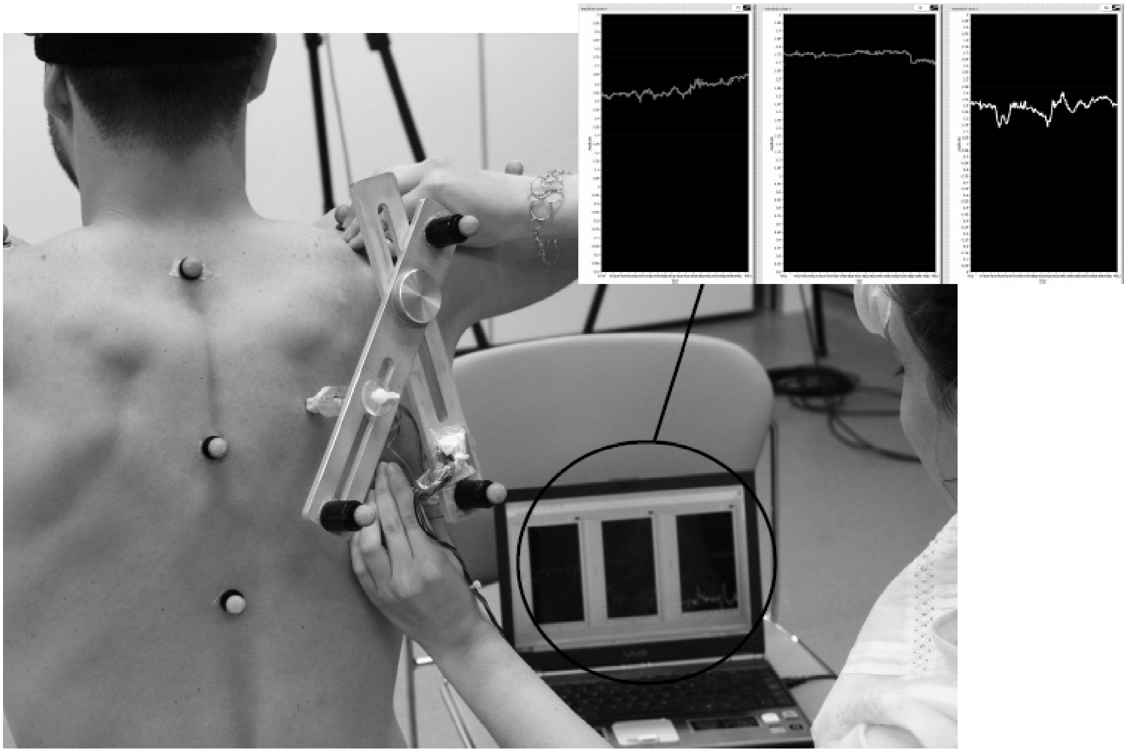

Figure 1: Using the scapula locator with pressure-feedback. The observer aims to apply regulated range of low pressure levels on the scapular landmarks using feedback displayed on the screen.

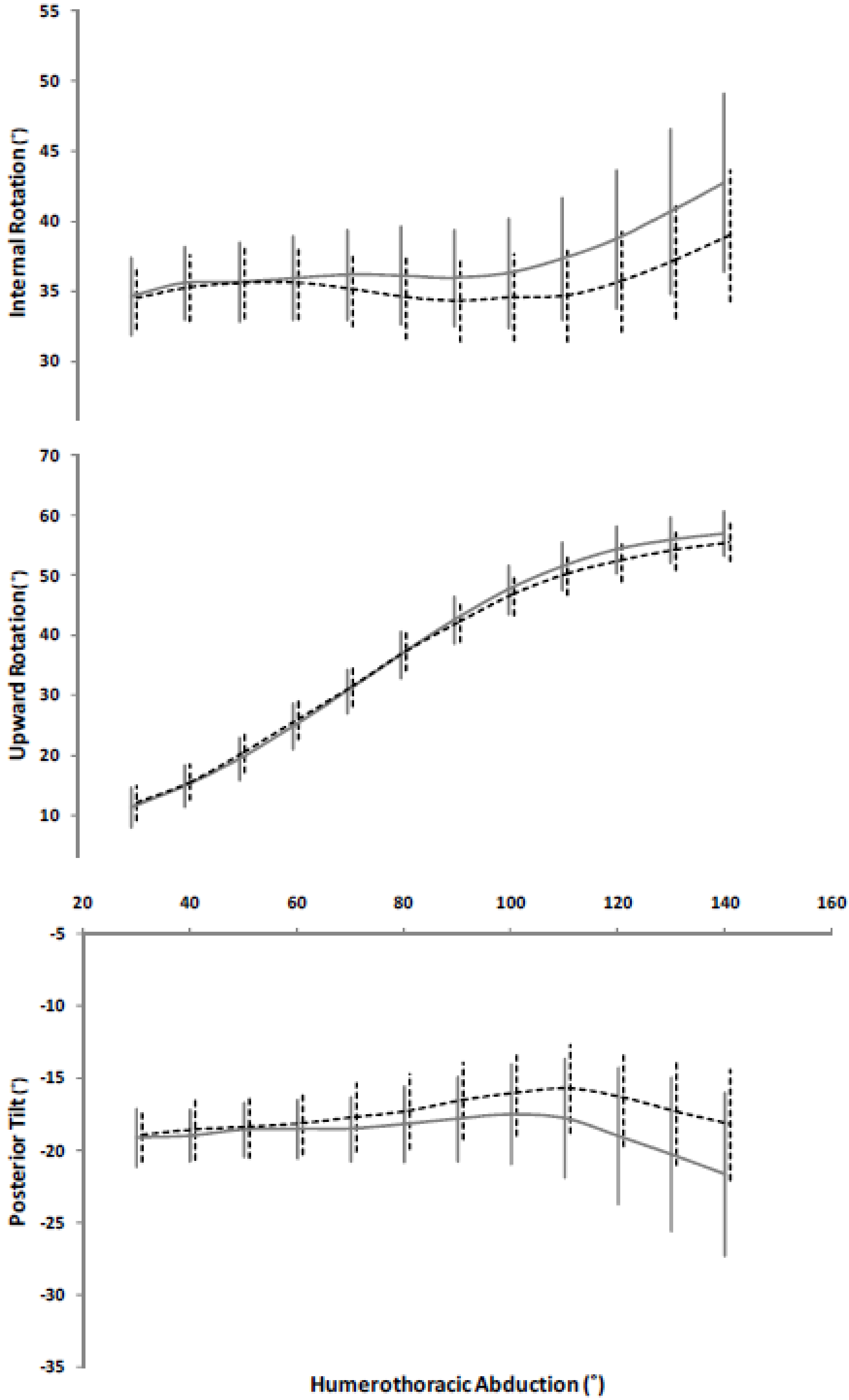

Figure 2: Mean scapulothoracic rotations for Method NF in a solid grey line and Method F in a dashed black line. The intra-observer errors for the two methods are shown as error bars

Table 1: Means, 95% confidence intervals, standard errors of measurements and p-values of the intra-observer and inter-observer variations for the three scapulothoracic rotations. Significance is set at p <0.05.

Scapulothoracic rotations	Method	Mean variations (°)	95% Confidence interval		Standard error of measurements S.E.M	Method (p-value)	Method*Angle (p-value)
			Lower bound	Lower bound			
Intra-observer variations							
Full Range of Motion (30 - 140°)							
Internal rotation	NF	3.90	3.20	4.54	0.31	0.045*	0.782
	F	3.07	2.55	3.60	0.24		
Upward rotation	NF	3.76	3.31	4.21	0.21	0.041*	0.897
	F	3.24	2.83	3.64	0.19		
Posterior tilt	NF	3.23	2.51	3.96	0.21	0.059	0.012*
	F	2.72	2.29	3.15	0.19		
< 90°							
Posterior tilt	NF	2.10	1.74	2.46	0.17	0.454	—
	F	2.20	1.88	2.51	0.15		
≥ 90°							
Posterior tilt	NF	4.37	3.18	5.56	0.55	0.031*	—
	F	3.25	2.63	3.86	0.29		
Inter-observer variations							
Full Range of Motion (30 - 140°)							
Internal rotation	NF	4.20	2.89	5.51	0.61	0.924	0.290
	F	4.12	2.78	5.46	0.62		
Upward rotation	NF	5.93	3.03	8.82	1.34	0.329	0.721
	F	5.06	2.78	7.34	1.06		
Posterior tilt	NF	3.49	2.42	4.57	0.50	0.815	0.309
	F	3.65	1.76	5.53	0.87		

Table 2: Means of ranges of motion and rotations, 95% confidence intervals, standard errors of measurements and p-values for the three scapulothoracic rotations. Significance is set at p <0.05.

Scapulothoracic rotations	Method	Mean rotation (°)	95% confidence interval		Standard error of measurements S.E.M.	Method (p-value)	Method*Angle (p-value)
			Upper bound	Lower bound			
Full Range of Motion (30 - 140°)							
Internal rotation	NF	37.18	32.84	41.52	2.01	0.014*	0.006**
	F	35.55	31.42	39.69	1.91		
Upward rotation	NF	37.29	32.24	42.34	2.34	0.792	0.115
	F	37.09	32.26	41.92	2.24		
Posterior tilt	NF	-18.81	-22.39	-15.24	1.66	0.018*	0.008**
	F	-17.42	-21.34	-13.50	1.81		
< 90°							
Internal rotation	NF	35.72	32.11	39.33	1.67	0.181	—
	F	35.15	31.35	38.95	1.76		
Posterior tilt	NF	-18.64	-22.01	-15.26	1.56	0.135	—
	F	-18.16	-21.81	-14.50	1.69		
≥ 90°							
Internal rotation	NF	38.64	33.25	44.04	2.50	0.009**	—
	F	35.96	31.12	40.80	2.24		
Posterior tilt	NF	-18.98	-23.10	-14.88	1.90	0.011*	—
	F	-16.68	-21.11	-12.25	2.05		