RAE2020

Ergonomic Brace Wear for Adolescent Idiopathic Scoliosis (AIS)

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PolyU UoA 38
# Ergonomic Brace Wear for Adolescent Idiopathic Scoliosis (AIS)

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Title: Ergonomic Brace Wear for Adolescent Idiopathic Scoliosis (AIS)

Descriptor

In this study, ergonomic brace wear for AIS is designed and developed based on clinical applications, materials science, and garment technology, with the aim to control spinal deformity, reduce the possibility of spinal curve progression, and address the needs of patients as well as taking into consideration their psychological concerns. In order to prevent the progression of spinal deformity, a 3-point pressure system and traction force is applied through the ergonomic brace wear by strategically inserting rigid components, like pre-shaped SMAs and paddings. The straps can exert additional corrective and compression forces onto the torso and spine. Also, the seamless design allows the brace to be worn next to the skin, which also helps to reduce the brace weight, offer a softer touch, and prevent uncomfortable markings. Bonding and ultrasonic welding technologies are applied to eliminate the seams and stitches in the brace wear. Therefore, compared to conventional bracing treatment, the new ergonomic brace wear is more aesthetically pleasing and comfortable, so that the compliance with brace treatment can be improved. In total, 31 subjects were invited to participate, with 21 subjects completing the clinical study. 12 subjects tried first prototype of the Ergonomic brace. It has no significant improvement in Cobb angles when comparing with hard brace. Nine subjects tried the second prototype by adding curved SMA struts. Among these subjects, four of them have >5° improvement, and five of them have <5° improvement. Significant differences (P<0.05) were found between out-brace and in-brace Cobb’s angle in both non-parametric tests and paired T-tests. The design patent was filed in China, and the results have been communicated in the Annals of Biomedical Engineering journal, at three conferences, and at The Global Healthcare Innovation Academy (GHIA) exhibition.
Principal investigator - Dr. Joanne Yip

**Associate Professor, ITC,**
The Hong Kong Polytechnic University

Dr. Yip, Joanne graduated with a BSc (Hons) in Textile Technology (with first class Honors) in 1999 from the Hong Kong Polytechnic University and obtained her PhD at the same university in 2003. Dr. Yip research interests include new materials and technology, surface treatments on textiles, moulding or seamless techniques used in Intimate Apparel. Recently, her research focus is related to posture correction and control of spinal deformity using a newly developed functional garments. Dr. Yip has published more than 100 referee and conference papers in Textile and Material Science Journals.

Co-investigators
Prof. Kenneth Cheung, Dr. P.Y. Jason Cheung and Dr. Y.H. Kenny Kwan are the co-investigators from HKU who were responsible for providing clinical opinion and subject recruitment for this project. Prof. Kenneth Cheung is the Jessie Ho Professor in Spine Surgery and the Head of the Department of Orthopedics and Traumatology, The University of Hong Kong, the President of The Hong Kong College of Orthopaedic Surgeons and was the President of the (international) Scoliosis Research Society, widely recognised as one of the leading spine societies globally. Dr. Jason Cheung and Dr. Kenny Kwan are clinical assistant professors at the University of Hong Kong. Dr. Cheung research focuses on the degenerative spine, spine deformity and orthopaedic infection. Dr. Kwan research focuses on basic and clinical research into adult and pediatric spine deformity.

Mr. C. Y. Tse is a prosthetics and orthotics practitioner. He provides orthosis consultation and fitting services. The scope of his services include the lumbar sacral and the cervical and thoracic lumbar sacral orthoses.

Dr K.L. Yick and Dr. S.P. Ng are the co-investigators who have also been carrying out scientific studies in the areas of anthropometric measurements, advanced materials and 3D modeling. Dr. Yick has carried out a number of GRF projects in patient clothing, such as the development of a textile nest and a phototherapy eyepatch protector for neonates in hospitals, pressure therapy gloves for hypertrophic scar treatment, and a corset for children with scoliosis (in the capacity of PI). Dr. Ng focuses on 3D body scanning, body motion capturing and garment pressure modeling. He also specialises in 3D modeling technology and stress analysis of textile composites by using the finite element method. He has formulated biomechanical finite element models for the arm, lower torso and chest, and a girdle-skin pressure prediction model from fabric stress-strain properties, fabric tension and body curvature.

As shown above, the research team has extensive research experience on clinical experience with scoliosis patients, anthropometric measurements, evaluation of material properties, garment technology and 3D modeling. In response to the psychological aversion and poor compliance of scoliosis patients in current brace treatment, the team has consolidated some previous research work that is related to the proposed brace development.
Research Output – First published on 27-June 2017

- Ergonomic brace wear with 3-point pressure system and traction forces.
- Selected suitable materials for ergonomic brace wear.
- Applied seamless and bonding techniques for comfort and possibility of mass production.
- Strategically inserted the SMA into the ergonomic brace wear
- Performed wear trial

![Ergonomic Brace](image)

**Fig. 1** Different types of braces to treat adolescent idiopathic scoliosis
Research Questions

Background

Adolescent Idiopathic Scoliosis (AIS)

Adolescent idiopathic scoliosis (AIS) is the most prevalent 3-dimensional spinal deformity that primarily affects peripubertal females\(^1\) (Fig. 2). This condition involves a curvature of the thoracolumbar spine that is greater than 10° in the coronal plane. The development of scoliosis is attributed to abnormal skeletal growth and overgrowth of the anterior spinal column with uncoupled neurological growth\(^2\). Idiopathic scoliosis (IS) is the most common type of scoliosis and affects about 3% of children worldwide\(^3\).

The onset of IS typically coincides with the period of growth during adolescence and affected youths are at risk of increasing deformity until they stop growing\(^4\)-\(^5\). As well, the physiological health of patients may be affected, as IS negatively affects their cardiac and pulmonary systems if the spinal deformity is allowed to progress. Consequently, it is very important to monitor and control the spinal curvature once AIS has been diagnosed.

\(\text{Fig. 2 (a) Lateral radiograph image of prototypical right thoracic spinal curvature. Shoulder imbalance evident in clinical photograph. (b) Prominent rib hump evident with forward bending}^{6}\)
Research Questions
Background

Braces for AIS

The diagnosed treatment for AIS patients is based on the type of curve, age and severity of the spinal curvature (Fig. 3). Surgery is recommended for severe deformity in which the spinal curvature is greater than 45 degrees while observation is recommended for more mild cases in which the spinal curvature is less than 20 degrees. The most common non-invasive type of treatment for patients with a smaller spinal curvature is bracing, usually for those with a curve greater than 20 degrees but less than 45 degrees at Risser stages 0, 1 or 27-10.

Fig. 3 Scoliosis Research Society Guidelines for Treatment of Scoliosis
Research Questions

Background

Bracing applies external corrective forces onto the spine and trunk by mainly using rigid and flexible braces. These two types of braces have the same objectives to correct scoliosis in the three main planes and reduce its progression which may reduce or avoid the need for spinal fusion surgery. Mechanical forces are applied onto the spine and trunk, such as 3-point pressure or dynamic forces, with the aim to restore the normal contours and alignment of the spine.\(^{11-12}\)

The Boston brace and Progressive Action Short Brace (PASB) (Fig 4a) are two examples of rigid braces. Their biomechanical principle is to control the spine dynamics with a special geometric design that would apply external forces and thus reduce spinal deformity with the generation of internal corrective forces during natural movement.\(^{13-14}\) Then there are semi-rigid braces, in which the TriaC brace is a popular example (Fig 4b), because the brace can be used for the treatment of all types of curves except those with an apex at the 12th thoracic and the 1st lumbar vertebra. This brace has three different functional elements: a frame, elastic elements, and pelottes. Corrective forces are produced through a 3-point pressure system. The force system used in the frontal plane of the TriaC brace is similar to that of conventional braces but can only act on the thoracic region in the sagittal plane.\(^{15-17}\) Finally, there are flexible braces, and SpineCor is a good example (Fig 4c). The correction principle of SpineCor is based on spinal coupling mechanics. SpineCor has a pelvic base, crotch bands and thigh bands that act as a fastening point. The bolero and corrective bands correct the scoliosis curve. The placement and tension of the brace can be adjusted before treatment is started\(^{18-19}\) which allows accommodation of different spinal curvatures.

\(\text{Fig. 4 Different types of braces to treat adolescent idiopathic scoliosis}\)
Research Questions

Background

In general, rigid braces provide stronger corrective forces. Rigid brace wear is recommended for up to 23 hours each day until growth is completed (approximately 4-6 years) for its effectiveness. Recently in 2013, Dr. Stuart Weinstein reported the results of an NIH-funded project, Bracing in Adolescent Idiopathic Scoliosis Trial (BrAIST), at the 48th Annual Meeting of the Scoliosis Research Society in Lyon, France. His results showed that bracing significantly reduces the progression of high-risk curves to the threshold for surgery in patients with AIS. The benefit increased with longer hours of brace wear\(^2\). Fig. 5 shows the rate of treatment success according to average hours of daily brace wear. On average, the subjects would wear the brace 12.1 ± 6.6 hours per day. The lowest quartile of wear (mean hours per day, 0 to 6.0) is associated with a success rate of 42%.

The low compliance rate is due to discomfort, activity limitations and unacceptable appearance of the brace.

\[\text{Fig. 5 Rate of treatment success vs. average hours of daily brace wear}\]
Research Questions

AIS is a multi-factorial, three-dimensional deformity of the spine and trunk which is prevalent and sometimes progressive during rapid periods of growth in apparently healthy children. Generally, bracing is suggested for those with AIS and a spinal curve between 20-45 degrees. Longitudinal statistical studies show that most of these patients are prone to depression\(^\text{23}\). There is also low compliance to treatment with a rigid brace because these braces are uncomfortable and have negative psychological effects on wearers due to the awkward and bulky appearance\(^\text{24}\). Most parents and adolescents also find it difficult to accept that an orthosis (regardless whether the brace is rigid, semi-rigid or flexible) is required at such a young age.

Therefore, in response to the low compliance and aversion towards braces, a garment type of brace wear that is aesthetically pleasing is proposed, which could be more readily accepted by patients and consequently increase user compliance while also addressing psychological barriers to brace use during treatment.

In order to prevent the progression of spinal deformity, a 3-point pressure system and traction forces will be applied through the ergonomic brace wear by strategically inserting rigid components, like pre-shaped SMAs and paddings. The supportive shoulder straps and waist band can exert additional corrective and compression forces onto the torso and spine. Also, the seamless design allows the brace to be worn next to the skin, which also helps to reduce the brace weight, offer a soft touch, and prevent uncomfortable markings. Bonding and ultrasonic welding technologies will be applied to eliminate the seams and stitches in the brace wear.

Therefore, compared to conventional bracing treatment, the new ergonomic brace wear is more aesthetically pleasing and comfortable to wear so that the compliance with brace treatment can be improved.
Biomechanical principles for spinal correction based on:

**Rigo Classification** – to classify type of scoliosis patients

<table>
<thead>
<tr>
<th>3-curves</th>
<th>4-curves</th>
<th>Non-three-non-four</th>
<th>Single lumbar/thoracolumbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td></td>
</tr>
<tr>
<td>Clinical Criteria</td>
<td>Clinical Criteria</td>
<td>Clinical Criteria</td>
<td></td>
</tr>
<tr>
<td>• Pelvis translocated to the concave thoracic side</td>
<td>• Pelvis translocated to the concave thoracic side</td>
<td>• Trunk imbalance to the convex thoracic side</td>
<td>• Single Major Thoracic/Lumbar Minor</td>
</tr>
<tr>
<td>• Single Thoracic/No Minima Scoliosis Lateral</td>
<td>• Single Thoracic/No Minima Scoliosis Lateral</td>
<td>• T1 imbalance to the convex thoracic side</td>
<td>•</td>
</tr>
<tr>
<td>• L1 imbalance to the convex thoracic side</td>
<td>• L1 imbalance to the convex thoracic side</td>
<td>• L4 shifted to the concave thoracic side - Negative L4 Counter-Tilting</td>
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</tr>
<tr>
<td>• Horizontal or tilted to the convex thoracic side</td>
<td>• Horizontal or tilted to the convex thoracic side</td>
<td>•</td>
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</tbody>
</table>

**Radiological Criteria**

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<th>Non-three-non-four</th>
<th>Single lumbar/thoracolumbar</th>
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<tbody>
<tr>
<td>A1</td>
<td>A2</td>
<td>A3</td>
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</tr>
<tr>
<td>Clinical Criteria</td>
<td>Clinical Criteria</td>
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</table>

**Fig. 6 Rigo classification**
Research Field & Key Works Referenced

**Biomechanical principles for spinal correction based on:**

Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) consensus paper on brace action: TLSO biomechanics of correction

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**Position of T1 and transitional point (TP) on central sacral line (CSL):**

- Balanced
- Imbalanced (T1/TP-offset) to the convex/concave thoracic side

**Orientation of L4 in frontal plane and its relationship with L5**

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**Fig. 7 TLSO biomechanics of correction**

**Thoracic Pad(s)**
- Level of the pad: apical vertebra
- Force vector: oblique (dorso-lateral to ventro-medial direction)
- Derotation: 'pair of forces' (ventral + dorsal pad)

**Lumbar Pad**
- Level of the pad: apical vertebra
- Force vector: oblique (dorso-lateral to ventro-medial direction)

**Pelvic Section**
- Follow the Rigo Classification
  - Positive L5-4 counter-tilting: open pelvis (except B2)
  - Negative L5-4 counter-tilting: A2, A3 -> asymmetric pelvic design, C1, C2 -> neutral pelvic design
Research Methods & Materials

Milestone 1: Design and develop ergonomic brace wear for youths with adolescent idiopathic scoliosis.
  • Task 1: Design and development of ergonomic brace wear with 3-point pressure system and traction forces.
  • Task 2: Material selection for ergonomic brace wear.
  • Task 3: Seamless and bonding techniques for comfort and possibility of mass production.

Milestone 2: Manufacturing and optimise the pressure and corrective forces applied through the ergonomic brace wear by conducting material testing.
  • Task 1: Material testing for choosing the most suitable parameter of materials.
  • Task 2: Manufacturing processes for producing the ergonomic brace wear.
  • Task 3: Strategically insert the SMA into the ergonomic brace.

Milestone 3: Overall evaluation of the effectiveness of ergonomic brace wear for adolescents with scoliosis.
  • Task 1: Subject recruitment.
  • Task 2: Preliminary tests.
  • Task 3: Clinical trial
Milestone 1: Design and develop ergonomic brace wear for youths with adolescent idiopathic scoliosis.

Task 1: Design and development of ergonomic brace wear with 3-point pressure system and traction forces.
Task 1: Design and development of ergonomic brace wear with 3-point pressure system and traction forces.

ceptive brace wear with 3-point pressure system and traction forces.

- **Single-layer Pad**
  - Used as a counter-force to correct minor curve of the scoliotic spine

- **Layered Pad**
  - Provide a main corrective force to correct major curve of the scoliotic spine
Research Methods & Materials

Task 2: Material selection for ergonomic brace wear.

Features:

1. Net structure: 
   - Breathability
2. Use of the cool-to-touch and deodorant yarn: 
   - Dry and refresh
3. Bone casing: 
   - To keep the posture of the patient upright and to prevent the bodice from puckering

Prototype

Tight-fitting Bodice
Research Methods & Materials

Task 3: Seamless and bonding techniques for comfort and possibility of mass production.

Knitted Prototypes

**Model:**
STOLL CMS ADF 32 BW

**Features:**
1. E7.2 fabric gauge
2. 50” (127cm) working width
3. Equipped with weave-in device
Research Methods & Materials

Task 3: Seamless and bonding techniques for comfort and possibility of mass production.

3D printing + Heat welding film

Steps of making the strap adjuster:

1. Make a 3D drawing with SolidWorks
2. 3D print on the heat welding film
3. Fix onto the bodice by using the heat-press machine
Research Methods & Materials

Milestone 2: Manufacturing and optimise the pressure and corrective forces applied through the ergonomic brace wear by conducting material testing.

Task 1: Material testing for choosing the most suitable parameter of materials.

Tensile Strain and Recovery

**Swatches**

**Knit Structure**
Double jersey with inlay

**Combination of Yarn**
1. 70D/48F Aqua-x
2. 75D/36F Freshgear
3. Inlay: Double covered yarn (DCY)

**Tensile Test**

**Equipment:** Instron 4411
**Standard:** ASTM D6614
**Setting:**
- 200mm gauge length
- 4lb (17.8N) maximum load
- 300mm/min speed

**Steps:**
1. **Extend** until reaches the maximum load (4lb)
2. **Hold** at the maximum load for 5 minutes
3. **Return** to the original gauge
4. **Hold** at the original gauge for 5 minutes
### Research Methods & Materials

**Task 1**: Material testing for choosing the most suitable parameter of materials.

<table>
<thead>
<tr>
<th>Target swatch</th>
<th>Yarn</th>
<th>Stretch (%)</th>
<th>Growth (%)</th>
<th>Recovery (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>45.21</td>
<td>2.18</td>
<td>95.18</td>
</tr>
</tbody>
</table>
| Swatch A1     | Front: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Back: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Inlay: [280D (spandex) + 150D + 150D] 580D DCY x 1 end | 81.57 | 3.75 | 95.4 |
| Swatch B1     | Front: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Back: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Inlay: [350D (spandex) + 140D + 140D] 630D DCY x 1 end | 47.95 | 5.52 | 88.5 |
| Swatch C1     | Front: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Back: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Inlay: [280D (spandex) + 150D + 150D] 580D DCY x 1 end | 70.71 | 3.91 | 94.47 |
| Swatch D1     | Front: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Back: 70D/48F Aqua-x x 4 ends + 75D/36F Freshgear x 4 ends  
Inlay: Zimmermann Ultraelastic x 1 end | 104.29 | 4.99 | 95.22 |
| Swatch A2     | Front: 70D/48F Aqua-x x 8 ends  
Back: 75D/36F Freshgear x 8 ends  
Inlay: [PE 150D (spandex) + 135D + 135D] 420D DCY x 1 end | 87.7 | 3.74 | 95.73 |
| Swatch B2     | Front: 75D/36F Freshgear x 8 ends  
Back: 70D/48F Aqua-x x 8 ends  
Inlay: [PE 150D (spandex) + 135D + 135D] 420D DCY x 1 end | 68.34 | 2.36 | 96.55 |
| Swatch C2     | Front: 70D/48F Aqua-x x 6 ends  
Back: 75D/36F Freshgear x 6 ends  
Inlay: [PE 150D (spandex) + 135D + 135D] 420D DCY x 1 end | 109.57 | 4.83 | 95.6 |
| Swatch D2     | Front: 70D/48F Freshgear x 6 ends  
Back: 75D/36F Aqua-x x 6 ends  
Inlay: [PE 150D (spandex) + 135D + 135D] 420D DCY x 1 end | 83.83 | 3.78 | 95.49 |
Research Methods & Materials

Task 2: Manufacturing processes for producing the ergonomic brace wear.

Ergonomic Brace

- Bodice with Bones
- Padding
- Strap adjuster with Boa
- Pelvic Belt

- Seamless Knitting
- Moulding
- 3D Printing & Lamination
- Moulding

Keep the posture of the patients upright
Locate at the convex points of the spine
Input directional force to the padding
Stabilize the pelvis for effective spinal correction
Research Methods & Materials

Task 2: Manufacturing processes for producing the ergonomic brace wear.

(Tight-fitting Bodice with Bones)

Features:

1. Net structure: **breathability**
2. Use of the cool-to-touch and deodorant yarn: **dry and refresh**
3. Bone casing: to keep the posture of the patient **upright** and to **prevent** the bodice from **puckering**

Prototype

Seamless Knitting
Task 2: Manufacturing processes for producing the ergonomic brace wear.

(Auxiliary: Padding)

1. **Thin edge**: to prevent bulging that shown through the brace if padding with thick edge is used.
2. **Peak height area**: to give concentrated corrective force to the spine.
3. **Adjustable position of peak height**: to allow customization according to the spinal situation of each patient.

**Padding Layering Idea**

1. **Moulding with vacuum forming machine**
Research Methods & Materials

Task 2: Manufacturing processes for producing the ergonomic brace wear.

(Auxiliary: Strap adjustor)

**Steps of making the strap adjuster:**

1. Make a 3D drawing with SolidWorks
2. 3D print on the heat welding film
3. Fix onto the bodice by using the heat-press machine

Deformation problem of the strap adjuster:
Resolved by fixing it onto the bodice with heat welding film
Research Methods & Materials

Task 2: Manufacturing processes for producing the ergonomic brace wear.

(Auxiliary: Strap adjustor)

**Pros**

1. **Rigid strap:** more stable force (versus elastic strap)

2. **Boa technology:** force increment can be easily made with **one hand**
Research Methods & Materials

Task 2: Manufacturing processes for producing the ergonomic brace wear.

- **Design 1**
  - Problem: Sliding up with body movements

- **Design 2**
  - Sliding up problem is **resolved**
  - Problem: Bulging, esp. during sitting

- **Design 3**
  - Sliding up problem is **resolved**
  - Bulging problem is much **improved**

*(Auxiliary: Pelvic Belt)*
Research Methods & Materials

Task 2: Manufacturing processes for producing the ergonomic brace wear.

The materials and accessories mentioned before for making forty ergonomic brace wears were purchased and prepared. The brace wears were assembled according to size of recruited subjects.
Research Methods & Materials

Task 3: Strategically insert the SMA into the ergonomic brace.

- The resin bones (RBs) were used as the supportive struts for the Ergonomic brace and inserted into the channels.
- All of these RBs have the same width (5 mm) but with 3 different thicknesses of 1.3, 1.5 and 1.8 mm.
- In this study, four other types of materials are used as the struts for comparison purposes: acrylic (ACR), aluminum (AL), titanium (TI) and shape memory alloy (NiTi) (Ti–55 wt.% Ni).
- The size of these struts was determined in accordance with the original RBs used in the girdle.
- All of the samples were placed in a conditioned room (23°C ± 2°C, 50% ± 10% relative humidity) for 40 hours prior to the commencement of testing.

Load-deflection curves of different supportive struts at bending depth of 15 mm (keys: ACR = Acrylic; SMA = Shape memory alloy; AL = Aluminum; TI = Titanium; RB = Resin bone)
Task 3: Strategically insert the SMA into the ergonomic brace.

Pressure distribution (kPa)

Pressure distribution (kPa) of Ergonomic brace with different supportive materials on soft mannequin
Task 3: Strategically insert the SMA into the ergonomic brace.

Subject 1:
Without brace

Brace with SMA Struts

Subject 2:
Without brace

Brace with Resin Bones

SMA: 33% in the Cobb’s angle in thoracic region, nearly no improvement in lumbar region

Resin: 26% in the Cobb’s angle in thoracolumbar region
Research Methods & Materials
How do different struts affect the pressure and spinal correction?

Task 3: Strategically insert the SMA into the ergonomic brace.

Rigid materials:
- Hard to be deformed → Cannot fit to body
  - Induced higher pressure on convex part (underbust and pelvis)
  - Better correction on thoracic curve

Flexible materials:
- Easy to be deformed → Fit to the body contour
  - Induce higher pressure on concave part (waist)
  - Better correction on thoracolumbar or lumbar curve

Good recovery materials:
- Can keep the original shape → maintain the pressure after repeated use
Research Methods & Materials

How do different struts affect the pressure and spinal correction?

Task 3: Strategically insert the SMA into the ergonomic brace.

**Improve fitting by molding SMA**

Mold for SMA bones (Curve shape from standard dummy)

- Before heat treatment
- Heat treatment in straight form
- After molding

At 800°C for 1 hour -> water quenching (Annealing)

At 550°C for 1/2 hour -> water quenching (Tempering)
Research Methods & Materials

Milestone 3: Overall evaluation of the effectiveness of ergonomic brace wear for adolescents with scoliosis

Task 1: Subject recruitment.

Subject Recruitment Progress

Location: The Duchess of Kent Children's Hospital (DKCH)

Target no. of subject recruit: 30-40

Inclusion criteria (SRS criteria):

- Age $10 \geq$ older when brace is prescribed
- Risser 0-2
- Primary curve angles 25°-40°
- Female (either pre-menarche or <1 year post-menarche)
- Undergoing hard brace treatment

Exclusion criteria (SRS criteria):

- Low risk of curve progression
- Non-idiopathic scoliosis (e.g. congenital, neuromuscular deformities)

Recruitment progress (Total: 31)

Excluded: 1
Withdrawal: 9

Completed (Total: 21):
2 (pilot study)
10 (original design)
9 (modified design)
Research Methods & Materials

Task 2: Preliminary tests

Subject EB001 (fitting of pads; locations of pressure measurement)

<table>
<thead>
<tr>
<th>Subjec t code</th>
<th>Curve type</th>
<th>Rigo</th>
<th>Major(+)/Minor(−) curve</th>
<th>Curve level</th>
<th>Apex</th>
<th>Curve region</th>
<th>Cobb angle (°)</th>
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<tbody>
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<td>Double Curve</td>
<td>C2</td>
<td>+</td>
<td>T7-T12</td>
<td>T9-T10</td>
<td>T</td>
<td>34.2 23.5 30.9</td>
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<tr>
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<td>+</td>
<td>T12-L5</td>
<td>L3</td>
<td>L</td>
<td>27 17.3 23.6 9.7 3.4</td>
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<td>EB004</td>
<td>Main Thoracic</td>
<td>A3</td>
<td></td>
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<td>L3-L4</td>
<td>L</td>
<td>21.9 17.6 25.1 4.3 3.2</td>
</tr>
</tbody>
</table>

Impossible to place pad higher than the level of underarm
## Research Methods & Materials

### Task 2: Preliminary tests

<table>
<thead>
<tr>
<th>Subject code</th>
<th>Curve type</th>
<th>Rigo</th>
<th>Major(+) / Minor(-) curve</th>
<th>Curve level</th>
<th>Apex</th>
<th>Curve region</th>
<th>Cobb angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OB</td>
<td>HB</td>
</tr>
<tr>
<td>EB005</td>
<td>Double Curve</td>
<td>B1</td>
<td>+</td>
<td>T5-T10</td>
<td>T8</td>
<td>T</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>T10-L4</td>
<td>L2-L3</td>
<td>L</td>
<td>27.9</td>
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<tr>
<td>EB006</td>
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<td>B1</td>
<td>+</td>
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<td>T9</td>
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<td>31.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>T12-L4</td>
<td>L2-L3</td>
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<tr>
<td>EB008</td>
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<td>+</td>
<td>T4-L1</td>
<td>T11</td>
<td>T</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>L1-L5</td>
<td>L3</td>
<td>L</td>
<td>29.4</td>
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<tr>
<td>EB009</td>
<td>Main Lumbar</td>
<td>E1</td>
<td>-</td>
<td>T9-L1</td>
<td>T10-T11</td>
<td>T</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>L1-L4</td>
<td>L3</td>
<td>L</td>
<td>35.2</td>
</tr>
<tr>
<td>EB010</td>
<td>Main Lumbar</td>
<td>E1</td>
<td>-</td>
<td>T6-T12</td>
<td>T8-T9</td>
<td>T</td>
<td>20.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>T12-L4</td>
<td>L2</td>
<td>L</td>
<td>32</td>
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<tr>
<td>EB011</td>
<td>Double Curve</td>
<td>B1</td>
<td>+</td>
<td>T6-T11</td>
<td>T9</td>
<td>T</td>
<td>28.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>T11-L4</td>
<td>L2</td>
<td>L</td>
<td>29.7</td>
</tr>
<tr>
<td>EB013</td>
<td>Main Thoracolumbar</td>
<td>E2</td>
<td>-</td>
<td>T5-T11</td>
<td>T8</td>
<td>T</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>+</td>
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<td>L1</td>
<td>TL</td>
<td>28.8</td>
</tr>
<tr>
<td>EB014</td>
<td>Double Curve</td>
<td>B1</td>
<td>+</td>
<td>T6-T11</td>
<td>T8-T9</td>
<td>T</td>
<td>31.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>T11-L4</td>
<td>L1</td>
<td>TL</td>
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<tr>
<td>EB015</td>
<td>Main Thoracic</td>
<td>A3</td>
<td>+</td>
<td>T5-T10</td>
<td>T8</td>
<td>T</td>
<td>27.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>T11-L3</td>
<td>L2</td>
<td>L</td>
<td>20.6</td>
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<tr>
<td>EB016</td>
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<td>B1</td>
<td>+</td>
<td>T6-L1</td>
<td>T10</td>
<td>T</td>
<td>19.9</td>
</tr>
</tbody>
</table>
Research Methods & Materials

Task 2: Preliminary tests

**Within Samples T-test**

*(All the major curves of each subject are included)*

- **HB vs OB**
  
  \[ t(15) = 6.545; \ p = 0.000 \]

  HB has **significant improvement in Cobb angles** when comparing with OB.

- **EB vs OB**
  
  \[ t(15) = 0.601; \ p = 0.557 \]

  EB has **no significant improvement in Cobb angles** when comparing with OB.

- **OB-HB vs OB-EB**
  
  \[ t(15) = 7.219; \ p = 0.000 \]

  HB is **significantly better** than EB.
Research Methods & Materials

Task 2: Preliminary tests

**Brace Efficacy: Correction of Cobb Angles**

*(All the major curves of each subject are included)*

\[
\frac{(OB-HB)}{OB} \times 100
\]

Mean = **35.13%**
Range = 7.81% to 74.20%

\[
\frac{(OB-EB)}{OB} \times 100
\]

Mean = **3.81%**
Range = -23.58% to 43.18%

\[
\frac{3.81}{35.13} \times 100
\]

= **10.86%**
Task 2: Preliminary tests

Brace Efficacy: Correction of Cobb Angles

*(Curve Regions)*

**Better efficacy:** thoracic curve region (OB-EB : OB-HB -> 1.26°: 8.81°)

<table>
<thead>
<tr>
<th>Curve region</th>
<th>OB-HB (Major curves)</th>
<th>OB-EB (Major curves)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thoracic</strong></td>
<td>Mean: 8.81°</td>
<td>Mean: 1.26°</td>
</tr>
<tr>
<td></td>
<td>(Range: 2.10° to 23.30°)</td>
<td>(Range: -7.50° to 4.90°)</td>
</tr>
<tr>
<td><strong>Thoracolumbar</strong></td>
<td>Mean: 7.00°</td>
<td>Mean: -3.00°</td>
</tr>
<tr>
<td></td>
<td>(Range: 4.70° to 9.30°)</td>
<td>(Range: -0.10° to -5.90°)</td>
</tr>
<tr>
<td><strong>Lumbar</strong></td>
<td>Mean: 11.69°</td>
<td>Mean: 1.14°</td>
</tr>
<tr>
<td></td>
<td>(Range: 4.10° to 19.10°)</td>
<td>(Range: -5.90° to 7.60°)</td>
</tr>
</tbody>
</table>
Task 3: Clinical Trial

Design modifications with Curved SMA Struts

Summary of X-ray results of wearing curved SMA Brace

<table>
<thead>
<tr>
<th>Brace Size</th>
<th>1st curve position</th>
<th>1st Cobb’s angle (°)</th>
<th>2nd curve position</th>
<th>2nd Cobb’s angle (°)</th>
<th>3rd curve position</th>
<th>3rd Cobb’s angle (°)</th>
<th>1st Cobb’s angle (°)</th>
<th>2nd Cobb’s angle (°)</th>
<th>3rd Cobb’s angle (°)</th>
<th>Improvement &gt;5°</th>
<th>Improvement &lt;5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>SZ001 S</td>
<td>T11-L4</td>
<td>18</td>
<td>T5-T10</td>
<td>8</td>
<td>/</td>
<td>/</td>
<td>12</td>
<td>0</td>
<td>/</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>SZ003 S</td>
<td>T11-L4</td>
<td>25</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>18</td>
<td>/</td>
<td>/</td>
<td>7</td>
<td>/</td>
</tr>
<tr>
<td>HK012 S</td>
<td>T9-L1</td>
<td>19</td>
<td>T6-T9</td>
<td>18</td>
<td>L1-L4</td>
<td>16</td>
<td>4.5</td>
<td>10.6</td>
<td>9.2</td>
<td>14.5</td>
<td>7.4</td>
</tr>
<tr>
<td>HK014 M</td>
<td>T5-T11</td>
<td>26.2</td>
<td>T11-L4</td>
<td>25.7</td>
<td>/</td>
<td>/</td>
<td>20.7</td>
<td>25.1</td>
<td>/</td>
<td>5.5</td>
<td>0.6</td>
</tr>
<tr>
<td>SZ002 M</td>
<td>T12-L4</td>
<td>28</td>
<td>T5-T11</td>
<td>23</td>
<td>/</td>
<td>/</td>
<td>25</td>
<td>20</td>
<td>/</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>SZ004 M</td>
<td>T4-T11</td>
<td>28</td>
<td>T11-L5</td>
<td>20</td>
<td>/</td>
<td>/</td>
<td>26</td>
<td>18</td>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>HK013 M</td>
<td>T11-L3</td>
<td>20.4</td>
<td>T5-T10</td>
<td>15.2</td>
<td>/</td>
<td>/</td>
<td>21.2</td>
<td>17.6</td>
<td>/</td>
<td>-0.8</td>
<td>-2.4</td>
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<tr>
<td>HK015 S</td>
<td>T12-L3</td>
<td>21.4</td>
<td>T6-T12</td>
<td>10.9</td>
<td>/</td>
<td>/</td>
<td>17.2</td>
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<td>/</td>
<td>4.2</td>
<td>0.2</td>
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<tr>
<td>HK016 M</td>
<td>T5-T11</td>
<td>22.4</td>
<td>T12-L3</td>
<td>17.1</td>
<td>/</td>
<td>/</td>
<td>20.4</td>
<td>14.9</td>
<td>/</td>
<td>2</td>
<td>2.2</td>
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</tbody>
</table>

Improvement >5°

Improvement <5°
Research Methods & Materials

Task 3: Clinical Trial

Design modifications with Curved SMA Struts

Results – Success Cases (Improvement > 5°)

<table>
<thead>
<tr>
<th></th>
<th>Out-brace X-ray</th>
<th>In-brace X-ray</th>
<th>Differences (Out-brace – In-brace)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st curve position</td>
<td>1st Cobb’s angle (°)</td>
<td>2nd curve position</td>
</tr>
<tr>
<td>SZ001</td>
<td>T11-L4</td>
<td>18</td>
<td>T5-T10</td>
</tr>
<tr>
<td>SZ003</td>
<td>T11-L4</td>
<td>25</td>
<td>/</td>
</tr>
</tbody>
</table>
Research Methods & Materials

Task 3: Clinical Trial

Design modifications with Curved SMA Struts

Results – Unsuccess Cases (Improvement < 5°)

<table>
<thead>
<tr>
<th></th>
<th>Out-brace X-ray</th>
<th>In-girdle X-ray</th>
<th>Differences (Out-brace – In-girdle)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st curve position</td>
<td>1st Cobb's angle (°)</td>
<td>2nd curve position</td>
</tr>
<tr>
<td>SZ002</td>
<td>T12-L4</td>
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<td>T5-T11</td>
</tr>
<tr>
<td>SZ004</td>
<td>T4-T11</td>
<td>28</td>
<td>T11-L5</td>
</tr>
</tbody>
</table>
Research Methods & Materials

Summary of X-ray results of wearing curved SMA Brace

Task 3: Clinical Trial

Design modifications with Curved SMA Struts

Summary of All-curved SMA Brace Results

<table>
<thead>
<tr>
<th>Summary of All-curved SMA Brace Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
</tr>
<tr>
<td>Pre-intervention (°)</td>
</tr>
<tr>
<td>Post-intervention (°)</td>
</tr>
<tr>
<td>Average in-girdle correction (°)</td>
</tr>
<tr>
<td>In-girdle correction (%)</td>
</tr>
</tbody>
</table>

Non-parametric Test

Hypothesis Test Summary

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test</th>
<th>Sig.</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The median of differences between OB_greatest and Girdle_greatest equals 0.</td>
<td>Related-Samples Sign Test</td>
<td>.039 ¹</td>
<td>Reject the null hypothesis.</td>
</tr>
<tr>
<td>The median of differences between OB_greatest and Girdle_greatest equals 0.</td>
<td>Related-Samples Wilcoxon Signed Rank Test</td>
<td>.011 ¹</td>
<td>Reject the null hypothesis.</td>
</tr>
</tbody>
</table>

Asymptotic significances are displayed. The significance level is .05.

¹Exact significance is displayed for this test.

Summary of Statistical Analysis Results

Significant differences (P<0.05) are found between out-brace and in-brace Cobb’s angle in both non-parametric test and paired T-test

Paired T-test

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>OB_greatest - Girdle_greatest</td>
<td>4.82222</td>
<td>4.35166</td>
<td>1.45055</td>
<td>1.47724 - 8.16720</td>
<td>3.324</td>
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</tbody>
</table>
Research Conclusions

In total, 31 subjects were recruited and 21 subjects were completed in the clinical study.

12 subjects have tried 1\textsuperscript{st} prototype of Ergonomic brace.
   • It has no significant improvement in Cobb angles when comparing with hard brace.

9 subjects have tried 2\textsuperscript{nd} prototype (adding curved SMA struts)
   • Among 9 subjects, 4 of them have >5° improvement, 5 of them have <5° improvement
   • Average 4.82° (20.85\%) in-brace correction could be found
   • Significant differences (P<0.05) are found between out-brace and in-girdle Cobb’s angle in both non-parametric test and paired T-test
Dissemination and distribution of outcomes

<table>
<thead>
<tr>
<th>Deliverables</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>01</td>
<td>Demonstration Video</td>
</tr>
<tr>
<td>02</td>
<td>One China Patent</td>
</tr>
<tr>
<td>03</td>
<td>One US Patent</td>
</tr>
<tr>
<td>04</td>
<td>One Journal Paper</td>
</tr>
<tr>
<td>05</td>
<td>Three Conference Papers</td>
</tr>
<tr>
<td>06</td>
<td>Intervention Exhibition</td>
</tr>
<tr>
<td>07</td>
<td>One Award</td>
</tr>
</tbody>
</table>
Dissemination and distribution of outcomes

1. Video – 3D Drawing of the wearing procedure

https://youtu.be/_VGx9K3FmD0
Dissemination and distribution of outcomes

2. Patents

China Patent "An orthopaedic pad for improving idiopathic scoliosis in adolescents" 一种供改善青少年特发性脊柱侧凸的矫形垫, filled date: 22-08-2018 Application no.: 201810954428.8

Ergonomic Brace Wear for Adolescent Idiopathic Scoliosis (AIS)
Dissemination and distribution of outcomes

2. Patents

US Patent “Customizable wearable top to treat scoliosis in a person”

Field

[0001] The invention relates to a customizable wearable top for the treatment of scoliosis, such as Adolescent Idiopathic Scoliosis (AIS), in a person.

Background

[0002] Scoliosis is generally defined as the three-dimensional deformity of spine, thorax and trunk. A diagnosis is made when the spine deviates laterally with a Cobb angle of 10° or more. The majority of scoliosis cases are idiopathic, in which no known cause can be found with a multifactorial etiology. It occurs mainly in adolescent, namely Adolescent Idiopathic Scoliosis (AIS), during the period of growth spurt from the age of 10 until the reach of skeletal maturity.

To halt the progression of AIS and avoid surgery, bracing is the most common non-operative treatment option for adolescents with a spinal curve of 25° to 40°. The external mechanical forces exerted by braces restore the alignment of spine and body contour. However, there are two main problems associated with the existing braces which affect the treatment outcomes: one is the long production lead time for scoliosis brace and the second is the low brace compliance in patients.

[0003] Scoliosis braces are custom-made in accordance with the spinal curvature and body shape of each patient. Treating orthosis is responsible throughout the fabrication process from shape capturing, design, fitting to follow-up adjustments, as trained skills are required to ensure a well-designed orthosis that fits well on patient. Techniques and ways to fabricate braces have been evolving from plaster cast to prefabrication and to CAD/CAM modelling; however, the required production lead time is still long. Existing fabrication methods include plaster casting, prefabrication, computer-aided design / computer-aided manufacturing (CAD / CAM), and simulation of brace fitting. Each of these is briefly discussed below.
Dissemination and distribution of outcomes

3. Patents

US Patent "Ergonomic Brace for Patients with Adolescent Idiopathic Scoliosis (AIS)" submitted to ITDO, PolyU

Invention Disclosure Form

I. TITLE OF THE INVENTION
Ergonomic Brace for Patients with Adolescent Idiopathic Scoliosis (AIS)

II. DESCRIPTION OF THE INVENTION
Inventions include new processes, products, apparatus, compositions of matter, living organisms or improvements to (or new uses for) things that already exist.

(a) (Background) What is the present technology? Are there any problems or deficiencies with the present technology?

Scoliosis is generally defined as the three-dimensional deformity of spine, thorax and trunk. A diagnosis is made when the spine deviates laterally with a Cobb angle of 10° or more [1]. The majority of scoliosis cases are idiopathic, in which no known cause can be found with a multifactorial etiology [2]. It occurs mainly in adolescent, namely Adolescent Idiopathic Scoliosis (AIS), during the period of growth spurt from the age of 10 until the onset of skeletal maturity. To halt the progression of AIS and avoid surgery, bracing is the most common non-operative treatment option for adolescents with a spinal curve of 25° to 40° [3].

The external mechanical forces exerted by braces restore the alignment of spine and body contour [3]. However, there are two major problems associated with the existing braces which affect the treatment outcomes: one is the long production lead time for scoliosis brace and the second is the low brace compliance in patients.

1) Long production lead time for scoliosis brace

Scoliosis braces are custom-made in accordance with the spinal curvature and body shape of each patient. Treating orthotist is responsible throughout the fabrication process from shape capturing, design, fitting to follow-up adjustments, as trained skills are required to ensure a well-designed orthosis that fits well on patient. Techniques and ways to fabricate braces have been evolving from plaster-cast to prefabrication and to CAD/CAM modeling; however, the required production lead time is still long. Four existing fabrication methods summarized from Zhoa et al. [4] and Catarin et al. [5] will be discussed as follows:

Plaster Casting:

Plaster casting is a traditional method introduced by French surgeon Yves Cabot and American physician Joseph Hooser. With the use of a casting frame, patient is put in a spine position with traction and corrective force applied (see Figure 1 left below). Plaster or synthetic material is then wrapped around the torso until harden, and a corrected spine impression of patient is captured upon bandage removal.

Figure 1: Front of the Ergonomic Brace (left); back of the Ergonomic Brace (right)

Bodice:

The knitted structure of the bodice is double jersey with an additional insertion of elastic in laid yarns in between. The face and the rear side of the double jersey are respectively knitted using the deodorant yarn and the cool-touch yarn. The cool-touch yarn knitted on the rear side of the bodice touches the skin, thus provides a cool sensation to the wearer. The deodorant yarn, on the other hand, is featured with deodorization, anti-microbial and moisture management functions, which helps keep the brace dry and fresh, especially during summer. To further enhance the comfort of wearer while wearing the brace, part of the bodice is knitted in net structure (Figure 2 right) to achieve a better breathability.

Figure 2: Bodice (left); net structure on bodice (right)
Dissemination and distribution of outcomes

4. Journal paper


Mechanical and Clinical Evaluation of a Shape Memory Alloy and Conventional Struts in a Flexible Scoliotic Brace

Wing-Yu Chan,1 Joanne Yip,1 Key-Long Yick,1 Sun-Pui Ng,1 Lo Lo,1 Kenneth Man-Chi Chiu,2 Kenny Yan-Hong Kim,3 Jason Ping-Yin Cheung,1 Kelvin Wai-Kwok Young,1 and Che-Ying Ting2

1Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China; 2Hong Kong Community College, The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China; 3Department of Orthopaedics and Traumatology, Kowloon Hospital, Kowloon, Hong Kong SAR, China; and Centre for Orthopaedic Surgery, Central, Hong Kong SAR, China

Abstract—Smart materials have attracted considerable attention in the medical field. In particular, shape memory alloys (SMAs) are most commonly utilized for their superelasticity (SE) in orthopedic treatment. In this study, the main struts of a flexible brace for adolescent idiopathic scoliosis (AIS) were fabricated from SMA. The correlative mechanism mainly depends on the compressive force applied to the brace at the deformed location. Therefore, the mechanical properties of the materials used and the interface pressure are both critical factors that influence the treatment effectiveness. The results indicate that tissues in the most rigid among the five types of materials, whereas the brace with SMA struts presents the best recovery properties and the most stable interface pressure. A radiographic examination of two patients with AIS is then planarized to validate the results, which shows that the SMA struts can provide better correction of thoracic curvature. These findings suggest that SMAs can be applied in braces because their SE allows for continuous and controllable corrective forces.

Keywords—Nitinol, Bonding stiffness, Interface pressure, Flexible brace, Material selection, Scoliosis.

INTRODUCTION

Scoliosis is the three-dimensional deformity of the spine and trunk. Adolescent idiopathic scoliosis (AIS) is the most common type of scoliosis, and emerges at or near the beginning of puberty and before skeletal maturity (generally between 10 and 16 years old).1,2 Non-surgical treatment, such as immobilization or dynamically correct posture by application of corrective forces with a spinal cage or brace, is an important treatment modality to prevent curve progression and reduce the spinal deformity of AIS patients with moderate scoliosis and a spinal curve that ranges from 20° to 45°. Conventional rigid orthotic braces, such as the Milwaukee brace, are fabricated with rigid materials, such as polyethylene and stainless steel, to provide support and stabilize the trunk and spine of patients.3 Recently, rigid braces are being constructed with more lightweight materials, such as carbon4 and polyurethane5 to improve their wear comfort. Most of these materials are widely used because of their good mechanical properties, low cost, and acceptable biocompatibility.6,7 However, they may not be able to satisfy the needs of patients because the rigid materials may cause pain, restrict daily activities and affect self-image. To overcome the problems of rigid scoliotic orthoses, new flexible braces composed of textile fabrics and straps have been developed, such as SpinCor, TITAC, Spinless, and a posture correction girdle.8 The researchers claim that these braces have greater wearer comfort and provide users with a better self-image and greater mobility in daily life. However, the braces can easily deform, which means that they do not offer optimal corrective effects. Moreover, these materials have attracted considerable attention in the medical field as an alternative option and are expected to play a crucial role in the translation of laboratory findings into clinical devices.9 Shape memory alloys (SMAs) are an example of a smart material.

FIGURE 7. X-ray image of scoliotic subject before (left) and after (right) wearing posture correction girdle with (a) SMA supportive struts (b) RR supportive struts.

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Dissemination and distribution of outcomes

5. Conference papers – The design and development process, 3D body shape changes, wear trial results of posture correction girdle were presented in different international conferences held in New Zealand and Hong Kong.

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6. Exhibition


Global healthcare innovation academy is initially developed by leading healthcare organizations in Geneva, Switzerland. This event has grown into an international collaboration between Switzerland, Canada and Hong Kong.

The overarching goal of this combined scientific and investment pitch competition is to provide a platform that allows entrepreneurs and healthcare professionals at any level with the encouragement and incentive to identify, nurture, and pioneer innovations in the health system.
## Dissemination and distribution of outcomes

### 7. Award

<table>
<thead>
<tr>
<th>Year</th>
<th>Title of Award and Name of Awarding Organisation</th>
</tr>
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<tbody>
<tr>
<td>2018</td>
<td>Annals of Biomedical Engineering Student Award for the paper “Mechanical and Clinical Evaluation of a Shape Memory Alloy and Conventional Struts in a Flexible Scoliotic Brace”, 17-20 October 2018, Atlanta, Georgia, USA.</td>
</tr>
</tbody>
</table>

August 15, 2018

Chai Wing Yu  
Doctoral Candidate  
Hong Kong Polytechnic University

Dear Miss Chai Wing Yu,

We will be holding our first annual Panhellenic ABME Student Award Session at the Biomedical Engineering Society's Annual Meeting held this year in Atlanta, Georgia October 17-20. We are pleased to inform you that we have selected your article “Mechanical and Clinical Evaluation of a Shape Memory Alloy and Conventional Struts in a Flexible Scoliotic Brace” for one of our student awards. Please notify your co-authors of this honor.

The award session will take place on Friday, October 19 at 3:30 pm. Each award recipient will present their paper, and receive a monetary award at the event. It is very important that you or a co-author attend the awards event so as to present your paper and receive the award in person. Please let me know as soon as possible if you will be attending BMES.

You may also wish to notify your institution’s news/media office such that they can write about this award during or immediately after the BMES meeting. Congratulations on an excellent paper, and we hope to see you at the meeting!

Sincerely,

Bethany Rowson  
Managing Editor, Annals of Biomedical Engineering  
Research Assistant Professor, Virginia Tech  
Department of Biomedical Engineering and Mechanics  
440 Kelly Hall, 325 Stanger St  
Blacksburg, VA 24061
References


6) Sharma S., Londono D., ... A PAX1 enhancer locus is associated with susceptibility to idiopathic scoliosis in females, Nature communication, 6: 6452 (2015).


References


References


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