Effect of Sitting Posture on 3-Dimensional Scapular Kinematics Measured by Skin-Mounted Electromagnetic Tracking Sensors

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ABSTRACT. Finley MA, Lee RY. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. Arch Phys Med Rehabil 2003;84:563-8.

Objective: To determine the effect of trunk sitting posture on scapular kinematics during humeral elevation by using skin-mounted electromagnetic tracking sensors.

Design: Repeated-measures design contrasting scapular kinematics in 2 different sitting postures.

Setting: A biomechanics laboratory in Hong Kong with a real-time, 3-dimensional electromagnetic tracking device for measuring movements of the scapula.

Participants: A sample of 16 healthy adults (12 women, 4 men; age, 21.6±3.92y) with full, pain-free shoulder range of motion and no history of shoulder pathology.

Interventions: Not applicable.

Main Outcome Measures: Movements of the scapula were measured while each subject performed humeral elevation in an upright seated position and a slouched seated position.

Results: In both postures, posterior tip, lateral and upward rotation of the scapula, and lateral rotation of the humerus were observed during humeral elevation. When the slouched posture was adopted, there were significant decreases in the posterior tip and lateral rotation of the scapula, but there was no significant change in the magnitude of the upward rotation of the scapula.

Conclusion: Increased thoracic kyphosis significantly alters the kinematics of the scapula during humeral elevation.

Key Words: Biomechanics; Kinematics; Posture; Rehabilitation; Scapula; Shoulder.

THE MOBILITY OF THE SHOULDER complex is the largest among all body joints.[1] Movements of the joint complex generally involve combined motions of the sternoclavicular, acromioclavicular, sternothoracic, and glenohumeral articulations.[1,2] The relation between scapular and glenohumeral movements during humeral elevation has been widely studied.[2-5] Inman et al[2] reported that there were 2 degrees of humeral elevation for each degree of scapular rotation. However, the relationship varies throughout the range of motion and among individuals. Ratios of 1.35:1 to 7.9:1 (the ratio of humeral elevation to scapular rotation) have been reported in normal, healthy subjects.[4,6,7] The ratio was found to be larger in the initial phase of elevation than in the final phase.[4,7]

The effects of muscle fatigue and external load on scapular kinematics during humeral elevation have also been examined.[3,7-11] Fatigue led to an increase in scapular movements in relation to the humerus.[12] External loads applied to the humerus during elevation resulted in reduced scapular rotation.[12] However, alteration in the relationship is dependent on the loads applied.[4,7]

Impingement pathology produces decreased posterior tipping of the scapula during elevation of the humerus.[9,10] When external loads were applied to individuals with impingement, increased scapular medial rotation about a vertical axis was noted.[9] During humeral elevation, individuals with glenohumeral instability presented with decreased scapular abduction and lateral rotation occuring about an axis perpendicular to the scapular plane.[11]

Several studies examined the effect of posture on scapular positions.[13,14] However, these studies used different methods and study designs and had different outcomes. Several studies determined scapular movement with the arms held in different static positions.[8,10,13,14] The isometric muscular contraction required to hold these static positions may alter the positions of the scapula. Because previous studies may not truly represent scapular kinematics during a dynamic task,[7] there is a need to further examine the effects of posture on scapular kinematics.

The purpose of the present study was to assess dynamically the effect of thoracic trunk posture on scapular kinematics during (1) elevation of the humerus in the scapular plane and (2) axial rotation of the humerus during elevation in the scapular plane.

METHODS

Participants

Sixteen adult volunteers participated in this study (12 women, 4 men; mean age, 21.6±3.92y; height, 165.06±5.36cm; weight, 51.75±4.46kg). A brief questionnaire was used to identify any history of shoulder pathology, as well as primary activities of daily living that involved overhead activity. Those who reported a history of shoulder pathology or were currently experiencing shoulder pain were excluded from the study. All subjects read and provided informed consent by signing a consent form approved by the human subjects ethics review committee at the Hong Kong Polytechnic University and the University of Maryland, Baltimore.

Instrumentation

Real-time 3-dimensional positions of the thorax, humerus, and scapula were collected by using the Fastrak[a] electromag-

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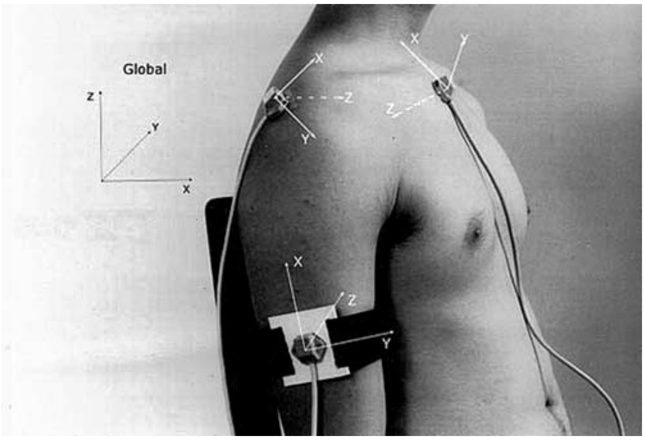

Fig 1. Experimental set-up. Global coordinate system and sensor (local) coordinate system are indicated.

netic device. This system has been previously described in several biomechanic studies.[15-17] Briefly, the transmitter generated a low-frequency electromagnetic field, which was detected by sensors. The transmitter was mounted on a rigid wood frame and established the global coordinate system. The electromagnetic sensors (2.63×2.29×1.52cm) were attached to the sternum (distal to the sternal notch), acromion process, and humerus (via a molded thermoplastic cuff). Figure 1 illustrates the global coordinate system and local coordinate systems established by the sensors.

The experimental setup provided an angular orientation accuracy of 1.3°.[7] The root mean square (RMS) error due to skin motion artifact was 2.0° to 9.4° when humeral elevation was less than 120°.[7,18] This method of measuring scapular motions by using skin-mounted electromagnetic sensors was considered sufficiently accurate for the purpose of the present study.

Procedures

Subjects performed humeral elevation along the scapular plane while sitting in an upright posture. The scapular plane was defined as an angle 30° to 45° anterior to the coronal plane, placing the deltoid and supraspinatus in an optimal position to perform humeral elevation.[3] A guide board was used to maintain the plane of motion in the scapular plane.[3,7,19] The neutral reference position of the shoulder complex was recorded before each elevation trial. This neutral position was considered as the position of 0°, and motions of the sensors were calculated with reference to this 0° position. Subjects were instructed to lift their arm to full elevation. Speed of movement was controlled by a standardized count of 4 seconds of elevation, followed by 4 seconds for the return motion. Three trials of the movements were performed so that the repeatability of the data obtained could be assessed. Subjects were then instructed to "slouch down" as far as they could, and the procedures were repeated with the subjects in a slouched (increased thoracic kyphosis) posture.

Data Reduction and Analysis

The output of the Fastrak machine comprised 3×3 direction cosine matrices describing the orientation of the scapular, thorax, and humeral sensors. The movements of the scapulothoracic and humerothoracic joints were described by the orientations of the scapular and humeral sensors relative to that of the thorax sensor, respectively. The mathematical procedures used in deriving the movements are based on those proposed previously[20,21] and are described in appendix 1.

Scapular upward and downward rotations were defined as rotations about its anteroposterior (AP) sensor axis (z), with upward rotation being movement of the glenoid fossa superiorly while the inferior angle moved laterally and upward. Anterior and posterior tipping was defined as rotation about the mediolateral (ML) sensor axis (y), with anterior tipping being movement of the inferior angle of the scapula away from the thorax. Rotation about the superoinferior sensor axis (x) was defined as medial and lateral rotation, with posterior movement of the vertebral border of the scapula being medial rotation. Humeral medial and lateral rotation occurred about the vertical, superior-inferior sensor axis (x), with abduction and adduction and flexion and extension occurring about the AP sensor axis (y) and ML sensor axis (x), respectively (fig 1).

Movements of the scapulothoracic and humerothoracic joints were plotted against time for each trial of humeral elevation. Repeatability of the data was assessed by examining the similarity of the angle-time curves by using the coefficient of multiple correlation (CMC). RMS error was used to assess intrasubject trial-to-trial differences. The 3 trials of elevation in each condition were averaged.

We examined the following dependent variables: the neutral positions of the scapula and humerus in the upright and slouched postures and the movements of the scapulothoracic joint and axial rotation of the humerus in the 2 postures. Repeated-measures multivariate analysis of variance (MANOVA) was performed to study the effects of posture (upright and slouched), the magnitude of humeral elevation (30°, 60°, 90°), and their interaction on each of the 4 dependent variables (3 scapular movements, 1 humerothoracic movement). We chose MANOVA to study the various dependent variables in a single statistical procedure because these variables could be correlated and should not be examined separately. Performing multiple ANOVAs for each dependent variable would also inflate the type I error. Because of variations in subjects' maximal range of humeral elevation, we limited analysis to 90°. Tukey honestly significant difference post hoc analysis ($P \leq .05$) for significant main effects was performed. The SPSS statistical package[b] was used to perform all the statistical analyses.

RESULTS

Repeatability of Data

The CMC ranged from .75 to .95, and the RMS error in determining the movements of the scapulothoracic and humerothoracic joints ranged from 0.8° to 1.0°. We concluded that the measurements were sufficiently reliable for the purpose of this study (table 1).

Table 1: Trial-to-Trial Reliability of Measurements of Scapular and Humeral Movements

Variable	RMS		CMC	
	Upright	Slouched	Upright	Slouched
S-T tipping	.84°	1.2°	.95	.93
S-T MR/LR	.84°	1.2°	.90	.86
S-T up/down rot	.85°	1.2°	.92	.75
HT MR/LR	1.0°	1.5°	.92	.95

Abbreviations: S-T, scapulothoracic; MR/LR, medial rotation/lateral rotation; rot, rotation; HT, humerothoracic.

Table 2: Changes in the Positions of the Scapula in the Resting Position of the Slouched Posture Compared With the Upright Posture

Motion	Starting Position
S-T anterior/posterior tipping	−2.5°±3.2° (anterior)*
S-T MR/LR	.66°±3.86° (medial)
S-T up/down rotation	−4.5°±5.1° (upward)*
HT MR/LR	7.7°±6.8° (medial)*

NOTE. Values are mean ± standard deviation (SD).
* Significant difference between upright and slouched resting posture ($P \leq .05$).

Neutral Positions of the Scapulothoracic and Humerothoracic Joints

In the slouched posture, there was significantly increased scapular anterior tip and upward rotation in the neutral position when compared with the neutral position of the upright posture. There were no significant changes in the orientation of the scapula in the transverse plane ($P>.05$). The humerus was also significantly ($P>.05$) more medially rotated in the slouched posture (table 2).

Movements of the Scapula and the Humerus in the 2 Postures

In both the upright and slouched postures, posterior tip, lateral rotation, and upward rotation of the scapula and lateral rotation of the humerus were observed during humeral elevation. Figure 2 shows a typical pattern of scapular motion of 1 subject during humeral elevation in reference to the neutral resting position. MANOVA indicated that the magnitude of the scapular and humeral movements significantly increased as the arm was elevated ($P>.05$). It also showed that there were significant decreases in scapular posterior tip ($P=.004$) and lateral rotation ($P=.000$) when the slouched posture was adopted, but there was no significant change in the magnitude of upward rotation ($P>.05$) (fig 3). We found no statistically significant interaction of humeral elevation angle and trunk posture ($P>.05$).

DISCUSSION

The electromagnetic tracking method provided data with good reliability, and the RMS errors were small for measuring scapular and humeral movements. This confirms the results of previous studies that also showed that the method provided highly reliable data.[7,9]

The changes in the scapular positions with the adoption of a slouched posture during humeral elevation, as observed in the present investigation, were in general agreement with those of earlier studies.[14,19] For instance, Culham and Peat[19] found that increased thoracic kyphosis resulted in an increase in anterior tilt of the scapula. Kebaetse et al[14] also found that the slouched posture (increased thoracic kyphosis) placed the scapula in a resting position with greater medial rotation, upward rotation, and anterior tip as compared with an upright posture.

The present study showed that posterior tipping and lateral and upward rotations of the scapula occurred during humeral elevation. Similar observations were made in previous studies,[9,14,22] although the researchers performed static or quasi-dynamic analysis of scapular movements only. The present study showed a smaller magnitude of scapular upward rotation and a greater amount of lateral rotation when compared with the studies of Ludewig et al[22] and Kebaetse et al.[14] The differences in the magnitude of movements might be due to biologic variation, differences in the methods of computing the scapular motions, and the fact that the scapular motions were determined with reference to the 0° reference positions, which would vary in different individuals. Nevertheless, the same pattern of scapular motions was observed in the present study and earlier studies.

A decrease in posterior tipping and lateral rotation of the scapula has been associated with glenohumeral impingement and instability.[9-11] Because of the anatomy of the subacromial space, Ludewig and Cook[9] suggested that alterations in scapular movements as small as 4° to 6° are clinically important. Although the changes in scapular movements in the slouched posture were small, the present study clearly showed that the slouched posture, with increased thoracic kyphosis, would lead to decreased posterior tip and decreased lateral rotation of the scapula. Furthermore, one could deduce that more pronounced alterations in scapular motion may be present with greater humeral elevation.[9,14,22] As reported by Flatow et al,[23] humeral elevation above 90° resulted in a reduction in the acromiohumeral interval, with the articular cartilage and rotator cuff tendons no longer being accommodated. It could be argued that repetitive humeral elevation in a slouched posture may increase the likelihood of encroachment of the supraspinatus tendon and development of shoulder pathology.[1,23]

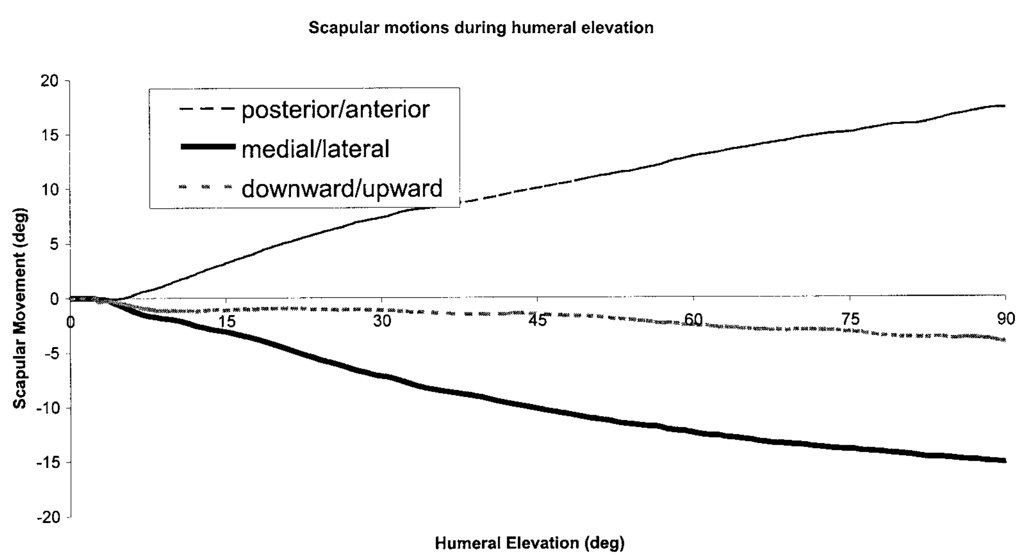

Fig 2. A typical pattern of scapular motion plotted against the humeral elevation angle in a subject sitting with upright posture. NOTE. The angles were relative to the 0° reference position of the scapula. Direction of motion around the axis: posterior (+), and anterior (−) tipping; downward (+) and upward (−) rotation; medial (+) and lateral (−) rotation.

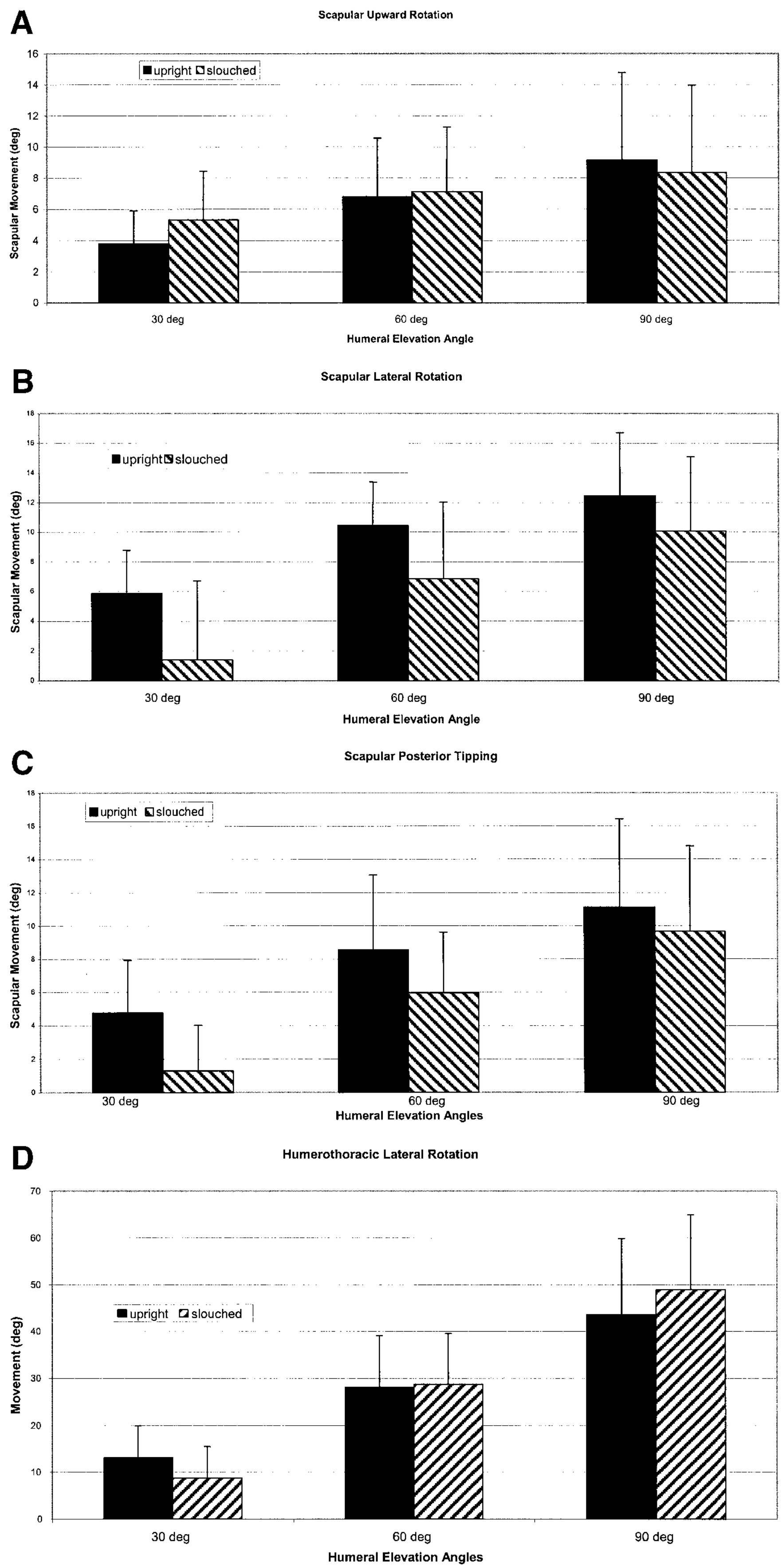

Fig 3. Comparison of the absolute mean (±SD) magnitude of scapulothoracic and humerothoracic movements between the upright and slouched postures for 3 humeral elevation angles. (A) Scapulothoracic upward rotation; (B) scapulothoracic lateral rotation; (C) scapulothoracic posterior tipping; and (D) humerothoracic lateral rotation.

It should be noted that the scapular angles reported in the present study were based on the motions of the skin-mounted sensors and do not refer to the absolute anatomic movements of the scapula. Caution should be exercised when comparing the data of the present study with those of previous work where absolute anatomic movements were reported. Determining the anatomic movements will require that the angles be expressed in terms of the anatomic axes of the scapula bone. Such information was unknown in this study and could be determined experimentally only by imaging methods such as radiography, which was ethically undesirable because it would require subjects to be exposed to radiation. To solve this problem, we determined the relative angles between the scapular and trunk sensors with reference to their 0° reference positions. The mathematical procedure described in appendix 1 allowed us to determine these angles without knowing the anatomic axes in such a way that they would reflect the motions of the scapulothoracic joint.

Another limitation of the present study was that the biomechanic analysis of scapular movements was limited to 90° of humeral elevation. Error due to skin movement had been shown to be large beyond 120°,[18] and our study was limited to 90° so that data would not be contaminated by such error. The present study did not provide any information on scapular kinematics at a greater range of humeral elevation. Future studies should examine kinematics beyond this range by using techniques such as radiography. Furthermore, the present study did not provide any information on scapular translation. We also did not quantify the magnitude of thoracic kyphosis in the 2 postures, creating another potential limitation of the study. Future studies should quantify the change in posture, and an attempt should be made to examine how the degree of kyphosis correlates with the degree of scapular motions. Electromyographic activities of shoulder muscles should also be measured in future work. This procedure would provide information that could help explain the changes in scapular kinematics in different postures. Finally, our convenience sample of university students and employees resulted in an unequal gender distribution, young age, and low weight, which could limit the generalizability of the findings.

CONCLUSION

Electromagnetic tracking is a reliable method of measuring scapular kinematics. The adoption of a slouched posture alters scapular kinematics. Changes in the movement patterns of the scapula may increase the likelihood of shoulder pathology. Further studies of the relation between posture and kinematics are needed to determine the mechanisms of injury and possible preventions for shoulder disorders.

APPENDIX 1

The movements of the scapulothoracic and humerothoracic joints are represented by the orientations of the scapula and humerus relative to that of the thorax. The matrix $[R_T]$ described the orthogonal base vector set of the scapula $[A_S]$ (or humerus $[A_H]$) with respect to those of the thorax $[A_T]$:

$$\begin{bmatrix} A_{S1x} & A_{S1y} & A_{S1z} \\ A_{S2x} & A_{S2y} & A_{S2z} \\ A_{S3x} & A_{S3y} & A_{S3z} \end{bmatrix} = \begin{bmatrix} R_{S11} & R_{S12} & R_{S13} \\ R_{S11} & R_{S12} & R_{S13} \\ R_{S11} & R_{S12} & R_{S13} \end{bmatrix} \times \begin{bmatrix} A_{T1x} & A_{T1y} & A_{T1z} \\ A_{T2x} & A_{T2y} & A_{T2z} \\ A_{T3x} & A_{T3y} & A_{T3z} \end{bmatrix}$$

$$\text{or } [A_S]=[R_S][A_T]$$

$$\text{or } [R_S]=[A_S][A_T]^{-1}=[A_S][A_T]^T,$$

where x, y, and z are the axes of the global reference system (ground) and $[A_T]^T$ is the transpose of $[A_T]$. The orthogonal base vector set representing the humerus to thorax relationship is the same, that is, $[R_H]=[A_H][A_T]^{-1}=[A_H][A_T]^T$.

The anatomic base vector sets $[A_s]$ and $[A_T]$ are unknown, but the Fastrak system provides information on the orientation base vector sets of the sensors attached to the scapula $[S_S]$ (or humerus $[S_H]$) and the thorax $[S_T]$. The anatomic and sensor axes are assumed to have fixed spatial relationships given the fact that the sensors are securely fixed to the body.

$$[S_S]=[M_S][A_S]$$

$$[S_H]=[M_H][A_H]$$

$$[S_T]=[M_T][A_T]$$

where $[M_S]$ and $[M_T]$ are the matrices that defined the spatial relationships.

If the upright sitting posture is taken as the 0° reference position, then $[A_S]_{upright}=[A_T]_{upright}=[A_H]_{upright}=[I]$, where [I] is the unit matrix. Thus,

$$[M_S]=[A_S]_{upright}$$

$$[M_H]=[A_H]_{upright}$$

$$[M_T]=[A_T]_{upright}.$$

Then it is possible the express $[R_S]$ and $[R_H]$ in terms of the base vector sets of the sensors:

$$[R_S]=[A_S][A_T]$$

$$[R_S]=[S_S][M_S]^T[S_T]^T[M_T]$$

$$[R_S]=[S_S][S_S]^T_{upright}[S_T]^T[M_T]_{upright}$$

$$[R_H]=[A_H][A_T]$$

$$[R_H]=[S_H][M_H]^T[S_T]^T[M_T]$$

$$[R_H]=[S_H][S_H]^T_{upright}[S_T]^T[S_T]_{upright}$$

The 3-dimensional motions of the scapulothoracic (α_S, β_S, γ_S) and the humerothoracic joints (α_H, β_H, γ_H) can be computed from $[R_S]$ and $[R_H]$ by using the method of Grood and Suntay.[21] It can be shown that

$$\alpha_S=\cos^{-1} R_{S13}-\pi/2$$

$$\beta_S=\tan^{-1} (R_{S23}/R_{S33})$$

$$\gamma_S=\tan^{-1} (R_{S12}/R_{S11}).$$

$$\alpha_H=\cos^{-1} R_{H13}-\pi/2$$

$$\beta_H=\tan^{-1} (R_{H23}/R_{H33})$$

$$\gamma_H=\tan^{-1} (R_{H12}/R_{H11}).$$

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