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original article

Reliability of electromagnetic tracking of scapular orientation and position in healthy sendentary individuals

Confiabilidade da avaliação da orientação e posição de repouso da escápula de indivíduos saudáveis e sedentários com o sistema eletromagnético de aquisição de dados

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Abstract – Electromagnetic systems for motion analysis are claimed as a precise technique for tracking position and orientation of human body segments. To date, reliability electromagnetic tracking was described only for the dynamic assessment of the scapula motion, and no reliability studies on its resting posture or positioning were found. The aim of this study was to analyze intra- and inter-session reliabilities and absolute errors of the scapular orientation and position at habitual resting posture in healthy individuals. Twenty-two shoulder symptom-free individuals non participants in professional or recreational sports activities involving upper extremities were volunteers in this study. The equipment used was 3SPACE Liberty system (Polhemus Inc.). The same examiner collected the kinematic data from subjects in two different sessions, with an interval from seven to ten days. Intraclass Correlation Coefficient ($ICC_{2,1}$ and $ICC_{2,k}$) and Standard Error of Measurement (SEM) were calculated. Inter-session reliability ranged from good to excellent (ICC from 0.66 to 0.96) and intra-session reliability was excellent (ICC ≥ 0.97). SEM values found for linear distances were smaller than 0.02 cm and scapular rotations ranged from 0.72° to 5.48°. Results of this study demonstrated that electromagnetic data acquisition of scapula habitual posture is a reliable tool for defining scapular position and orientation in sedentary shoulder symptom-free individuals.

Key words: Biomechanics; Physical therapy; Posture; Reproducibility of results; Shoulder.

Resumo – *Sistemas eletromagnéticos para análise de movimento são conhecidos como precisos para registrar a posição e orientação dos segmentos do corpo humano. Até o momento, a confiabilidade do registro eletromagnético foi descrita apenas para a dinâmica da escápula, não sendo encontrados estudos de confiabilidade da posição de repouso ou postura da mesma. O objetivo deste estudo foi a análise da confiabilidade intra- e inter-sessão e erros absolutos do registro eletromagnético da posição e orientação da escápula na postura habitual de repouso de indivíduos saudáveis. Foram voluntários no estudo 22 indivíduos sem sintomas no complexo articular do ombro e não-praticantes amadores ou profissionais de esporte e atividade física envolvendo os membros superiores. O equipamento utilizado foi o sistema 3SPACE Liberty (Polhemus Inc.). Um mesmo avaliador coletou os dados cinemáticos em duas sessões diferentes com um intervalo de sete a dez dias. O Coeficiente de Correlação Intraclasse ($ICC_{2,1}$ e $ICC_{2,k}$) e o Erro Padrão de Medida (EPM) foram calculados. A confiabilidade inter-sessão variou entre boa a excelente (ICC de 0,66 a 0,96) e a confiabilidade intra-sessão foi sempre excelente (ICC ≥ 0,97). Os valores de EPM encontrados para as distâncias lineares foram menores que 0,02 cm e para as rotações da escápula relativa ao tórax variaram entre 0,72 º e 5,48 º. Os resultados deste estudo demonstraram que o registro eletromagnético da posição habitual de repouso da escápula é confiável para determinar a posição e a orientação da mesma em um população sedentária e sem sintomas no complexo articular do ombro.*

Palavras-chave: *Biomecânica ; Fisioterapia; Ombro; Postura; Reprodutibilidade dos testes*

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INTRODUCTION

Assessment of scapular positioning is a theme has been emphasized in scientific literature[1-11]. Positioning and orientation of the scapula on thorax are important to centralize the humeral head and base for normal function of shoulder joint complex during daily and sport activities[5-7,9]. Resting scapular position may be influenced by thorax shape, muscle activity and anatomic variations of acromioclavicular joint[7,9,13]. Moreover, many muscles are inserted on scapula and therefore its resting position influences the length-tension relationship and the efficiency of these muscles[7,12].

Three-dimensional systems have already been used in several studies to determine scapular position and rotation[1,13,14]. Among them, electromagnetic system for tracking of human movement allows noninvasive, three-dimension, extensive and detailed analysis of the position and movement of body segments[15].

Electromagnetic systems are subject to decreased reliability of data collected due to interference in the electromagnetic field by metals and movement between sensors and the skin[16,17]. In addition to the sources of error related to instrumental unreliability, examiner's errors and data entry errors may also occur. This is because the examiner should fix the sensors in the body of the volunteer, palpate pre-determined anatomical structures and by placing another sensor fixed to a pen (stylus) on these structures, informs these data to the system to create the orthogonal axes and determine local coordinate systems of each segment studied. Thus, any variation in the stages of constructing the local coordinate system can interfere with data reliability. Training and understanding of examiner in relation to equipment, creation of local coordinate systems and data collection reduces measurement errors.

In scientific literature review, studies assessing the reliability of electromagnetic system for acquisition of scapular kinematics during arm movements were found[6,10,15]. However, to date, no reliability data to assess resting scapular position with this system were found. Determining the reliability of a system that allows three-dimensional detailed analysis of scapular position and orientation is important to ensure consistency of measures and quality of future clinical trials for the treatment of different shoulder diseases.

Thus, the aim of this study was to establish reliability and absolute errors of scapular position and orientation in usual resting position of sedentary and healthy subjects using an electromagnetic tracking system.

METHODOLOGICAL PROCEDURES

Overall, 24 volunteers were recruited in the campus of the University of São Paulo, Ribeirão Preto. The volunteers of both sexes should be in good health condition and age between 18 and 40 years. This age range was chosen to ensure full bone development and to prevent age-related degenerative alterations[3].

Presence or history of pain or any dysfunctions of upper limbs with medical diagnosis, trauma or surgery on shoulder, cervical spine or thoracic spine and participation in physical activity or sport (amateur or professional) that primarily use upper limbs were among exclusion criteria. One participant was excluded from the study after kinetic-functional evaluation due to the presence of history of trauma and clavicle fracture and one participant quit participation due to unavailability of time for second review.

Final sample consisted of twelve female and ten male participants. Twenty volunteers showed dominance of right arm and two of left arm. The mean age was 23 years (± 2.8), mean height was 170 cm (± 0.07) and mean weight was 63.1 kg (± 16.5).

The experimental study protocol was reviewed and approved by the Ethics Research Committee of the Hospital das Clínicas, School of Medicine of Ribeirão Preto, University of São Paulo - HCFMRP - USP. All participants read and signed the informed consent before inclusion in the study.

Evaluation system used was 3SPACE Liberty (Polhemus Inc.). The system consists of passive sensors and an electromagnetic field transmitter. This system is used to collect positioning and orientation data of body segments through sensors fixed to segments to be studied, which allow three-dimensional positional reconstruction of segments and human movements[2].

Five sensors were fixed with adhesive tape to the skin of volunteers on scapula, thorax and arms bilaterally. The scapula sensor was fixed on the acromion, the thorax sensor was fixed on manubrium of the sternum and the sensor on the arms near the insertion of the deltoid muscle. In addition to the adhesive tape, sensors fixed to the arms were wrapped with elastic strip to aid fixation. Determination of local coordinate system was performed according to recommendations for upper limbs of International Society of Biomechanics (ISB)[18]. Location of anatomical structures transverse processes of T3 and T7 were also included for analysis of resting scapular position in relation to thoracic spine.

Since the beginning of procedure until the end of data collection, the volunteer was positioned on the side and front of the transmitter so that the X axis was horizontal with positive direction forward; the Y axis was vertical with positive direction upward and the Z axis was horizontal with positive direction from left to right. Combined analysis of the local coordinate system and the coordinate system of motion sensors allowed the three-dimensional analysis of the joint position (Figure 1).

During procedure for determining the position of anatomical structures and creation of local coordinate systems, the volunteer remained sat on a wooden box in military position with straight trunk, arms along the body and face turned to positive direction of X axis in the global coordinate system.

Data collection was performed without visual feedback with volunteer standing with face in the same direction in the rest position and instructed

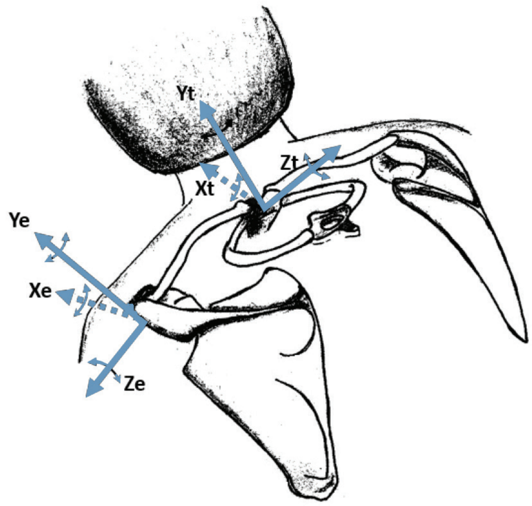

Figure 1. Local coordinate systems of trunk (Xt, Yt, Zt) and left scapula (Xe, Ye, Ze) with rotations around axes represented by arrows.

to remain in habitual posture with muscles as relaxed as possible. Moreover, before data acquisition, the volunteers were instructed to raising and lowering the arms, after which they should stand still with arms along the body and palms turned inside.Three sets were performed at rest, lasting five seconds each. The interval between collections was determined by the time spent to save the data.

Entire set procedure was repeated by same examiner after an interval of 7 to 10 days for inter-session reliability analysis. Three collections of each day were compared for intra-session reliability analysis and the average of collections of each day was calculated for inter-session reliability analysis. In a sequence of measures, some values may be higher or lower, so the average of these measures is the closest to the true value, being used to minimize random errors inherent to the measurement process[19].

Scapula linear positioning at rest was analyzed in relation to the distance between the root of the scapular spine and T3 spinous process and between the inferior angle of the scapula and T7 spinous process (Figure 2). Superior-inferior, medial-lateral and anterior-posterior tilt scapular rotations were determined by Euler angles using the YX'Z'' sequence recommended by ISB[18].

Scapular rotation values and linear distance between scapula and thorax were processed through The Motion Monitor System® software (Innsport Inc.) and statistical analyses were performed using the IBM SPSS software v.16.0 (Chicago, IL, USA) and Excell program (Microsoft Corporation). Reliability statistics included Intraclass Correlation Index (ICC) and Standard Error of Measurement (SEM), as recommended for reliability studies[21].

Relative reliability was quantified by ICC values, which were used to determine 95% confidence interval. $ICC_{2,1}$ was used for intra-session reliability among the three collections of the same session and $ICC_{2,k}$ was used for inter-session with the mean of three collections of each session.

ICC values were interpreted as poor when less than 0.40, good for values between 0.40 and 0.75, and excellent when exceeding 0.75[20,22,23].

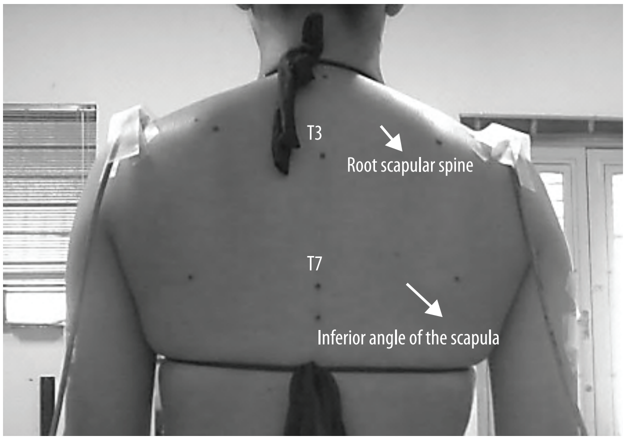

Figure 2. Anatomical reference points to determine the linear distance between the root of the scapular spine and its inferior angle and spinous process of the third (T3) and seventh (T7) thoracic vertebrae, respectively

Absolute reliability was determined by the standard error of measurement using the following formula: $SEM_{90} = 1.65*SD*\sqrt{(1 - ICC)}$, with standard deviation (SD) of the measure in the first assessment and $ICC_{2,1}$ and $ICC_{2,k}$ derived from intra- and inter-session reliability[20].

RESULTS

Resting scapular position and orientation values are shown in Table 1. The results showed the scapular rest position with medial and upward rotation and anterior tilt. The lower and upward bone references were about 9 cm away from T3 spinous process and 10 cm of T7, respectively.

Table 1. Resting scapular position relative to the thorax in degrees (°) and linear distances in centimeters (cm)

	Dominant Mean [maximum; minimum]		Non-dominant Mean [maximum; minimum]	
	Test	Retest	Test	Retest
Medial rotation (º)	31.11 [49.63;19.19]	29.11 [50.63;19.31]	25.89 [37.8;16.41]	26.07 [39.0;7.56]
Upward rotation*(º)	3.44 [25.98;-7.79]	03.40 [18.5;-8.79]	6.36 [25.98;-9.38]	05.75 [21.2;-2.13]
Anterior tilt(º)	10.71 [19.81;0.88]	10.90 [20.82;2.36]	8.47 [18.64;0.88]	8.44 [17.44;1.12]
Root of the scapular spine at T3 (cm)	9.61 [14.82;6.62]	9.86 [15.43;7.43]	9.43 [14.54;6.66]	9.28 [15.9;6.79]
Lowe angle of the scapula at T7 (cm)	10.26 [14.14;7.18]	10.06 [15.14;7.80]	10.2 [14.56;6.75]	10.18 [15.24;7.47]

* Negative values correspond to the lower rotation

Tables 2 and 3 show the ICC, CI95% and SEM values for the variables analyzed. The inter-session reliability ranged from good to excellent (0.66 ≤ ICC ≥ 0.96) and intra-session reliability has always been excellent (ICC ≥ 0.97). All ICC values were found within the 95% confidence interval. SEM values found for the linear distances were smaller than 0.02 cm. In scapular rotations, the SEM values were lower in intra-session measures (0.72º ≤ SEM ≥ 1.21º) compared with inter-session values (2.39º ≤ SEM ≥ 5.28º).

Table 2. Intraclass Correlation Coefficients (ICC), confidence intervals (CI) and inter-section Standard Error of Measurement (SEM) expressed in degrees for rotations and centimeters for linear distances of resting scapular position and orientation.

	Dominant			Non-Dominant		
	ICC	CI*	SEM	ICC	CI*	SEM
Medial rotation	0.89	0.75-0.96	4.02	0.72	0.33-0.89	5.48
Upward rotation	0.92	0.81-0.97	3.24	0.77	0.46-0.91	5.19
Anterior tilt	0.89	0.75-0.96	2.39	0.8	0.53-0.92	3.65
Root of the scapular spine at T3	0.96	0.90-0.98	0.01	0.77	0.45-0.90	0.02
Lowe angle of the scapula at T7 (cm)	0.94	0.86-0.97	0.01	0.66	0.20-0.86	0.02

* $\alpha = 0.05$

Table 3. Intraclass Correlation Coefficients (ICC), confidence intervals (CI) and intra-section Standard Error of Measurement (SEM) expressed in degrees for rotations and centimeters for linear distances of resting scapular position and orientation.

	Dominant			Non-Dominant		
	ICC	CI*	SEM	ICC	CI*	SEM
Medial rotation	0.99	0.98-1.00	1.21	0.99	0.99-1.00	1.04
Upward rotation	0.99	0.99-1.00	1.14	0.99	0.98-1.00	1.08
Anterior tilt	0.99	0.99-1.00	0.72	0.99	0.99-1.00	0.82
Root of the scapular spine at T3	0.97	0.94-0.99	0.01	0.97	0.94-0.99	0.01
Lowe angle of the scapula at T7 (cm)	0.98	0.97-1.00	0.00	0.99	0.99-1.00	0.00

* $\alpha = 0.05$

DISCUSSION

In this experiment, at least three sources of error can cause reduced reliability of the measures studied: equipment accuracy, examiner ability to palpate, mark and scan reference points for the construction of repeatable anatomical models and natural variation of scapular position, which may be affected by changes in muscle tension or climate, posture inattention and emotional stress. Nevertheless, inter-session reliability of variables related to the resting scapular position and orientation in relation to thorax in the present study ranged from good to excellent and intra-session reliability was always excellent.

Although it was not possible to compare findings of this study with those previously reported in literature, studies on the reliability of measures of the dynamic movements of shoulder with the same system also found reliability results from good to excellent and SEM values similar to those shown here[9,13,14].

Results of this study also showed greater inter-session reliability for dominant limb compared to non-dominant limb. More functional use in daily living tasks and greater active and passive tension of muscles stabilizing the scapula of the dominant limb may be an explanation for this finding[24].

Since equipment accuracy is established by the manufacturer (systematic error or relatively fixed between repeated measures), the most likely sources of variation in the data collected are associated to the examiner and to changes in the natural scapular position and orientation (random errors that need to be minimized and estimated whenever possible). Although the systematic error involving the examiner cannot be completely ruled out, in this study, the person responsible for the creation of the local coordinate system of segments was submitted to a period of six months of training, repeating the necessary steps. Although not investigated in this study, the learning curve effect was observed during the training period, previously to procedures of this study, pointing to importance of this step for consistency of results.

However, a source of systematic error is this study cannot be controlled or minimized are muscles overloads, which are derived from physical activity or exercise, physical or psychological effects on posture to which participants may have been exposed, especially in inter-day assessments[3,24].

Regarding the scapular position in relation to the thorax during maintenance of ortostatia, a variety of results can be found in literature[3,4,9]. The present study found that scapula of dominant limb is at approximately 4° of upward rotation, 31° of medial rotation and 10° of anterior tilt.

Ludewig et al.[25] found similar results with values of 5° of upward rotation, 41° of medial rotation and 13° of anterior tilt in a sample of healthy subjects and using electromagnetic sensors attached to pins transcortically inserted into the bones of the shoulder complex [25]. Except for the medial rotation, the values reported by Ludewig et al.[25] are similar to those found in this study, in which the effect of the movement of sensors on the skin of volunteers on the values found was considered minimum.

Oyama et al.[4] compared the resting scapular position of healthy shot put athletes in relation to the dominant and non-dominant limb and found that the dominant limb had greater upward rotation, greater internal rotation and greater anterior tilt[4]. In our sample of individuals not engaged in physical or sports activities with upper limbs, higher internal rotation and anterior tilt values in the dominant limb and higher upward rotation were found in the non-dominant limb.

On the cost-benefit ratio considering records of static posture, previous studies have used photogrammetry, which is relatively cheaper than electromagnetic systems, and found conflicting inter-day reliability values for scapular symmetry measures[26,27], while data of the present study revealed that repeated measures in distinct procedures for obtaining data via electromagnetic systems are more reliable and, given the estimate of absolute error of measurements, allow researchers to track natural changes or those resulting from interventions.

Finally, considering the current relevance given the scapula in the context of evaluation and treatment of shoulder disorders[28], the possible influences of pain on muscle activity and amount of use of the upper limb during functional activities, further studies are needed to establish the reliability the variables tested in sports activities and in patients who have pain and reduction in the use of the stabilizing muscles of the scapula or with scapular dyskinesis diagnosis.

CONCLUSION

Results presented in this study indicate that the linear and angular measurements for determining the resting scapular position of asymptomatic and sedentary population are reliable, which were achieved through an electromagnetic system for three-dimensional movement record. Taking into account the need to evaluate the influence of scapular dyskinesis and the amount of use of the upper limbs in functional and sports activities, further reliability studies should be carried out using the same system to assess resting scapular position in samples of participants with symptomatic dysfunction of the shoulder complex and in participants in professional or recreational sports activities.

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