Three dimensional analysis of brace biomechanical efficacy for patients with AIS

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Abstract

Purpose Corrective three dimensional (3D) effect of different braces is debatable. We evaluated differences in in-brace radiographic correction comparing a custom thoracic-lumbo-sacral-orthosis (TLSO) (T) brace to a Chêneau type TLSO (C) brace using 3D EOS reconstruction technology. Our primary research question was the 3D effect of brace on the spine and in particular the apical vertebra rotation (AVR).

Methods This was a retrospective comparative analysis of patients with adolescent idiopathic scoliosis who had orthogonal AP and lateral X-rays with and without brace. A 3D image of the spine was reconstructed. Coronal, sagittal and axial spine parameters were measured before bracing and then on the first post-brace X-ray. Brace efficacy in controlling coronal, sagittal and axial parameters was evaluated.

Results Eighteen patients treated with the C brace and ten patients treated with the T brace were included. No difference was found regarding patients' age, gender, magnitude of Cobb angle, sagittal parameters or AVR at inclusion. Following bracing, AVR was significantly reduced by the C brace compared to the T brace [average correction of 8.2° vs. 4.9° ($P = 0.02$)]. Coronal and sagittal correction did not differ significantly between the two groups.

Conclusions By utilizing a novel 3D reconstruction technology, we were able to demonstrate that braces differ in their immediate effects on the spine. Although clinical

relevance should be evaluated in a future trial we feel that the ability to measure treatment effects in 3D, and especially the transverse plane, is an important tool when evaluating different treatments.

Keywords Scoliosis · 3D · Apical vertebrae rotation (AVR)

Introduction

Brace treatment for adolescent idiopathic scoliosis (AIS) is indicated for a defined group of patients based on their age, sex, magnitude of curve and pubertal status [1]. Although different types of braces are commercially available, it is biomechanically difficult to justify the use of a particular brace.

Three-dimensional (3D) reconstruction technique (Biospace Med, Paris) is based on a novel technology in which orthogonal antero-posterior and lateral low dose X-rays are used for a 3D detailed semiautomatic reconstruction of the spine. This technique seems to be promising in testing key questions regarding different treatment modalities [2, 3].

The technique provides 3D reconstructions of the entire spine and pelvis while exposing the patient to a low dose radiation in a standing position [4–6].

Boston thoracic-lumbo-sacral-orthosis (TLSO) braces correct scoliosis in the coronal plane at the expense of a significant reduction of the thoracic kyphosis in the sagittal plane with no effect on the rotation of the apical thoracic vertebrae [7]. Chêneau braces are intended to derotate the apical segment of the curve and provide a 3D correction of the spinal deformity [8]. The proposed concept was never demonstrated in vivo.

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To study the effect of these braces, we conducted a retrospective comparative study analyzing 3D reconstructions of the spine. We evaluated the corrective effect comparing the custom made Boston type TLSO (B) braces to Chêneau type TLSO (C) braces.

Our primary research objective was to investigate the immediate effect of brace application on the spine and particularly, the apical vertebra rotation (AVR) profile utilizing 3D analysis.

Methods

Subjects

The study was conducted after obtaining institutional ethics committee approval.

Inclusion and exclusion criteria: Inclusion criteria were patients diagnosed with AIS [thoracic/thoraco-lumbar scoliosis (Lenke type 1)], who had standing orthogonal antero-posterior and lateral X-rays (Biospace Med, France) both with and without the brace. Patients were included if they had a new prescription for either a custom made Boston type TLSO (T), or a Chêneau type TLSO (C). Patients who were previously treated with a brace were excluded from the study.

Interventions: Patients were divided into two groups according to the brace that was prescribed by the treating surgeon. Eighteen patients were treated with the Chêneau (C) brace and ten patients were treated with the conventional TLSO brace.

Imaging: Our institution routinely utilizes the low dose biplanar X-rays for patients with spine deformity since 2008. Full length, orthogonal antero-posterior and lateral simultaneous X-rays were taken in a standardized standing position, with arms folded anteriorly in 45° to avoid overlap with spinal structures [4]. Radiographs were eligible for reconstruction when all vertebrae from C7 proximally to L5 distally were included and both hips appeared on the same radiograph.

3D reconstruction of the spine based on orthogonal radiographs was performed for pre- and first in-brace radiographs.

The preliminary step in reconstruction was digitalization of both acetabuli and the sacral endplate to create the “patient frame” which was used as a reference axis for further calculations.

Coronal (Cobb angle), sagittal (thoracic kyphosis T1–T12 and lumbar lordosis L1–L5) and axial spine parameters (vertebrae rotation) were automatically calculated referring to the “patient frame” that was reconstructed at the preliminary stage. Automatic correction of patients’ plane was performed based on the “patient frame”.

Therefore, standardization of X-rays was performed regardless of patient’s position. All the measurements were calculated accordingly.

Correction in coronal and sagittal planes was calculated in degrees and as a percentage by comparing in-brace measurements to those made before bracing. Rotations of the apical and end vertebrae were calculated as the total rotation regardless of the direction.

Statistical analysis

Two-tailed *t* test was used to compare pre- and post-brace measurements.

A *P* value of <0.05 was considered to be statistically significant.

Results

Out of 488 patients who were treated with a brace in our institution for scoliosis between 2001 and 2011, 28 patients met our inclusion criteria (other patients were either early onset patients, did not have antero-posterior and lateral X-rays, treated with a different brace or treated prior to first X-ray). Eighteen patients treated with the C brace and ten patients treated with the T brace were included in the study. No difference was found in patient’s age, gender, magnitude of Cobb angle, sagittal parameters or AVR at inclusion (Table 1). There was no difference between the two groups, concerning the apex of the deformity.

Following the brace treatment, AVR was significantly improved by the C brace compared to the T brace [average change of 8.2° vs. 4.9°, respectively (*P* = 0.02)]. Coronal and sagittal correction did not differ significantly between the two groups. Cobb angle correction showed a trend toward greater correction in the T group although this difference was not statistically significant (41 % vs. 32 % with the C braces, *P* = 0.1). Measurement of the superior and inferior end vertebrae rotation did not reveal any difference (Table 2).

Table 1 Demography and pre-brace analysis

	Custom Boston type TLSO (N = 10)	Chêneau TLSO (N = 18)	PV
Age (years)	12.75 ± 2.2	12.9 ± 1.9	0.42
Risser	1.25 ± 1.29	1.05 ± 1.1	0.33
Gender (F/Total)	10/10	18/18	
Cobb°	38.9 ± 9.7	40.3 ± 13.4	0.38
Kyphosis° (T1–T12)	23.4 ± 13.2	30.2 ± 13.3	0.1
Lordosis° (L1–L5)	45.8 ± 15.2	51.2 ± 8.3	0.14
AVR°	6.1 ± 4.2	7.7 ± 6	0.15

AVR apical vertebral rotation

Table 2 Brace correction

	Custom Boston type TLSO (<i>N</i> = 10)	Chêneau TLSO (<i>N</i> = 18)	PV
Cobb (% of correction)	16.2 ± 6 (41 %)	12 ± 8 (32 %)	0.1
Kyphosis (T1–T12)	−1 ± 7.6	−3.2 ± 9.3	0.25
Lordosis (L1–L5)	−13.3 ± 16.1	−6.6 ± 5	0.1
AVR	4.9 ± 2.7	8.2 ± 5.5	0.02
Superior end vertebra rotation	3.9 ± 3.2	5.7 ± 5	0.16
Inferior end vertebra rotation	6.6 ± 3.4	6.5 ± 5.8	0.48

Data represents change in degrees ± STD

AVR apical vertebral rotation

Discussion

We hypothesized that different braces would have distinct corrective effect on the spine. In this study, we utilized a novel imaging technique and a 3D reconstruction. We found that Chêneau type brace has significant effect on the AVR when compared to the conventional TLSO type brace.

Several studies have addressed brace biomechanics in scoliosis. Clin et al. [9] simulated different brace parameters on three patients with scoliosis by utilizing a finite element model (FEM). The authors showed that the position of the thoracic posterior pad improved the rib hump and the AVR at the expense of reducing the thoracic kyphosis and lumbar lordosis. Small differences in brace design could be evaluated on the same patients without the need for repeated X-rays with FEM. Nevertheless, FEM could not simulate the effect of muscle and ligamentous forces which are likely important in brace biomechanics in the clinical setting. In a different study by the same author [10], the immediate in-brace effect on the coronal deformity and correlation between coronal correction and the bending moments acting on the apical vertebrae were simulated. Three patients with scoliosis were simulated with a FEM. The author concluded that there is a direct correlation between the in-brace immediate correction magnitude and the bending moments acting on the apical vertebra. Immediate in-brace correction had minimal effect on the AVR and on the rib cage deformity correction (3 and 4 %, respectively). Furthermore, there was no correlation between the immediate in-brace correction obtained in the coronal plane and the immediate correction in the transverse plane. These findings are consistent with our data regarding the immediate coronal deformity correction

achieved by the T brace without any significant effect on the AVR.

Aubin et al. [11] studied the 3D effect of the Boston TLSO brace on the rib cage by utilizing a stereoradiographic technique on 36 patients with right thoracic scoliosis. Rib cage rotation was found to be affected by the Boston brace but this effect was not translated to the apical vertebra, which was found to stay the same in the transverse plane ($0.3^\circ \pm 7^\circ$). Similar results were published by Labelle et al. [7]. The Boston type TLSO brace was tested on 40 adolescents with AIS and authors performed 3D reconstruction of the spine and rib cage. Significant decrease in the coronal and sagittal parameters was reported (Cobb angle was decreased by an average of 27 %). However, neither apical vertebra de-rotation nor rib cage change was reported. Our findings are partially in concordance with their data. Coronal deformity was corrected by the conventional TLSO brace by 41 %. At the same time we found a modest de-rotation with a 4.9° change of the AVR.

The reproducibility of coronal plane and sagittal plane angular measurements made with the Biospace (Paris) system has been demonstrated in the past [2, 12]. Humbert et al. [2] found that among AIS patients with moderate deformity the precision of AVR measurement found to be 3.4° . Recently, the precision of the axial measurement was compared to CT scan axial measurements and found to be good [13].

Limitations of the present study include a small number of patients and the possibility of selection bias. Because the C and T braces were tested on different patients, it is possible that more flexible patients were selected for the C group. This is unlikely, however, given the slightly greater Cobb angle correction in the T group.

Our results demonstrate a significant de-rotation effect of the C brace. Nevertheless, careful interpretation is needed knowing the limitations of the Biospace (Paris) measurement error.

Finally, the differences in immediate correction may not translate into differences in brace effectiveness. Brace effectiveness is still being debated after large investments of time and effort into clinical trial design, and we are not in a position to contribute to those results with our data.

We have shown that different brace types have distinctly different effects on AVR. Recent imaging advances have allowed us to directly measure the effect of the brace on the three dimensional deformity in a very practical manner and with a low radiation dose. The long-term effect of this difference should be further tested in a prospective clinical study.

Conflict of interest None.

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