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Scapular kinematics in adolescent idiopathic scoliosis: A three-dimensional motion analysis during multiplanar humeral elevation

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ABSTRACT

The scapula plays a critical role in supporting shoulder function. Considering the closed anatomical relationship between the scapula and the thoracic cage, the presence of postural disturbances could be linked to alterations in the scapular position and orientation in adolescent idiopathic scoliosis (AIS). However, currently there is a lack of descriptive research and detailed assessment of scapular kinematics in AIS. The aim of this study was to investigate the three-dimensional scapular kinematics in AIS. Nineteen AIS patients and fourteen healthy controls participated in this study. Bilateral shoulder kinematics were measured with an electromagnetic tracking device during shoulder elevation in the sagittal, scapular, and frontal planes. Data for the scapular orientation were analyzed in the resting position and at 30°, 60°, 90°, and 120° of humerothoracic elevation. Scapular behavior was different in participants with AIS, compared to healthy controls, with different patterns observed on convex and concave sides. While examining all three planes of elevation, the scapula was more internally and anteriorly tilted on the convex side, while the scapula was more externally, downwardly rotated, and posteriorly tilted on the concave side in participants with AIS. Furthermore, there was a decreased peak humerothoracic elevation and altered scapular posterior tilt in participants with AIS in the resting position. These findings increase our knowledge and understanding of scapular alterations and the reported scapular alterations can be considered as adaptive compensation strategies in AIS.

1. Introduction

Shoulder elevation is a complex motion that occurs because of combined humerus, clavicle, spine, and scapula movement (Inman et al., 1996; Theodoridis and Ruston, 2002). The scapula plays a critical role in supporting a wide range of glenohumeral motions and normal shoulder function (Kibler, 1998). Alterations in scapular kinematics are often related to various shoulder disorders (Ludewig and Reynolds, 2009). Common causes including postural problems, dysfunction of the scapular muscular force couples, and flexibility deficits of the pectoralis minor and posterior capsule may affect scapulohumeral motion (Ludewig and Reynolds, 2009).

Adolescent idiopathic scoliosis (AIS) is a structural, lateral, rotated curvature of the spine that arises in otherwise healthy children at or around puberty (Weinstein et al., 2008). This spinal deformity is characterized by a curved spine and is usually accompanied by geometric and morphologic changes in the trunk and thoracic cage deformity (LeBlanc et al., 1997; Stokes, 1994). Despite decades of intensive research, the cause and pathophysiology of AIS is not well understood; however, many factors have been associated with AIS including central nervous system alteration (Adler et al., 1986; Herman et al., 1985; Keessen et al., 1992; Sahlstrand et al., 1978), sensory-motor deficits (Barrack et al., 1988; Keessen et al., 1992; Wyatt et al., 1986), and impaired static and dynamic neuromuscular control (Beaulieu et al., 2009; Byl and Gray, 1993; Lao et al., 2008; Nault et al., 2002). The spinal deformity not only modifies the shape of the trunk but also changes relations between body segments (Goldberg et al., 2001; Samuelsson and Noren, 1997; Stokes, 1994). Considering the closed anatomical relationship between the scapula and the thoracic cage, the presence of the aforementioned factors could be linked to alterations in the scapular position and orientation in AIS. Altered proximal orientation may further affect shoulder and upper extremity function and lead to altered force transfer.

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Upper limb dysfunction such as lower levels of self-reported shoulder function (Lin et al., 2010), decreased grip strength (Martinez-Liorens et al., 2010), proprioceptive deficit (Keessen et al., 1992) and shoulder pain (Grubb and Lipscomb, 1992) were previously reported especially for adult scoliosis. Lin et al. (2010) investigated resting and scapular plane elevation kinematics and reported alterations in scapular orientation in the resting position when comparing idiopathic scoliosis in adolescents and adults with healthy controls. However, younger populations have different scapular behavior compared with adults (Dayanidhi et al., 2005). There is a lack of descriptive research and detailed assessment of scapular kinematics in AIS. Investigating three-dimensional (3D) scapular kinematics during shoulder elevation in different movement planes may therefore enhance the field's knowledge regarding scapular behavior in AIS and help advance our understanding of the patterns and magnitude of scapulothoracic movement adaptations in this population. Accordingly, we aimed to investigate 3D scapular kinematics in AIS. We hypothesized that the convex and concave shoulder side of participants with AIS would have alterations in scapular kinematics during multiplanar humeral elevation and scapular orientation in the resting position, when compared with the dominant and nondominant side of healthy controls.

2. Materials and methods

2.1. Participants

A total of thirty-three pain-free participants with AIS (n = 19) and healthy controls (n = 14) were recruited in the study (Table 1). Inclusion criteria for participants with AIS consisted of a right thoracic left lumbar double curve pattern scoliosis with a primary thoracic curve Cobb angle between 20° and 45°. Cobb angle was measured using standard antero-posterior radiographs in a standing position. Participants with AIS also had no history of shoulder pain, no prior intervention, and had arm dominance on their convex side. Healthy controls were selected from asymptomatic volunteers who had no history of shoulder pain or injury related to the upper body and extremities. Participants were excluded if they had any known systemic or neurological disorders including cervical radiculopathy, performed repetitive overhead shoulder movements related to occupation or sports activities on a regular basis, or had a body mass index >30 kg/m^2.

The Institutional Research Ethics Board approved the protocol for this study and all participants signed informed consent forms.

2.2. Instrumentation

3 D kinematic data for the scapula were collected with a Flock of Birds electromagnetic tracking system (Ascension Technology Corporation, Shelburne, VT, USA). This system interfaced with the Motion Monitor software program (Innovative Sports Training Inc., Chicago, IL, USA).

Table 1
Characteristics of participants.

	Participants with AIS n = 19	Healthy controls n = 14	*p*
Age (years)	13.8 (1.9)	13.7 (2)	0.93
Height (m)	157.7 (11.1)	159.7 (8.3)	0.57
Weight (kg)	46.2 (9.4)	50.1 (7.8)	0.22
Gender (n)	17 Female 2 Male	11 Female 3 Male	0.38
Cobb Angle (degrees)	32.6 (7.9)	N/A	N/A
ASES Score (points)	96.1 (2.6)	97.4 (1.8)	0.12

Note: Data given as mean and standard deviation (for age, height, weight and Cobb angle), or as counted numbers (gender).
AIS; Adolescent idiopathic scoliosis, ASES; American Shoulder and Elbow Surgeons. Exact *p* values based on student-*t* test for age, height, and weight; and Fisher's exact test for gender.

2.3. Experimental procedure

First, five sensors were attached directly to the skin over flattest aspect of the each acromion, postero-lateral aspect of the each humerus distal to triceps belly and T1 thoracic vertebrae with double-sided adhesive tape and further secured with nonelastic tape. Second, specific bony landmarks were digitized with a stylus based on International Society of Biomechanics standard protocol while participants were standing with their arms relaxed (Wu et al., 2005). Third, the data analysis were performed and further described using the Euler angle sequence (Ayhan et al., 2015; Turgut et al., 2016).

Scapular orientation in the resting position was recorded bilaterally; kinematic data were collected for 5 s in the patient's resting standing posture with arms relaxed at the sides. Sagittal plane, scapular plane, and frontal plane elevation were assessed. Scapular plane was oriented 40° anterior to the coronal plane (Borstad and Ludewig, 2005). Participants performed three repetitions of bilateral, full overhead arm elevation in three movement planes, using the wooden poles as a guide, at a speed matching the beat of a metronome set at 60 beats per minute, using 3 s for elevation. Prior to recording, each participant performed a series of elevation in the specific movement plane to warm-up and to familiarize. Thirty seconds were provided between recordings to avoid fatigue. Additionally, during kinematic recordings, verbal comments were made to achieve full elevation. The order of the movement plane was randomized using random numbers generated by a computer.

Data for scapular orientation at 30°, 60°, 90°, and 120° of humerothoracic elevation were obtained for each repetition. The y-x'-z'' sequence was used to define scapular rotations; the first rotation defined the amount of internal-external rotation, second upward-downward rotation, and last anterior-posterior tilt. The scapular orientation values at rest, at each angle of humerothoracic elevation, and peak humerothoracic elevation angles for each movement were averaged across the three repetitions.

Data collected with this electromagnetic tracking system are reliable, with calculated between-day ICC values ranging from 0.70 to 0.82; standard error of measurement values ranging from 3.37° to 6.79° for scapular kinematics (Haik et al., 2014). This method of measuring 3D scapular kinematics has previously been validated below 120° of elevation (Karduna et al., 2001).

2.4. Statistical analysis

Sample size was determined based on a pilot study with nine patients using a power of 0.80 and $\propto = 0.05$. Using the primary outcome variable of scapular upward rotation, it was determined that 14 participants were required in each group. The assumption of normality was tested prior to statistical analysis by inspecting skewness and kurtosis. Statistical analysis of kinematic data was then performed using two separate two-way ANOVAs (group-by-angle) for each scapular movement obtained during sagittal, scapular and frontal plane elevations; with the group set as the between-subjects factor and the angle (30°, 60°, 90°, and 120° humerothoracic elevation) set as the repeated factor. One ANOVA was used to compare scapular rotations between the convex side of participants with AIS to the dominant side of healthy controls, and one was used to compare the concave side of participants with AIS to the nondominant side of healthy controls. When an interaction term was significant, pairwise analyses were performed using a Bonferroni adjustment. The examination of post-hoc results was

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