Anisotropic Textile Brace for Adolescent Idiopathic Scoliosis: Immediate in-brace effect and biomechanics

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Abstract

Background

Rigid bracing is a universal effective treatment for scoliosis. However, body movement restriction and discomfort usually are its shortcomings. The purpose of this case series study was to investigate the feasibility of novel anisotropic textile braces with an artificial hinge adopting the direct three-point pressure system for the initial spinal correction and its biomechanics.

Methods

Five scoliotic female patients who were on average 12.2 years old with a BMI of 18.7, Risser grade of 1.6 and Cobb's angle of 22.3° were recruited. The outcome measures are spinal correction, contour asymmetry, and interface pressure distribution of the brace. The correlation between the rate of in-brace correction and variables such as the Cobb's angle, posterior trunk asymmetry index and interface pressure were studied.

Results

The initial in-brace rate of spinal correction ranged between 9.7% and 87%. The rate of correction based on posterior trunk asymmetry index ranged between 14.1% and 43.2%. The interface pressure from the brace ranged from 4.1 kPa to 25.6 kPa, which is comparable to that exerted by rigid braces. Based on the data in this study, no correlation was found between the in-brace rate of correction and the Cobb's angle and the pressure exerted by the pads.

Conclusions

The main finding is that the anisotropic textile brace offers good initial in-brace correction through the application of the three-point pressure system with textile materials. Nevertheless, further follow-up work is recommended to investigate its long-term efficacy.

Trial registration:

This study was registered at ClinicalTrials.gov (NCT02271256 – Registration date 22nd October 2014).

Introduction

Adolescent idiopathic scoliosis (AIS) is a spinal deformity in which the spine has a lateral curvature $\geq 10^\circ$. The onset of AIS occurs between 10 and 16 years old. This condition is an unknown etiology with a prevalence of 0.47–5.2% in the adolescent population [1, 2]. Scoliosis not only leads to asymmetry of the body profile but also causes spinal pain, restricts body movement, affects cardiac and pulmonary functions or even leads to death [1, 3]. Thus, proper management of AIS is essential.

To manage AIS, rigid bracing is currently the most common conservative treatment that slows down the rate of progression of the spinal curvature until bone maturity or stops the progression entirely. Most rigid braces have a convex design or padding that pushes into the body against the curvature of the spine in the perpendicular direction based on a three-point pressure system that involves exerting an external lateral force on the apical vertebra and contralateral forces above and below the apical vertebra [4, 5]. However, the common shortcomings of rigid braces are restriction of body movement and discomfort [6, 7].

Apart from rigid braces, there are also flexible braces. The first flexible brace offered in the market is called SpineCor which corrects and stabilizes a curved spine by applying a corrective movement principle. This principle realigns the orientation of the thoracic, thoracolumbar, and lumbar segments of the spine through dynamic movement that involves clockwise and counter-clockwise rotations of the thorax and tilts of the shoulders and pelvis, lateral shifting of the trunk, and inclination and bending of the trunk, etc. [8–10]. Rożek and Jasiewicz [11] found that a history of preoperative treatment with the SpineCor brace restores normal coronal balance more quickly after scoliosis surgery.

Flexible braces therefore could very well be a major revolutionary scoliotic orthosis due to its breathability, comfort and flexibility. However, some researchers continue to debate on the corrective mechanism and effectiveness of existing flexible braces [6, 12, 13]. In contrast, the corrective mechanism of rigid braces has been well accepted even though they cause discomfort and limit movement. Therefore, to provide effective spinal control and maximize comfort and mobility, the idea of using textile materials to construct a flexible brace that directly applies three points of pressure onto the curvature of the spine will be discussed in this paper. The aim of this study is to investigate the efficacy and biomechanics of a novel anisotropic textile brace.

Materials And Methods

The subject selection criteria are as follows: females between 10 and 13 years old who are diagnosed with AIS, have a Cobb's angle between 20° and 30° , and a Risser grade ≤ 2 . Between March 2018 and January 2019, 5 females were recruited through a school screening programme conducted in local secondary schools in Hong Kong or at The Duchess of Kent Children's Hospital at Sandy Bay.

The proposed anisotropic textile brace (Fig. 1) in this study is a flexible yet tight-fitting pressure garment that incorporates a rigid artificial hinge. The rigid artificial hinge allows the wearer to bend forward, inhibits the rotation of the trunk and loss of suspension of the brace as well as stabilises the lateral corrective panels. The lateral corrective panel is constructed by the elastic woven strap in warp direction with the Young's modulus as 0.59 MPa. The corrective principle is based on the three points of pressure directly exerted by the high modulus elastic textile which pushes into the body perpendicularly against the curvature of the spine and an asymmetrical design that provides free space in the concavity of the body for expansion.

Anteroposterior radiographs were taken before intervention took place in which the brace was donned by the patient. In-brace radiographs were taken after the subject wore the brace for 2 hours. The Cobb's angle, and Risser grade were measured on the radiograph images. The rate of in-brace correction was then calculated.

Three-dimensional body scanning was also carried out before intervention took place and when the subject wore the brace by using a Vitus Smart XXL three-dimensional (3D) body scanner (Human Solutions GmbH, Kaiserslautern, Germany). The 3D scanned images of the body were used to construct the posterior trunk asymmetry index (POTSI) which is positively related to contour asymmetry.

The interface pressure from the new anisotropic textile brace was measured by using the Pliance®-xf-16 system (Novel, Munich, Germany) with 6 single sensors. Each sensor offers a sensing area of 78 mm^2 , and its pressure ranges from 0 to 200 Kilopascal (kPa). The sensors were placed onto the apex of the corrective pads and the middle of left and right pelvis belts. During the measurement, the participants were required to perform their habitual standing posture. The interface pressure was recorded for one minute and the mean pressure and standard deviation were reported for the result.

A nonparametric Kendall's Tau correlation test was carried out to investigate the correlation between the rate of correction of the spinal curvature when the brace is worn, and variables such as the Cobb's angle, POTSI and interface pressure. Nonparametric independent sample Mann-Whitney U tests were carried out to compare the interface pressure between the pads and thoracic region of the spine and that between the pads and lumbar region of the spine. The Statistical Package for Social Science Version 25 (IBM, New York, United States) was used, and the confidence interval was set at 95% ($p < 0.05$).

Results

The degree of in-brace correction of the subjects is shown in Table 1. Of the 5 subjects, 3 (Subjects 3, 4 and 5) show a reduction of their spinal curvature of more than 5° (Subject 2, see Fig. 2). Subject 1 has a reduction that is less than 5° while Subject 2 has an increase of 5° in the progression of her spinal curvature. Based on the results of the Kendall's Tau correlation test, there is no significant correlation between in-brace correction and the Cobb's angle ($p = 1$).

Table 1
Demographics, allocation of pads and in-brace correction of subjects

Subject code	Age	BMI	Curve type	Primary curve			Pad location			In-brace correction/deterioration (°)	In-brace correction/deterioration rate (%)
				Curve level	Apex	Cobb's angle (°)	1st pad	2nd pad	3rd pad		
1	12	20.8	Right thoracic Left lumbar	T4-T11	T8	21.6	Right of 10th rib	Left of 3rd to 4th lumbar	-	2.1	9.7
2	12	18.7	Right thoracic Left lumbar	T11-L4	L2	21.8	Right of 9th rib	Left of 2nd to 3rd lumbar	Right of pelvis	-4.9	-22.5
3	12	20.2	Right thoracic Left lumbar	T5-T11	T8-9	25.3	Right of 9th rib	Left of 3rd to 4th lumbar	-	6.6	26.1
4	12	16.8	Right thoracic Left lumbar	T12-L4	L2	20.0	Right of 10th rib	Left of 3rd lumbar	-	6.3	31.5
5	13	17.1	Left thoraco-lumbar	T8-L3	T12	23.0	Left of 10th rib	-	-	20.4	87.0

The POTSI parameters for when the brace is worn and not worn are shown in Fig. 3. Among the 5 subjects, 4 of them show an improvement in their posterior symmetry and the rate of correction ranges from 14.1% and 43.2%. According to the results of Kendall's Tau correlation test, no correlation was found between the rate of in-brace correction and changes in the POTSI ($p = 0.14$).

The interface pressure of all areas with padding ranges from 4.1 kPa to 25.6 kPa (see Fig. 4). The Mann-Whitney U test indicated that the interface pressure of the areas with padding against the thoracic region is higher than that of the areas with lumbar padding ($p = 0.02$). The Kendall rank correlation test indicated that there is no correlation between the interface pressure and rate of in-brace correction ($p = 1$).

Discussion

This preliminary study investigates the possibility of using a novel anisotropic brace to control spinal curvature. It has been already well established that in-brace correction is the initial factor that is used to evaluate the efficacy of new braces [13]. Studies about the reliability of Cobb's angle measurement suggested that 5° is the standard error of measurement [13, 14]. In the current study, more than half of subjects obtained a greater than 5° change of Cobb's angle, which is greater than the standard error of measurement. This result implicates that the intervention of propose brace had a positive effect on spinal curvature in certain cases.

Guo, et al. [15] conducted a randomized controlled study with scoliotic subjects who have a Cobb's angle between 20°-30° to determine the efficacy of rigid braces and the SpineCor brace, and reported that the initial rate of in-brace correction for the rigid braces and SpineCor is 15.9% and 21.3% respectively. Karol [16] examined the effectiveness of several different types of rigid braces in male subjects with scoliosis who have a Cobb's angle between 18°-45° and found that the initial rates of in-brace correction with the Milwaukee, Boston and Charleston braces are 17.4%, 35.6% and 62.2% respectively. The initial results of the anisotropic textile brace approximate those of some of the existing braces.

Lang, et al. [17] conducted a retrospective analysis with 112 AIS subjects who were undergoing rigid brace treatment and found that the Cobb's angle, sagittal and coronal balances and lumbar-pelvis relationship affect in-brace correction. Nevertheless, the data in this study show that there is no relationship between in-brace correction and the Cobb's angle.

Trunk asymmetry affects the self-confidence and feelings of sexual attractiveness of women with scoliosis. In addition to spinal correction, improving the brace aesthetics is also an important treatment outcome [18]. Kotwicki, et al. [19] investigated the external morphology of the trunk in a cross-sectional study of 24 girls who were wearing a brace versus 26 girls who were not undergoing bracing treatment and pointed out that there is no significant difference in the POTSI parameters between the two groups. This study further confirms the discrepancy between the Cobb's angle and POTSI. A possible explanation is that the Cobb's angle only attests to the tilt of the two end vertebrae of the curvature in the frontal plane [19].

The equilibrium of the artificial hinge bone is critical for the biomechanics of spinal correction as it is related to the pressure distribution of the brace. According to the equilibrium principle, the sum of the forces and the bending moments created must be zero to main stability. For Subject 2, pads were inserted at the right thoracic region, left lumbar region and right side of the pelvis. The intention was to apply the three-point pressure system in these three areas and correct the lumbar spinal curvature. However, as the pressure on the right side of the pelvis was increased due to the pad, the pressure from the corrective panel on the right side of the thoracic spine was reduced to maintain the balance of the artificial hinge bone. As a result, the forces exerted onto the right side of the thoracic spine were insufficient to counter the lumbar curve in the upper region, and thus an increase in the lumbar curve might be the result. To solve this issue, it is recommended that no pads are inserted at pelvis belt.

On the other hand, Subjects 1, 3, 4, and 5 show that the three-point pressure system can be effective with equilibrium of the artificial hinge bone. It was found that the location (left or right side) of the corrective panel that was placed against the lumbar/ thoracolumbar curve would influence the pressure distribution of the pelvis belt which holds the end point of the artificial hinge bone in place. After installing the corrective panel against the left lumbar/ thoracolumbar curve, the right of the pelvis belt was found to exert greater tension on the artificial hinge bone than the left side of the pelvis belt in order to maintain equilibrium of the hinge bone. In such cases, even if no pads were inserted at the right side of the pelvis belt, the right side of the pelvis belt also exerted a lower counter force against the lumbar curve when the corrective panel was placed against the left lumbar/ thoracolumbar curve.

Wong, et al. [20] investigated the biomechanics of rigid braces and reported that the pressure exerted by rigid braces ranges from 4.9 kPa to 9.34 kPa. Mac-Thiong, et al. [21] also conducted experimental measurements with rigid braces and found that the pressure induced by the Boston brace ranges between 10 kPa and 30 kPa. In this study, the interface pressure from the novel anisotropic textile brace ranges between 4.1 kPa and 25.6 kPa, which is very similar to the rigid braces. This shows that the textile brace also generates the same corrective forces as rigid braces against the torso. These results show the possibility of using elastic textile materials to provide adequate corrective pressure.

Another interesting finding in this study is that the pressure from the pad exerted onto the thoracic curve is significantly higher than that exerted onto the lumbar curve. This finding is consistent with those of a previous biomechanics study on rigid braces by Wong, et al. [20]. A possible explanation is that the ribcage directly absorbs the pressure from the pad exerted onto the thoracic curve, while the fat in the waist area might distribute the pressure exerted onto the lumbar curve.

Based on the law of mechanics, higher exerted forces would result in higher rates of in-brace correction. Adequate corrective forces are undoubtedly important to correct spinal curvature. However, our preliminary results agree with those [22] in that there is no significant correlation between interface pressure and in-brace correction, which might imply that after the corrective forces reach a certain level, any further increases in force will not increase spinal correction. However, further studies with a larger sample size are recommended to investigate the correlation between the interface pressure and in-brace correction.

Conclusions

The main finding is that the anisotropic textile brace provides good initial in-brace correction through the application of the three-point pressure system with textile materials. Nevertheless, further follow-up work is recommended to investigate its long-term efficacy.

List Of Abbreviations

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AIS	Adolescent Idiopathic Scoliosis
BMI	Body Mass Index
kPa	Kilopascal
POTSI	Posterior Trunk Asymmetry Index
3D	Three-dimensional

Declarations

Ethics approval:

This clinical study was approved by The Hong Kong Polytechnic University and the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (HKU/HA HKW IRB). This study was registered at ClinicalTrials.gov (NCT02271256 – Registration date 22nd October 2014).

Consents of participate

Informed consent was obtained from the volunteer subjects and their parents.

Availability of data and materials:

All data generated or analysed during this study are included in this published article

Conflict of interest:

The authors declare that they have no conflicts of interest.

Consent for publication:

All authors gave the consent for the publication in Journal of Orthopaedic Surgery and Research.

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Authors' contributions:

The novel functional intimate apparel was designed by Q.F. and J.Y. The experiments were designed by Q.F., J.Y., K.L.Y., and S.P.N. conducted by Q.F. Data analysis was performed by Q.F. The results of experiment were discussed among Q.F., J.Y., K.L.Y., S.P.N., X.L. and Z.L. The manuscript was written by Q.F. and J.Y. and was reviewed by all authors.

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Figures

Figure 1

Novel anisotropic textile brace

Figure 2

Standing radiographs of Subject 5: (a) Pre-intervention (b) In-brace

Figure 3

Posterior trunk asymmetry index: brace vs. no brace

Figure 4

Mean pressure: pad and thoracic region, pad and lumbar region and right and left sides of pelvis