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# Acute effects of spinal bracing on scapular kinematics in adolescent idiopathic scoliosis

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A R T I C L E I N F O

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A B S T R A C T

*Background:* Bracing is the most common nonsurgical treatment for adolescent idiopathic scoliosis. Spinal braces affect glenohumeral and scapulothoracic motion because they restrict trunk movements. However, the potential spinal-bracing effects on scapular kinematics are unknown. The present study aimed to investigate the acute effects of spinal bracing on scapular kinematics in adolescent idiopathic scoliosis.

*Methods:* Scapular kinematics, including scapular internal/external rotation, posterior/anterior tilting, and downward/upward rotation during scapular plane elevation, were evaluated in 27 in-brace and out-of-brace adolescent idiopathic scoliosis patients with a three-dimensional electromagnetic tracking system. Data on the position and orientation of the scapula at 30°, 60°, 90°, and 120° humerothoracic elevation were used for statistical comparisons. The paired *t*-test was used to assess the differences between the mean values of in-brace and out-of-brace conditions.

*Findings:* The in-brace condition showed significantly increased ($P < 0.05$) scapular anterior tilting and decreased internal rotation in the resting position on the convex and concave sides; increased scapular downward rotation at 120° humerothoracic elevation on the convex side and at 30°, 60°, 90°, and 120° humerothoracic elevation on the concave side; increased scapular anterior tilt at 30°, 60°, 90°, and 120° humerothoracic elevation on the convex and concave sides; and decreased ($P < 0.05$) maximal humerothoracic elevation of the arm.

*Interpretation:* Spinal bracing affects scapular kinematics. Observed changes in scapular kinematics with brace may also affect upper extremity function for adolescents with idiopathic scoliosis. Therefore, clinicians should include assessments of the glenohumeral and scapulothoracic joints when designing rehabilitation protocols for patients with adolescent idiopathic scoliosis.

## 1. Introduction

Bracing is the most commonly used treatment method for skeletally immature patients with adolescent idiopathic scoliosis (AIS) who have progressive curves > 20° (Negrini et al., 2015; Rigo et al., 2006). Several types of underarm braces exert three-dimensional (3-D) corrective forces to resist the curve forces in the opposite direction (Kim, 2014). These braces apply passive forces on the torso to produce coronal Cobb angle correction and transverse vertebral derotation and contribute to the force equilibrium within the brace (Périé et al., 2003). However, little is known about the load transmission mechanism from the brace–torso interface to the spine.

The forces applied through braces may be nonequilibrated and cause stiffness of the spine (Perie et al., 2004). Thoracolumbosacral orthoses (TLSO) have a rigid construction and, therefore, should not only correct the curve but also reduce the mobility of the thoracolumbar spine. A previous study showed that TLSO braces restricted the gross range of motion of the spine especially in the sagittal plane (Lantz and Schultz, 1986). Van Leeuwen et al. confirmed TLSOs effect in reducing spinal movement especially from T10 to L4 (van Leeuwen et al., 2000). During arm elevation, the trunk is recruited before recruitment of the arm joints for activating appropriate muscles to stabilize the trunk and scapula, and also the trunk accompanies to the movement for maximum humerothoracic elevation (Kaminski et al., 1995). All biomechanical factors for maintaining optimal correction may have restrictive effects on the trunk and, therefore, on the shoulder function in scoliosis.

Proper scapular biomechanics is essential for normal shoulder

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function (Kibler, 1998). Altered shoulder kinematics was shown in patients with AIS in several studies (Lin et al., 2010; Masso and Gorton, 2000; Raso et al., 1998). Scapular asymmetry is a predictive factor for the overall impression of trunk deformity in AIS (Raso et al., 1998). Thus, the assessment of changes in scapular kinematics with 3-D motion analysis systems may be essential when planning a rehabilitation program. Lin et al. also emphasized that shoulder kinematics should be analyzed in rehabilitation programs (Lin et al., 2010). However, no study evaluating the possible changes in scapular kinematics in patients using spinal braces has been published thus far. Changes in scapular orientation and movements reportedly lead to musculoskeletal dysfunction, including instabilities, impingement, and tendinitis (Borstad, 2006; Ludewig and Cook, 2000; Solem-Bertoft et al., 1993).

Measurement of in-brace scapular kinematics during shoulder elevation may provide additional information for in-brace design and rehabilitation programs. We hypothesized that the spinal brace used to correct the curve in scoliosis may adversely affect scapular kinematics due to its restrictive effects on trunk motions. The present study aimed to investigate the effects of spinal bracing on scapular kinematics and compare the results between in-brace and out-of-brace conditions in patients with AIS.

## 2. Methods

### 2.1. Participants

Twenty-six right-hand-dominant patients with idiopathic scoliosis participated in the study. Inclusion criteria included age (10–17 years), curve pattern (primary thoracic scoliosis, with apical regions at T8–T10), primary curve magnitude (curve size, 20°–45° Cobb angle), and having no prior history of scoliosis treatment, shoulder pathology, surgery, or shoulder or back pain. Patients were excluded if they declined to participate in the study or wear a spinal brace from the beginning.

Demographic characteristics regarding age, gender, height, weight, and body mass index were recorded for each patient [23 female, three males; mean age: 13.8 (1.9) years, range: 10–17 years; mean height: 157.7 (10.3) cm, mean weight: 45.9 (8.9) kg, mean body mass index (BMI): 18.3 (2.9) $kg/m^2$]. The Cobb angle was examined using antero–posterior radiographs. The mean thoracic Cobb angle was 32.1 (8.3)°, range of 22°–45°, and the mean lumbar Cobb angle was 29.2 (10.4)°, range of 14°–45°. Twenty-one patients had a right thoracic left lumbar curve pattern, whereas five patients had a right thoracolumbar curve pattern. Direction of the curve convexity was right side of the trunk (according to the primary curve) in all patients. The University Research Ethics Board approved the study. All patients and their parents were informed about the study and signed an informed consent form.

### 2.2. Spinal brace

An underarm thoracolumbosacral corrective spinal brace was manufactured on the basis of the individual properties of the curves for each patient included in this study (Fig. 1). The brace was prepared from medium density polyethylene. The brace extended from the thoracic region to the iliac crest, preserved the physiological lumbar lordosis, and applied forces directly to the ribs and spine to correct the curve using symmetrical design principles. The main functions of the brace were to actively correct lateral deviation and rotation and restore sagittal plane deformity by pushing upward from the pelvis. For the correction of the curve, the force was applied from postero-lateral of the apex of convexity and a high counter-force was applied from the opposite side. Therefore the concave side of the brace was higher (just below the axilla), depending on the apex, than the convex side on the lateral part of the trunk. A thoracic window in the front of the brace allowed thoracic expansion and mammary growth (Gur et al., 2015).

**Fig. 1.** Anterior and posterior views of the spinal brace.

### 2.3. Instrumentation

A Flock of Birds electromagnetic tracking system (Ascension Technology Corporation, Shelburne, VT) interfaced with the MotionMonitor software program (Innovative Sports Training, Inc., Chicago, IL) was used to collect 3-D scapular and humeral kinematics. Data collected with this electromagnetic tracking system are reliable, with previously reported trial-to-trial, within-day, and without-removal-of sensors correlation coefficient values ranging from 0.8 to 0.9 and a standard error of measurement values ranging from 1.3° to 1.7° (Thigpen et al., 2005).

### 2.4. Experimental protocol

Before the kinematic recordings, five sensors (one thoracic sensor, two scapular and two humeral sensors) were directly attached to the skin of the patients with double-sided tape over the landmarks for data collection. The thoracic sensor was placed over the T1 spinous process. The scapular sensor was placed on each scapula over the flattest aspect of the posterolateral aspect of the acromion to reduce the artifact produced by skin movement, and the humeral sensor was placed on each arm over the posterior aspect of the humerus distal to the triceps muscle belly (Fig. 2A; Ludewig and Cook, 2000). Digitization was completed with humerus, scapula, and thorax landmarks based on the International Society and Biomechanics guidelines for subjects standing in the anatomical position (Wu et al., 2005). Following the digitization process, the scapular position and orientation at the resting position were tested bilaterally, and kinematic data were collected for 5 s at the patient's resting standing posture with arms relaxed at the sides. Furthermore, dynamic 3-D scapular and humeral kinematic data were collected on the scapular plane of shoulder elevation. Patients were asked to perform abduction with the scapular plane oriented 40° anterior to the coronal plane (Borstad and Ludewig, 2005). Each movement was performed bilaterally and repeated three times going through the maximum overhead arm elevation and lowering the arm in the scapular plane using a wooden pole as a guide at each movement repetition. A tone signal instructed the subjects to start the arm movement. Elevation movement was recorded in 3 s, and the recorded activity was then analyzed for each humerothoracic elevation level. Data on the position and orientation of the scapula at the resting position, at 30°, 60°, 90°, and 120° humerothoracic elevation in the scapular plane, were further analyzed. Furthermore, the maximum humerothoracic elevation angles were recorded.

The testing protocol lasted approximately 1 h per person and was performed in a single session. Patients were tested for in-brace and out-of-brace conditions (Fig. 2B and C). The braces were fitted to the patients for in-brace measurement. Participants wore no shirt (males) or a tank top or sports bra (females) in the out-of-brace condition. In-