

Title:

Effects of Attachment Position and Shoulder Orientation during Calibration on the Accuracy
of the Acromial Tracker

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Abstract

The acromial tracker is used to measure scapular rotations during dynamic movements. The method has low accuracy in high elevations and is sensitive to its attachment location on the acromion. The aim of this study was to investigate the effect of the attachment position and shoulder orientation during calibration on the tracker accuracy. The tracker was attached to one of three positions: near the anterior edge of the acromion process, just above the acromial angle and the meeting point between the acromion and the scapula spine. The scapula locator was used to track the scapula during bilateral abduction simultaneously. The locator was used to calibrate the tracker at: no abduction, 30°, 60°, 90° and 120° humerothoracic abduction. ANOVA tests compared RMS errors for different attachment positions and calibration angles. The results showed that attaching the device at the meeting point between the acromion and the scapula spine gave the smallest errors and it was best to calibrate the device at 60° for elevations $\leq 90^\circ$, at 120° for elevations $> 90^\circ$ and at 90° or 120° for the full range of abduction. The accuracy of the tracker is significantly improved if attached appropriately and calibrated for the range of movement being measured.

Keywords: scapula, kinematics, acromial tracker, attachment position, calibration angle

1. Introduction

At present, the most accurate non-invasive method of measuring scapular motion is the scapula locator method. The locator is used to statically capture the orientation of the scapula (Johnson et al, 1993) or to track its motion at slow/medium speeds (Shaheen, 2010), but has not been shown to be able to do so during fast dynamic activities.

Whereas, the acromial tracker is a single sensor that can be conveniently attached to the acromion and is used to measure scapular dynamic movements (McQuade and Smidt, 1998; Ludewig and Cook, 2000; McCully et al., 2005). The tracker has low accuracy at high elevation angles (Karduna et al., 2001; Meskers et al., 2007; van Andel et al., 2009) and it is sensitive to where it is placed on the acromion. The optimal location on the acromion has not yet been established.

The calibration of the tracker with the locator to reduce errors caused by skin deformation was suggested (Meskers et al., 2007) and carried out at the anatomical position (van Andel et al., 2009), but high errors above 90° of abduction were still found.

The aim of this study was to improve the accuracy of the acromial tracker by identifying the optimal position of attachment on the acromion as well as the best shoulder orientation during calibration.

2. Methods

Study Population and Instrumentation

7 male subjects with a mean age of 23.9 ± 3.9 years, a fully functional shoulder as assessed by the Oxford Shoulder Score, and no history of shoulder pain or surgery participated in the study.

An Optical Motion Tracking system was used to track the trajectories of reflective markers attached to landmarks on the thorax and the humerus according to Wu et al. (2005) and on the scapula locator and the acromial tracker.

The locator had three pins adjusted to fit the acromial angle, the inferior angle and the root of the scapular spine (Johnson et al, 1993). Pressure-sensors attached to the tips of the pins provided feedback to the observer which was used to maintain low and equal pressures on the landmarks whilst tracking their motion, hence reducing any possible effects on the physiological scapular movement (Shaheen, 2010). A custom-designed tracker shown in Figure 1-A was attached to the acromion and was also used to obtain scapular measurements.

Data Capture

The tracker was attached to one of three positions on the acromion (Figure 1-B):

- Position A – near the anterior edge of the acromion as suggested by Matsui et al (2006).
- Position B – just above the most latero-caudal point of the acromion (the acromial angle) as used by Karduna et al (2001) and Meskers et al (2007).
- Position C – the meeting point between the acromion and the scapular spine. This position has not been previously documented.

At each of these positions, the subjects performed three trials of bilateral elevation in the scapular plane. Measurements of the dominant shoulder only were obtained. Once the acromial tracker was placed in one of these positions it was not replaced until all three trials were completed. During these trials, measurements of the scapular motion were also obtained

simultaneously using the scapula locator (Figure 1-A). During tracking, care was taken to avoid impinging the soft-tissue or influencing skin deformation using the scapula locator; which could indirectly influence the tracker orientation.

Data Processing

ISB recommended co-ordinate frames were defined for the thorax, humerus and scapula (Wu et al., 2005). The locator measurements were used to define a reference co-ordinate frame for the scapula and to calibrate the acromial tracker. Five other scapular co-ordinate frames were defined using the scapular landmarks measured relative to the orientation of the acromial tracker at five calibration angles: no abduction, 30°, 60°, 90° and 120° of humerothoracic abduction.

Euler rotations were used to calculate glenohumeral and humerothoracic rotations in the sequence of x-z'-y'' (abduction, flexion, axial rotation) and scapulothoracic rotations were calculated using a sequence of y-x'-z'' (internal rotation, upward rotation, tilt).

Root-mean-square (RMS) errors were calculated from the differences between the scapulothoracic rotations using the scapular reference co-ordinate frame and the co-ordinate frames defined relative to the acromial tracker. Repeated-measures ANOVA tests were used to investigate differences between the attachment positions and calibration angles for low elevations ($\leq 90^\circ$), high elevations ($> 90^\circ$) and for the entire range-of-motion for the three scapulothoracic rotations.

3. Results

There was a significant difference in the RMS errors between the positions of attachment for scapular upward rotation (Table 1). The highest errors were found with the tracker placed near the anterior edge of the acromion (Position A). Position C was least affected by soft-tissue deformation, had the smallest errors for all participating subjects, and is therefore the best position for attaching the acromial tracker (Figure 2).

For studies measuring the scapular motion within the functional range ($\leq 90^\circ$), 60° was found to be the best calibration angle. Calibrating at 120° was best for end-of-range movements and calibrating at 90° and 120° was best for the full range-of-motion.

4. Discussion

The RMS values for Position B and calibration angle (no abduction) presented here are of similar magnitudes (6 - 10°) to those reported previously (Karduna et al, 2001; Meskers et al, 2007; van Andel et al, 2009) and are double the RMS errors for the best position (Position C) and angle (90° for the full range) combination (3 - 5°) found in this study. This emphasises the importance of choosing the correct attachment position and calibration angle according to the movement being measured to obtain accurate scapular measurements.

The results achieved in this study are significant advancements on the current use of the acromial tracker. However, it is important to acknowledge that there are errors associated with the reference method arising from the dependence on an observer to correctly track the movement of the scapula. These may have led to an underestimation of the calculated errors of the tracker method, and consequently question the credibility of the statistical analyses. Therefore, it is important to look at the variability in the reference method before drawing firm conclusions about the effect of the attachment positions. In the absence of an absolute measure of the scapular movement, the inter-trial variations of using the locator were used to give an estimation of the variability. In this study, these variations (Table 2) are much smaller than the calculated errors of using the tracker (Figure 2) and are also smaller than the locator errors reported in the literature (de Groot et al., 1997; Meskers et al., 1998; Shaheen, 2010); this could be because an experienced observer obtained the measurements. The small errors of the reference method as well as the statistical significance between the attachment positions of the tracker method ($p < 0.01$, Table 1) point towards the existence of a real difference.

Although the scapula locator measurements were available for the full range of abduction; the acromial tracker was only calibrated at specific positions and compensation of the errors was not carried out. This methodology was chosen for two reasons, firstly because the aim of the

work is to improve on the current use of the acromial tracker method in dynamic activities where the use of the scapula locator is inconvenient; in such cases it would not be possible to track the scapular motion with the locator. Secondly, it is unknown whether the errors produced by the bulging of the deltoid are consistent even in a simple movement such as the one used in this study as evidenced by the inter-trial errors of the tracker (Table 2). This is caused by the possibility of using different muscle force distributions to achieve the same shoulder orientation or what is referred to as motor noise.

Interestingly, the errors obtained for the best position and calibration angle are comparable to the inter-observer errors of using the scapula locator reported in previous studies (de Groot et al., 1997; Meskers et al., 1998; Shaheen, 2010). This suggests that provided the tracker has been placed and calibrated correctly, the method can be used to acquire more convenient and more dynamic scapular measurements for the full range than when the locator method is used on its own, without compromising on the accuracy. However, such a method has to be used with caution because attaching the device in an incorrect position can yield high measurement errors, particularly at the end-of-range and in more muscular subject groups.

Other limitations in this study include the restriction of movement to elevations in the scapular plane. However, previous studies that have looked at the errors of other planes and movements have found similar error values to those obtained during abduction in the scapular plane (Karduna et al., 2001; van Andel et al., 2009). Another limitation is the assessment of rotational errors only; positional errors have not been assessed within this work. This could also be the reason for the discrepancy between the results presented here and those obtained in studies that have focused in measuring positional errors (Matsui et al., 2006; McQuade and Smidt, 1998).

Acknowledgements

This research was partially funded by the Saudi Arabian Ministry of Higher Education.

Conflict of Interest Statement

None of the authors have any relationship with people or organisations that could inappropriately influence this work.

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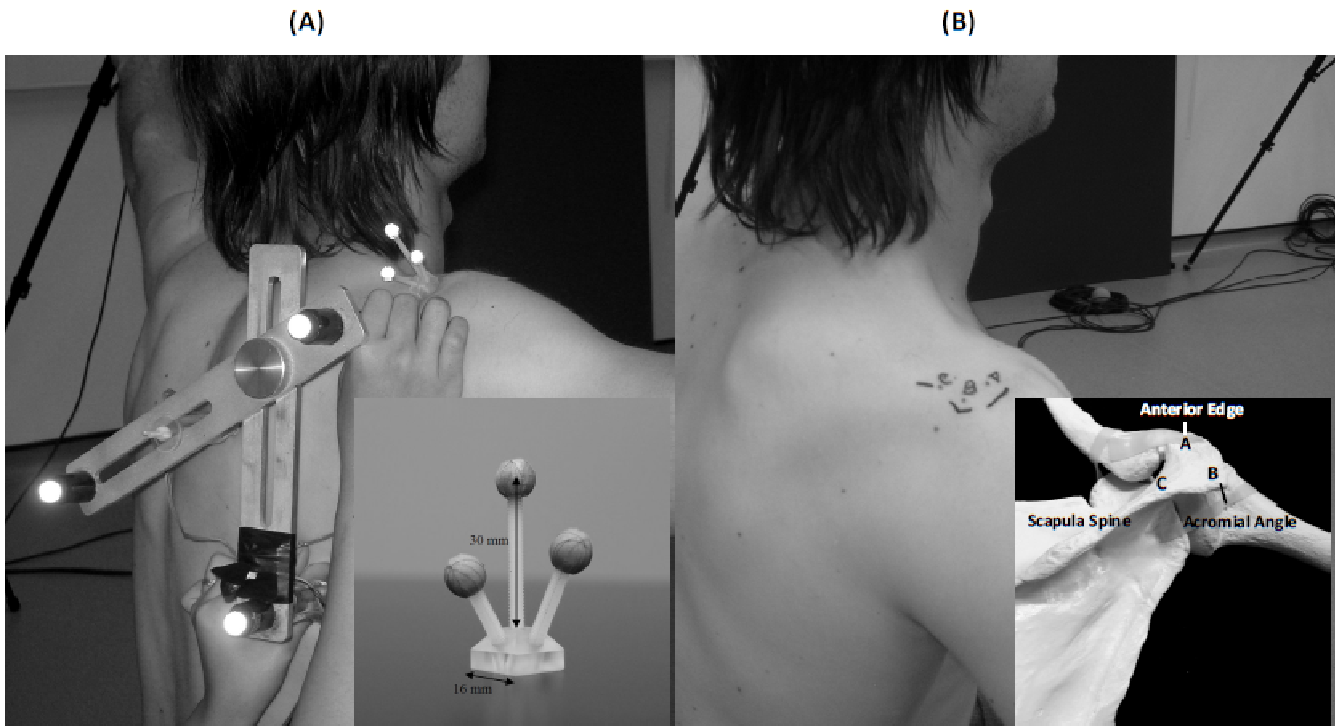
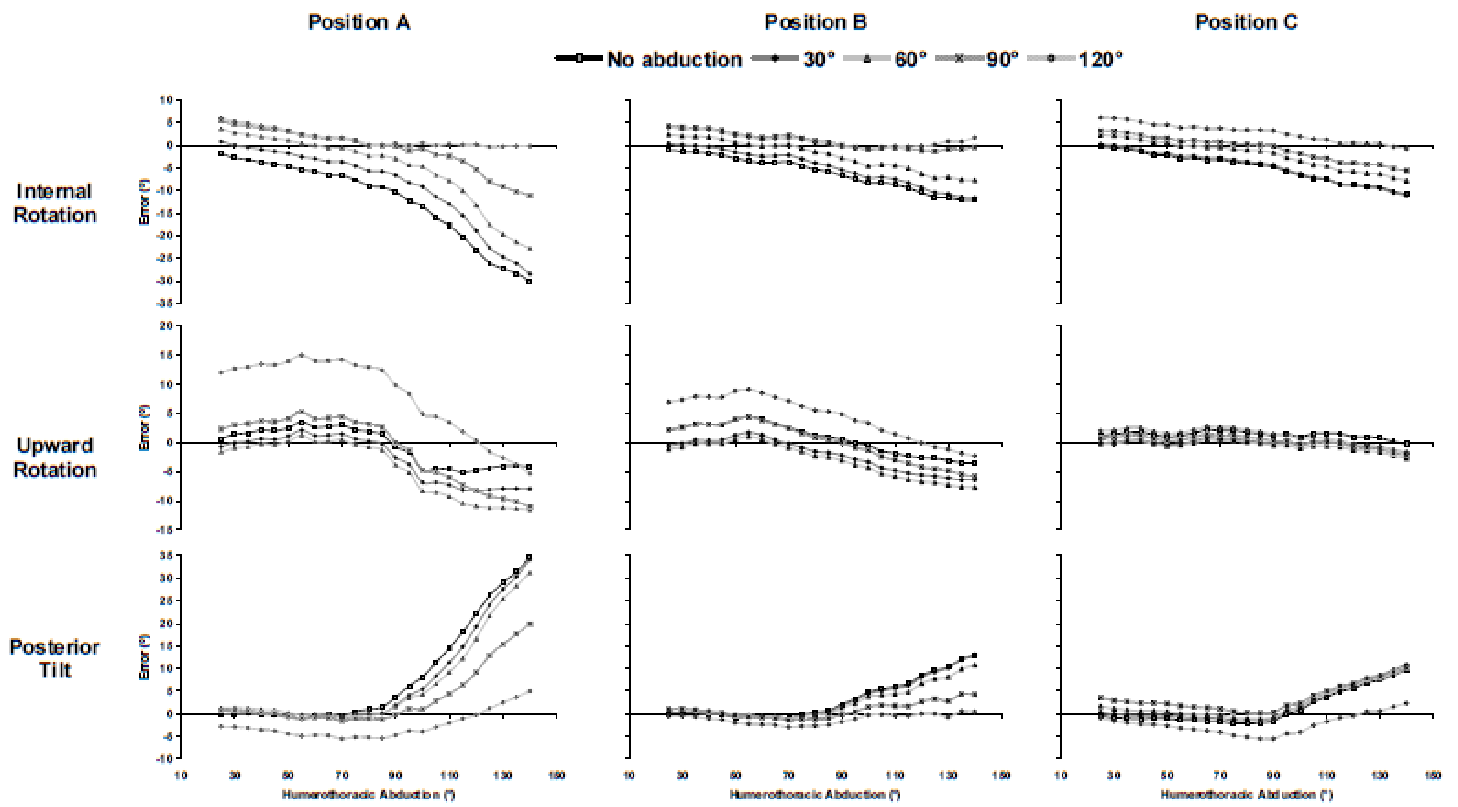


Figure 1: (A) The acromial tracker and the scapula locator are used simultaneously to obtain scapular measurements during bilateral abduction. (B) Acromial tracker attachment positions on the acromion. Position A: near the anterior edge, Position B: just above the acromial angle and Position C: the meeting point between the acromion and scapula spine.

Figure 2: Acromial tracker errors for the internal rotation, upward rotation and tilt.



The errors are shown for positions A, B and C and when calibrated at no abduction, 30°, 60°, 90° and 120° of humerothoracic abduction.

Table 1: The probability values (p-value) generated from the repeated-measures ANOVA tests for the scapular internal rotation, upward rotation and tilt for humerothoracic ranges of elevation of $\leq 90^\circ$, $> 90^\circ$ and the full range (* p < 0.05, ** p < 0.01, * p < 0.001)**

Scapulothoracic rotation	Range of elevation	Position (p-value)	Angle (p-value)	Position * Angle (p-value)
Internal rotation	$\leq 90^\circ$	0.322	0.001**	0.314
	$> 90^\circ$	0.235	0.015*	0.248
	Full	0.238	0.024*	0.203
Upward rotation	$\leq 90^\circ$	0.009**	0.001**	0.032*
	$> 90^\circ$	0.004**	0.000***	0.140
	Full	0.003**	0.013*	0.013*
Tilt	$\leq 90^\circ$	0.906	0.000***	0.734
	$> 90^\circ$	0.272	0.008**	0.266
	Full	0.232	0.035*	0.412

Table 2: The inter-trial mean errors and the errors at 30°, 90° and 120° of humerothoracic elevations for the scapular internal rotation, upward rotation and tilt. The errors are shown for the locator method and the acromial tracker method when the tracker is attached to positions A, B and C and calibrated at humerothoracic abduction angles of: no abduction, 30°, 60°, 90° and 120°.

Method	Attachment Position	Calibration Angle	Inter-trial errors (°)											
			Internal Rotation				Upward Rotation				Tilt			
			Mean	30°	90°	120°	Mean	30°	90°	120°	Mean	30°	90°	120°
Scapula locator	—	—	1.69	1.79	1.81	1.80	3.02	2.87	3.47	2.93	1.43	1.07	1.36	2.01
Acromial tracker	A	No abduction	4.53	2.63	3.73	7.80	3.39	3.01	2.82	4.12	4.00	1.32	3.51	7.54
		30°	4.04	1.85	2.62	6.90	3.34	2.92	3.15	3.98	3.82	1.04	2.65	6.95
		60°	3.81	2.50	2.21	6.43	4.41	4.53	3.73	4.90	3.38	1.47	1.98	6.25
		90°	4.05	3.16	2.12	5.51	5.54	7.11	3.66	4.46	3.81	3.43	1.36	5.05
		120°	2.85	3.42	2.51	1.92	5.15	7.02	4.62	3.09	2.61	2.37	2.61	2.04
Scapula locator	—	—	1.76	1.81	1.56	1.73	2.94	2.81	2.93	2.90	1.40	1.03	1.36	1.38
Acromial tracker	B	No abduction	3.96	2.44	2.85	6.25	3.20	2.31	3.23	3.76	3.89	1.51	2.77	6.30
		30°	4.06	1.67	3.34	6.72	3.63	2.91	3.41	3.79	3.99	1.58	3.43	6.25
		60°	4.09	2.10	3.14	6.40	4.06	3.95	4.70	4.21	3.89	2.46	2.71	5.78
		90°	3.96	3.17	1.46	6.18	4.23	4.50	2.83	3.89	3.59	2.76	1.26	5.57
		120°	3.89	4.23	5.02	1.52	4.76	6.05	4.27	2.80	3.49	3.40	3.85	1.16
Scapula locator	—	—	1.95	2.17	1.98	1.27	2.70	2.47	2.94	2.86	1.03	0.81	1.06	1.53
Acromial tracker	C	No abduction	2.90	2.36	2.82	3.13	2.88	1.86	3.02	3.77	2.82	1.13	3.43	3.60
		30°	2.77	2.21	2.10	3.03	3.24	2.38	2.87	4.16	2.70	0.72	3.37	3.40
		60°	2.96	2.66	2.67	3.59	2.72	2.41	2.89	2.99	2.53	1.50	3.00	3.37
		90°	2.83	2.67	2.10	3.04	2.98	2.44	3.19	2.69	2.29	2.11	1.27	2.88
		120°	2.85	2.95	2.76	1.54	4.15	3.55	5.01	2.96	2.30	2.26	3.23	1.50