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Measurement of scapular dyskinesis using wireless inertial and magnetic sensors: Importance of scapula calibration

Josien C. van den Noort [a,b,*], Suzanne H. Wiertsema [a], Karin M.C. Hekman [a], Casper P. Schönhuth [c], Joost Dekker [a,d], Jaap Harlaar [a,b]

[a] VU University Medical Center, Department of Rehabilitation Medicine, PO Box 7057, 1007 MB Amsterdam, The Netherlands
[b] MOVE Research Institute Amsterdam, The Netherlands
[c] VU University Medical Center, Department of Orthopaedics, Amsterdam, The Netherlands
[d] EMGO Institute for Health and Care Research, Amsterdam, The Netherlands

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ABSTRACT

Measurement of 3D scapular kinematics is meaningful in patients with shoulder pathologies showing scapular dyskinesis. This study evaluates the effect of single and double anatomical calibration (0° and 120°) with a scapula locator compared to standard calibration (using sensor alignment with the spina scapulae and static upright posture, ISEO-protocol) on 3D scapular kinematics measured with an inertial and magnetic measurement system (IMMS).

Ten patients with scapular dyskinesis performed humeral anteflexion and abduction movements while 3D scapular kinematics were measured using IMMS sensors. The sensor on the scapula was anatomically calibrated (i) according to the ISEO-protocol, (ii) using single scapula locator calibration (0°) and (iii) double scapula locator calibration (0° and 120°). For calibration, the scapula locator (with IMMS) was positioned on the scapula, while holding the humerus at several anteflexion and abduction postures.

Single and double calibration resulted in a significant increase of scapular anterior tilt (14–30°) with respect to the skin-fixed sensor (ISEO). Protraction angles were not significantly different. During anteflexion, double calibration did not show a significant increase in lateral rotation compared to single calibration. During abduction of $>90°$, double calibration showed 10–14° increased lateral rotation with respect to single calibration, although this was not significant ($P>0.06$).

Calibration with a scapula locator when applying IMMS is necessary, because measures of scapular anterior tilt are grossly underestimated with the ISEO-protocol. For shoulder movements that exceed 90° elevation, a double calibration prevents small but relevant underestimation of lateral rotation angles of the scapula.

1. Introduction

Measurement of 3D scapular kinematics is particularly meaningful in patients with shoulder pathologies showing scapular dyskinesis (Kibler et al., 2009; Kibler and Sciascia, 2010; Ludewig and Reynolds, 2009; McClure et al., 2009; Tate et al., 2009; van den Noort et al., 2014). Scapular dyskinesis is defined as a posterior displacement of the scapular medial border and/or inferior angle away from the thorax (winging) or a dysrhythmia of the scapular motion, such as premature or excessive elevation or protraction during arm elevation, a rapid medial rotation during arm lowering, or a non-smooth motion during arm elevation or lowering (McClure et al., 2009). Such alterations have been observed in e.g. shoulder instability, rotator cuff injury and impingement syndrome (De Baets et al., 2013; Lukasiewicz et al., 1999; McClure et al., 2006; Roren et al., 2013; Struyf et al., 2011; Warner et al., 1992).

Wireless sensors of an inertial and magnetic measurement system (IMMS) are suitable to conveniently measure the 3D kinematics of the scapula. A few studies evaluated the intra- and inter-observer reliability and precision of such a system in healthy subjects (Cutti et al., 2008; Parel et al., 2014, 2012; van den Noort et al., 2014). Technical dynamic accuracy of IMMS sensors used in the latter study is reported to be around 2° (Xsens Technologies B. V., 2011). Standard errors of measurement (SEM) of IMMS in scapular kinematic measurement were found to be within 5° for both intra-and inter-observer data of medio/lateral rotation, anterior/posterior tilt and for intra-observer data of scapular re/protraction (van den Noort et al., 2014). Inter-observer data of re/

* Corresponding author at: VU University Medical Center, Department of Rehabilitation Medicine, PO Box 7057, 1007 MB Amsterdam, The Netherlands. Tel.: +31 20 444 3192; fax: +31 20 444 0787.
E-mail address: j.vandennoort@vumc.nl (J.C. van den Noort).

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protraction showed a SEM of 6–8°. Palpation errors of bony landmarks of the shoulder are shown to be about 2° (de Groot, 1997) whereas reliability of a scapula locator has been shown to be within 4° (Barnett et al., 1999).

Using IMMS, anatomical calibration of the sensor placed on the skin with respect to the underlying scapular bone (sensor-to-segment orientation) can be based on alignment of the sensor with the spina scapulae and the gravity vector, such as described in (Cutti et al., 2008) and applied by (van den Noort et al., 2014) (ISEO-protocol). However, according to the ISEO-protocol, anatomical alignment of the scapula sensor is crucial as well as the measure of a static upright posture. Therefore, differences between examiners may result in inaccuracies. This was in particular seen in offsets and change in range of motion in anterior/posterior tilt and re/protraction (van den Noort et al., 2014). Furthermore, soft tissue artifacts of the loose skin, fat tissue and bulging deltoid muscles might cause a difference between sensor movement and actual scapula movement in all 3 planes of movement, especially for higher humeral elevation angles (Brochard et al., 2011; Meskers et al., 2007; Shaheen et al., 2011b; van Andel et al., 2009).

To improve the anatomical calibration, a scapula locator with adjustable bars (a tripod, placed on the angulus inferior, angulus acromialis and trigonum scapulae), including a sensor, could be used (Johnson et al., 1993). A scapula locator has been formerly used to validate an acromion marker cluster (van Andel et al., 2009) and an electromagnetic tracking device on the acromion (Meskers et al., 2007) that aimed to track scapular motion. Meskers et al. (2007) suggested that the locator should be used to calibrate such skin-fixed sensors. A similar approach, i.e. the use of an external frame on palpable anatomical landmarks for calibration, has been previously described for IMMS in the measurement of lower limb kinematics (Picerno et al., 2008).

The calibration position of the scapula locator, i.e. at which degree of humeral elevation, is shown to be important for accurate measurement of scapular kinematics (Prinold et al., 2011; Shaheen et al., 2011a). Brochard et al. (2011) even described a double calibration technique in which the locator is applied at 0° and 180° of humeral elevation. They modified the 3D positions of anatomical landmarks measured with optical markers between these two postures by linear interpolation in time (Cappello et al., 2005; Zhang, 2002). Recently, also Cereatti et al. (2015) applied a double calibration technique (at start and end of the arm range of motion) in combination with an acromion skin marker cluster in cadaveric specimens. Both studies showed that double calibration improved the estimate of scapular kinematics, whereas single calibration resulted in errors at higher humeral elevation angles (Brochard et al., 2011; Cereatti et al., 2015) since it possibly only corrects for initial scapula angular offsets but not for soft tissue artefacts during the scapular motion.

Therefore, calibration with a scapula locator might correct for offset differences in retraction/protraction and anterior/posterior tilt as observed by van den Noort et al. (van den Noort et al., 2014). Furthermore, double calibration at both low and high humeral elevation angles might be promising to further optimize the measurement of scapular kinematics with IMMS, by correcting for the underestimation of scapular lateral rotation at high elevation angles with a skin-fixed sensor (Meskers et al., 2007). In this way, scapular kinematics measurement with IMMS might be as close as possible to measurement with bone pins, which can be considered to be the ‘golden standard’ (Brochard et al., 2011; McClure et al., 2001).

The primary purpose of this study was to evaluate the change in 3D scapular kinematics caused by single and double anatomical calibration with a scapula locator versus standard calibration using sensor alignment with the spina scapulae (ISEO-protocol (Cutti et al., 2008; van den Noort et al., 2014)) in patients with scapular dyskinesis. Single calibration was performed at 0°, while 120° humeral anteflexion (AF) and humeral abduction (AB) was added for double calibration. We hypothesized that double calibration will result in higher scapular lateral rotation angles compared to single calibration for higher humeral elevation angles. The secondary aim of the study was to evaluate the difference in 3D scapular kinematics between static posture (arm elevation of 0°, 30°, 60°, 90° and 120°) and dynamic humeral elevation (movement). This is of interest because Brochard et al. (Brochard et al., 2011) compared their results of double calibration with data obtained in static postures. We hypothesized that scapular lateral rotation is higher during dynamic motion than in static posture (Fayad et al., 2006).

2. Methods

2.1. Patients

Ten patients with scapular dyskinesis according to the scapular dyskinesis test (SDT) (McClure et al., 2009; Tate et al., 2009) participated in the study. Underlying shoulder pathologies varied between patients. Patients characteristics are shown in Table 1. For each patient, the most affected shoulder was selected and analyzed. Measurements were performed at the VU University Medical Center (VUmc) in Amsterdam (The Netherlands), department of rehabilitation medicine. The Medical Ethics Committee of the VUmc approved the study protocol. Full written informed consent was obtained from all patients.

Table 1
Patient characteristics.

Patient number	Gender	Age	BMI	Side	Diagnosis	SDT	SRQ	CM
1	M	54	23.7	R	Anterior labrum tear	AF normal. AB obvious	59	81
2	M	55	22.8	R	Shoulder instability, tendinopathy	AF subtle, AB obvious	96	95
3	F	28	22.5	L	Posterior impingement	AF subtle, AB obvious	94	84
4	M	24	23.1	R	Unstable painfull shoulder	AF obvious, AB obvious	Unknown	Unknown
5	M	43	23.9	L	Glenohumeral luxation	AF obvious, AB obvious	69	86
6	M	27	24.3	R	SLAP laesion	AF subtle, AB subtle	82	93
7	M	58	24.2	L	Partial supraspinatus tear	AF subtle, AB subtle	77	81
8	M	47	31.6	L	Shoulder instability, tendinopathy	AF obvious, AB obvious	48	45
9	F	46	20.1	R	Tendinitis calcarea	AF obvious, AB subtle	71	77
10	M	63	24.1	R	Full thickness supraspinatus tear	AF obvious, AB obvious	58	53

M=male, F=female, BMI=Body Mass Index (kg/m^2), R=right, L=left, SDT=Scapular Dyskinesis Test, AF=anteflexion, AB=abduction, SRQ=Shoulder Rating Questionnaire (0–100, a score of 100 implies no complaints), CM = Constant-Murley Shoulder Outcome Score (0–100, a score of 100 implies no complaints).

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