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Functional Intimate Apparel for Adolescent Idiopathic Scoliosis (AIS)

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PolyU UoA 38
# Functional Intimate Apparel for Adolescent Idiopathic Scoliosis (AIS)

<table>
<thead>
<tr>
<th>Section</th>
<th>Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Descriptor</td>
<td>03</td>
</tr>
<tr>
<td>2</td>
<td>Biography of Principle Investigator</td>
<td>04</td>
</tr>
<tr>
<td>3</td>
<td>Research Output</td>
<td>05</td>
</tr>
<tr>
<td>4</td>
<td>Research Questions</td>
<td>09</td>
</tr>
<tr>
<td>5</td>
<td>Knowledge gap</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Research Field &amp; Key Works Referenced</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Research Methods &amp; Materials</td>
<td>23</td>
</tr>
<tr>
<td>8</td>
<td>Research Conclusions</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>Dissemination and distribution of outcomes</td>
<td>26</td>
</tr>
<tr>
<td>10</td>
<td>References</td>
<td>43</td>
</tr>
</tbody>
</table>
Title: Functional Intimate Apparel for Adolescent Idiopathic Scoliosis (AIS)

Descriptor

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spinal disorder. Rigid bracing is the universal conservative treatment that has been found to be effective for AIS. However, rigid braces inhibit the mobility and cause physical discomfort to AIS patients. To address this issue, a functional intimate apparel garment for AIS patients was designed and developed. The principles behind the use of this textile brace was to increase the mobility and perceived comfort of patients. An artificial hinge bone was developed to stabilize the corrective components and allow forward bending. Corrective straps attached to the artificial hinge are used to exert corrective forces onto the scoliotic spine. Semi-rigid silicon pads with high conformability to the body were developed to enhance the corrective forces. Moreover, an ergonomic open-gusset design was employed to eliminate the inconvenience of doffing the garment when using the toilet. The prototype has been tested by five subjects in a clinical trial. Among them, 3 showed a reduction of over 5 degrees in their spinal curvature. When the Cobb’s angle was compared pre- and post-intervention, it was found that the functional intimate apparel provided a correction of 6.1 degrees on average, which is equivalent to about a 27% correction of the scoliotic spine. The functional intimate apparel is more flexible, more comfortable, and lighter in weight so that scoliotic patients who need to undergo bracing treatment will enjoy improved quality of life. The study received two awards, and a Chinese patent has been filed for the artificial hinge design. The results of the study have been published in the Orthopedic Research Online Journal, and shared at the 14th Asian Textile Conference, the Textile Summit 2018 in Japan, the International Conference on Science and Innovative Engineering in Rome, and the Silicon Valley International Invention Festival in the US.
**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 is the co-investigator 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 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.
Research Output
Final Design of the Functional Intimate Apparel for Adolescent Idiopathic Scoliosis – First published on Aug 2018

Fig. 1 Illustration of the Functional Intimate Apparel for Adolescent Idiopathic Scoliosis

Bra cup
Bones
Corrective panel
Semi-rigid padding inserted to enhance the correction effect
Velcro
Adjustable shoulder straps
Lining tube
Artificial hinge bone
Adjustable straps
Bones
Open gusset
Adolescent idiopathic scoliosis (AIS)

Adolescent idiopathic scoliosis (AIS) is a structural 3-dimensional curvature of spine with unknown etiology during the puberty. Scoliosis (Fig. 2) is commonly defined as a lateral curvature equal or greater than 10 degrees\(^1\). The prevalence rate for AIS is up to 5.2\(^2\) and girls had a 3.17 times higher prevalence rate than boys\(^3\). Scoliosis would not only affect the body profile (Fig. 3) such as spinal asymmetry, trunk deformity, shoulder obliquity, scapular asymmetry, and pelvis declination, but also induce spinal pain, restrict body movement, affect cardiac and pulmonary functions or even lead to death\(^1\).\(^4\). Thus, a proper treatment for AIS is essential.

**Fig. 2** Lateral radiograph image of scoliotic spine

**Fig. 3** Asymmetric body profiles of scoliotic patients\(^4\)
Research Questions

Background

Treatment for AIS

According to the guidelines of The international Scientific Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) (Fig. 4), patient with curvature under 20 degrees is still under observation. If the curvature is over 20 degrees, bracing treatment is prescribed until the bone turns mature. The aims of bracing is to avoid surgery, improve aesthetics and quality of life, and reduce disability and pain. If the curvature is greater than 45 degrees, surgery may be needed.

Fig. 4 Guidelines for AIS treatment
Research Questions

Bracing treatment

Bracing is an effective non-invasive treatment for AIS to slow or arrest the scoliotic progression until the bones turn mature. Eighty-two percent patient successfully controlled the progression within 6 degrees with wearing the brace for more than 12 hours per day. In general, there are two types of brace which are rigid brace and flexible brace.

Rigid bracing is a traditional bracing treatment. Rigid brace is usually made of thermoplastic material. Boston brace and Lyon brace are the examples of rigid brace. The correcting mechanism of most rigid braces is acting direct corrective force onto the torso to correct the scoliotic spine. The application of corrective forces usually adopts three-point pressure system which involves a lateral external force on the apical vertebra and contralateral forces above and below the apical vertebra. However, such rigid braces have the limitations such as skin irritation, discomfort, unappealing appearance, and psychological impact.

Apart from rigid brace, flexible is developed to overcome the limitation of rigid braces. SpineCor is the typical example of flexible brace. SpineCor applies corrective movement principle to correct the scoliotic spine which involves the de-torsion of shoulders, thorax, thoracolumbar, lumbar, and pelvis segment of the spine. Nevertheless, the correction performance of SpineCor are still questionable.
Knowledge Gap

Adolescent idiopathic scoliosis is a prevalent spinal disorder condition for adolescent. The progression rate of spinal deformity for adolescent is high due to their rapid growth rate\textsuperscript{12}. Therefore, there is a need to control the scoliotic deformity. Rigid bracing is an universal effective non-invasive treatment for AIS. However, immobility, discomfort, and unpleasing appearance usually are the limitations which results a low compliance and poor quality of life\textsuperscript{8-10}.

Therefore, in response to the limitation of rigid braces, a functional intimate apparel for AIS aiming to maximise patients’ mobility and comfort with an effective correction effect is designed and developed.

The proposed design adopts the corrective mechanism of rigid braces which applies direct corrective forces to control the scoliotic spine. An artificial hinge bone was developed to stabilize the corrective components and allow forward bending. Corrective straps attached to the artificial hinge are applied to create corrective forces to the scoliotic spine. Semi-rigid silicon padding is developed to enhance the corrective forces with a high conformability to body. Moreover, an ergonomic open-gusset design is applied to eliminate the inconvenience when going toilet.

Therefore, comparing to traditional rigid bracing, the proposed functional intimate apparel is more comfortable to wear so that the quality of patients’ life would be improved.
### Research Field & Key Works Referenced

Table 1. Design features and its advantages of Lyon brace\(^\text{13}\)

<table>
<thead>
<tr>
<th>Design features</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustable</td>
<td>It is easily modified, accommodating up to 7 cm of growth, while also being more cost effective, requiring fewer and less frequent changes.</td>
</tr>
<tr>
<td>Active</td>
<td>The rigidity of the PMM structure stimulates the child to initiate an active axial auto correction which decreases superficial pressures.</td>
</tr>
<tr>
<td>De-compressive</td>
<td>As a consequence of the “Adjustable” feature, the effect of extension between the two pelvic and scapular girdles also decreases the pressure on the intervertebral discs and promotes more effective pushes.</td>
</tr>
<tr>
<td>Symmetrical</td>
<td>In addition to being more aesthetically pleasing, the brace is much easier to build.</td>
</tr>
<tr>
<td>Stable</td>
<td>The stability of both shoulder and pelvic girdle facilitates the intermediate corrections.</td>
</tr>
<tr>
<td>Transparent</td>
<td>Skin pressures are easily observed and direct control of the pushes, stops, drives and reliefs is possible. Complementary pads are rarely needed.</td>
</tr>
</tbody>
</table>
Research Methods & Materials

**Milestone 1 Design and develop a functional intimate apparel for adolescent idiopathic scoliosis**

Design and develop the functional intimate apparel according to the functional, expressive and aesthetic model. It includes the design frameworks, material selection, pattern drafting, garment assembling, and fitting modification.

**Milestone 2 Evaluation of the effectiveness of the proposed design**

Conduct a clinical study to investigate the effectiveness of the functional intimate apparel. It includes the subject recruitment, wear trial protocol, and clinical results.

**Milestone 3 Biomechanical model of the proposed design**

Develop a biomechanical model of the proposed design using finite element analysis method to estimate the biomechanics and correction of the proposed design. It includes the construction of models, and model stimulation.
Research Methods & Materials

Design and develop a functional intimate apparel for adolescent idiopathic scoliosis

Problem Identification
- Immobility of rigid brace
- Discomfort of rigid brace
- Unpleasing appearance of rigid brace
- Un-effective correction performance of existing flexible brace

Preliminary Ideas
- Direct corrective force to correct the scoliotic spine
- Using textile material to provide flexibility

Design Refinement
- Semi-rigid padding is developed to enhance the corrective performance
- Artificial hinge bone is developed to stabilise the corrective panel

Prototype Development
- Physical testing for material selection
- Body measurement for pattern making
- Prototype making

Evaluation
- Fitting
- Interface pressure measurement
- X-ray

Implementation
- Confirm final design

Fig. 9 Flow of the design and development process according to the Functional, Expressive, and Aesthetic model
Research Methods & Materials

Body measurement of scoliotic patients for pattern making

21 scoliotic subjects were invited to undergo a 3D body scanning.

<table>
<thead>
<tr>
<th>n=21</th>
<th>Age</th>
<th>BMI</th>
<th>Cobb's angle (degree)</th>
<th>a Upper breast circumference (mm)</th>
<th>b Under breast circumference (mm)</th>
<th>c Under band circumference (mm)</th>
<th>d Pelvis circumference (d)(mm)</th>
<th>e Hip circumference (mm)</th>
<th>f Waist to gusset (mm)</th>
<th>g Under band to pelvis (mm)</th>
<th>h Upper breast to pelvis (mm)</th>
<th>i Leg hole (mm)</th>
<th>j Shoulder strap length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12</td>
<td>19</td>
<td>17</td>
<td>772</td>
<td>681</td>
<td>675</td>
<td>802</td>
<td>871</td>
<td>195</td>
<td>78</td>
<td>359</td>
<td>513</td>
<td>385</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.7</td>
<td>2.3</td>
<td>4.4</td>
<td>35.1</td>
<td>38.7</td>
<td>61.2</td>
<td>48.8</td>
<td>49.9</td>
<td>24.5</td>
<td>25.7</td>
<td>30.5</td>
<td>40.4</td>
<td>23.8</td>
</tr>
<tr>
<td>Max.</td>
<td>14</td>
<td>24</td>
<td>28</td>
<td>834</td>
<td>760</td>
<td>838</td>
<td>916</td>
<td>974</td>
<td>260</td>
<td>146</td>
<td>439</td>
<td>594</td>
<td>427</td>
</tr>
<tr>
<td>Min.</td>
<td>11</td>
<td>15</td>
<td>11</td>
<td>700</td>
<td>608</td>
<td>583</td>
<td>717</td>
<td>766</td>
<td>154</td>
<td>42</td>
<td>311</td>
<td>444</td>
<td>343</td>
</tr>
</tbody>
</table>

Fig. 10 Body measurement for pattern making

Fig. 11 Patterns of the functional intimate apparel
Research Methods & Materials

Padding development

Fig. 12 Silicon paddings

Fig. 13 Moulding of silicon paddings

Fig. 14 Silicon KE-1310ST and CAT-1310 used for the padding

Fig. 15 Mould head of the padding

Fig. 16 3D illustration of the padding
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Back bone development

Fig. 17 Resin joint
Fig. 18 PU bone
Fig. 19 Hinge bone

Fig. 20 Printing parts for hinge bone prototypes
Fig. 21 Prototype of resin joint
Fig. 22 Prototype of hinge bone
Research Methods & Materials

Hinge bone development

Fig. 23 Material selection for hinge bones

<table>
<thead>
<tr>
<th>Material of leaf</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast acrylic (PMMA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyoxymethylene (POM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon fiber reinforced polymer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6061 Aluminium alloy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6061 Aluminium alloy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material of pin</td>
<td>Iron</td>
<td>Iron</td>
<td>Iron</td>
<td>Iron</td>
<td>Steel</td>
</tr>
<tr>
<td>Thickness</td>
<td>5mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm3)</td>
<td>1.19</td>
<td>1.41–1.42</td>
<td>1.75–2.00</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Breaking strength (kN)</td>
<td>0.4969</td>
<td>0.7156</td>
<td>1.1867</td>
<td>6.0120</td>
<td>11.3925</td>
</tr>
</tbody>
</table>

Table. 3 Material selection for hinge bones

Fig. 24 Tensile strength tester

Fig. 25 Tensile strength testing

Fig. 26 Load-displacement curves of different materials
Research Methods & Materials

Fabric and elastic selection

Table 4 Fabric selection

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Supplier</th>
<th>Production name</th>
<th>Composition</th>
<th>Fabric width</th>
<th>Weight (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell fabric</td>
<td>DN64013S</td>
<td>Derun Textile</td>
<td>Weft knit spacer</td>
<td>25% Spandex, 75% Micro Nylon</td>
<td>52inch</td>
<td>320</td>
</tr>
<tr>
<td>Shell fabric</td>
<td>DXN873S</td>
<td>Derun Textile</td>
<td>Weft knit interlock</td>
<td>36%Xtra Life Lycra, 64%Nylon</td>
<td>55inch</td>
<td>225</td>
</tr>
<tr>
<td>Shell fabric</td>
<td>DN818SM</td>
<td>Derun Textile</td>
<td>Weft knit interlock</td>
<td>38% Spandex, 62% Micro Nylon</td>
<td>60inch</td>
<td>175</td>
</tr>
<tr>
<td>Shell fabric</td>
<td>DXN72001S</td>
<td>Derun Textile</td>
<td>Weft knit interlock</td>
<td>34%Xtra Life Lycra, 66%Nylon</td>
<td>60inch</td>
<td>190</td>
</tr>
<tr>
<td>Elastic straps</td>
<td>1280914_25</td>
<td>Pioneer</td>
<td>Woven</td>
<td>88% stretch nylon, 2% bright yarn and 10% spandex</td>
<td>25mm</td>
<td></td>
</tr>
<tr>
<td>Elastic straps</td>
<td>1280761_25</td>
<td>Pioneer</td>
<td>Woven</td>
<td>10% nylon66, 80% stretch nylon and 10% spandex</td>
<td>25mm</td>
<td></td>
</tr>
<tr>
<td>Elastic straps</td>
<td>4443_25</td>
<td>Pioneer</td>
<td>Woven</td>
<td>90% stretch nylon and 10% spandex</td>
<td>25mm</td>
<td></td>
</tr>
<tr>
<td>Elastic straps</td>
<td>4246_25</td>
<td>Pioneer</td>
<td>Woven</td>
<td>90% stretch nylon and 10% spandex</td>
<td>25mm</td>
<td></td>
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</table>

Table 5 Physical testing for material selection

<table>
<thead>
<tr>
<th>Mechanical performance</th>
<th>Thermal comfort</th>
<th>Durability</th>
<th>Sensorial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weft knitted</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Elastic band</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Elastic straps</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Research Methods & Materials

Prototype development

Fig. 27 First prototype of bra top

Fig. 28 Second prototype of bra top

Fig. 29 Third prototype of bra top

Fig. 30 Fourth prototype of bra top and bottom
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Clinical study

**Table. 6 Criteria for subject recruitment**

<table>
<thead>
<tr>
<th><strong>Inclusion criteria</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aged 10 to 13 years</td>
</tr>
<tr>
<td>Diagnosis of AIS in early stage</td>
</tr>
<tr>
<td>Primary Cobb angle 15-35 degrees</td>
</tr>
<tr>
<td>Pre-menarche or post-menarche by no more than 1 year</td>
</tr>
<tr>
<td>Skeletally immature (Risser grade 0, 1 or 2)</td>
</tr>
<tr>
<td>Ability to read and understand English or Chinese</td>
</tr>
<tr>
<td>Physical and mental ability to adhere to functional intimate apparel protocol</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Exclusion criteria</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Contraindications for x-ray exposure</td>
</tr>
<tr>
<td>Diagnosis of other musculoskeletal or developmental illness that might be responsible for the spinal curvature</td>
</tr>
<tr>
<td>History of previous surgical or orthotic treatment for AIS</td>
</tr>
<tr>
<td>Contraindications for pulmonary and/or exercise tests</td>
</tr>
<tr>
<td>Psychiatric disorders</td>
</tr>
<tr>
<td>Recent trauma</td>
</tr>
<tr>
<td>Recent traumatic (emotional) event</td>
</tr>
</tbody>
</table>

Fig. 31 Protocol of wear trial
Research Methods & Materials

Clinical study

Table. 7 Clinical trial results

<table>
<thead>
<tr>
<th>Subject code</th>
<th>Age</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>BMI</th>
<th>Lenke type</th>
<th>Curve level (Primary curve)</th>
<th>Apex (Primary curve)</th>
<th>Cobb’s angle Pre-intervention (Primary curve)</th>
<th>Cobb’s angle Post-intervention (Primary curve)</th>
<th>Difference between pre and post (Pre – Post)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIA19001</td>
<td>12</td>
<td>35.8</td>
<td>148</td>
<td>16.8</td>
<td>6</td>
<td>T12-L4</td>
<td>L2</td>
<td>20.0</td>
<td>13.7</td>
<td>6.3</td>
</tr>
<tr>
<td>FIA19002</td>
<td>13</td>
<td>37.9</td>
<td>149</td>
<td>17.1</td>
<td>1</td>
<td>T8-L3</td>
<td>T12</td>
<td>23.0</td>
<td>2.6</td>
<td>20.4</td>
</tr>
<tr>
<td>FIA18001</td>
<td>12</td>
<td>45.5</td>
<td>148</td>
<td>20.8</td>
<td>3</td>
<td>T4-T11</td>
<td>T8</td>
<td>21.6</td>
<td>19.5</td>
<td>2.1</td>
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<tr>
<td>FIA18002</td>
<td>12</td>
<td>43.7</td>
<td>153</td>
<td>18.7</td>
<td>5</td>
<td>T11-L4</td>
<td>T8</td>
<td>21.8</td>
<td>26.7</td>
<td>-4.9</td>
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<td>FIA18003</td>
<td>12</td>
<td>45.4</td>
<td>150</td>
<td>20.2</td>
<td>3</td>
<td>T5-T11</td>
<td>T8-9</td>
<td>25.3</td>
<td>18.7</td>
<td>6.6</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>12.2</strong></td>
<td><strong>41.66</strong></td>
<td><strong>149.6</strong></td>
<td><strong>18.72</strong></td>
<td><strong>3</strong></td>
<td></td>
<td></td>
<td><strong>22.3</strong></td>
<td><strong>16.2</strong></td>
<td><strong>6.1</strong></td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>0.4</td>
<td>4.5</td>
<td>2.1</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>8.9</td>
<td>9.2</td>
</tr>
</tbody>
</table>

**Fig. 32** Subject wearing the functional intimate apparel

**Fig. 33** X-ray of the pre- and post- intervention
Research Methods & Materials

Biomechanical model of functional intimate apparel

Table. 8 Demographic data of subject

| Gender | Female |
| Age    | 13     |
| Weight | 45.4 kg|
| Height | 150 cm |
| Curve type | Lenke 3 (S-curve, major in thoracic) |
| Cobb’s angle | T5-T11:25°, T11-L3:22° |

Fig. 34 Skeletal model developed according to the x-ray

Table. 9 Material properties of the finite element model analysis

<table>
<thead>
<tr>
<th></th>
<th>Vertebral body, ribcage, and pelvis</th>
<th>Intervertebral disc</th>
<th>Torso</th>
<th>FIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>200</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.1</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Fig. 35 Finite element model of (a) skeleton, (b) torso, and (c) functional intimate apparel (FIA)

Fig. 36 Simulation of fabrication of FIA
Research Methods & Materials

Biomechanical model of functional intimate apparel

Fig. 37 Pressure distribution of torso after wearing FIA

Fig. 38 Pressure distribution of skeleton after wearing FIA

Fig. 39 Resultant displacement of torso after wearing FIA

Fig. 40 Resultant displacement of skeleton after wearing FIA
Research Conclusions

Instant spinal correction

5 subjects were conducted a clinical trial. Among 5 subjects, 3 subjects have >5 degrees in-brace improvement, 1 subject has <5 degrees in-brace improvement, and 1 subject has <5 degrees in-brace deterioration.

Comparing the Cobb’s angle between pre- and post-intervention, the functional intimate apparel provides 6.1 degrees instant in-brace correction in average, which provides about 27% in-brace correction in average of scoliotic spine.

The greatest instant correction is found in subject FIA19002, which is a single thoracolumbar curve and achieves a 89% in-brace scoliotic correction

Table. 10 Comparison of clinical trial results

<table>
<thead>
<tr>
<th>Subject code</th>
<th>Cobb’s angle</th>
<th>Cobb’s angle</th>
<th>Difference between pre and post (°)</th>
<th>Percentage of correction/progression (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-intervention (°)</td>
<td>Post-intervention (°)</td>
<td>(Pre –Post)</td>
<td>(Pre-Post /Pre x100%)</td>
</tr>
<tr>
<td>FIA19001</td>
<td>20.0</td>
<td>13.7</td>
<td>6.3</td>
<td>31%</td>
</tr>
<tr>
<td>FIA19002</td>
<td>23.0</td>
<td>2.6</td>
<td>20.4</td>
<td>89%</td>
</tr>
<tr>
<td>FIA18001</td>
<td>21.6</td>
<td>19.5</td>
<td>2.1</td>
<td>10%</td>
</tr>
<tr>
<td>FIA18002</td>
<td>21.8</td>
<td>26.7</td>
<td>-4.9</td>
<td>-22%</td>
</tr>
<tr>
<td>FIA18003</td>
<td>25.3</td>
<td>18.7</td>
<td>6.6</td>
<td>26%</td>
</tr>
<tr>
<td>Average</td>
<td>22.3</td>
<td>16.2</td>
<td>6.1</td>
<td>27%</td>
</tr>
<tr>
<td>S.D.</td>
<td>2.0</td>
<td>8.9</td>
<td>9.2</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Fig. 41 X-ray of the pre- and post-intervention of subject FIA19002
Dissemination and distribution of outcomes

<table>
<thead>
<tr>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
</tr>
<tr>
<td>02</td>
</tr>
<tr>
<td>03</td>
</tr>
<tr>
<td>04</td>
</tr>
<tr>
<td>05</td>
</tr>
<tr>
<td>06</td>
</tr>
<tr>
<td>07</td>
</tr>
</tbody>
</table>
Dissemination and Distribution of Outcomes

1. Video – Development of functional intimate apparel

https://youtu.be/3E_Yw0c7Q1s
Dissemination and Distribution of Outcomes

2. China patent Filled on 30th July 2018 “Artificial hinge bone for orthosis” submitted to National Intellectual Property Administration

https://qrgo.page.link/UQFsD
Dissemination and Distribution of Outcomes


Effectiveness of Posture Correction Girdle as Conservative Treatment for Adolescent Idiopathic Scoliosis: a Preliminary Study

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Submissions: November 13, 2017. Published: January 31, 2018

Abstract

A one-year quasi-experimental pretest-posttest control trial has been conducted to assess the efficacy of a posture correction girdle to control the progression of scoliosis and its correction ability by comparing the girdle when it is disassembled as opposed to when it is dressed. Comparison of the Cobb’s angle was measured at baseline and at 12 months post-intervention. It was found that the Cobb’s angle of the control group is statistically significantly higher than that of the experimental group. This study therefore demonstrates the efficacy of using posture girdles for clinical or short-term use and for other types of functional garments.

Keywords: Functional garments; Adolescent idiopathic scoliosis; Flexible braces; Posture correction girdles

Introduction

Adolescent idiopathic scoliosis (AIS) is one of the most common spinal conditions with a prevalence of 2-3% in the general population [1], in the last ten years. Flexible braces for treating AIS have been receiving much attention due to their flexibility, permeability and improved physical appearance.

Case Report

During October 2015 to December 2016, a total of 14 AIS patients were recruited for a clinical trial study of the posture correction girdle through a school screening program in local secondary schools or by referral from a physician. The inclusion criteria were adolescents diagnosed with idiopathic scoliotic deformity with a Cobb’s angle between 25°-29°, between 15 and 18 years old, Rimmer grade 0-4 of the apophysis of the iliac crest, and no prior treatment. All subjects were required to wear the posture correction girdle for at least 8 hours a day for 6 months while the rest of time (16 hours) was allowed for bathing, doing physical exercises, and sleeping.

Standardized antero-posterior radiographs of the entire spine were taken at pre-intervention, 6 months intra- and 6 months post intervention to assess the degree of spinal deformity to reduce inter-operator or intra-operator bias, all radiographic measurements were conducted by two independent orthopaedic doctors.

Results

Ten out of the 16 subjects completed the trial and withdrew from the program. The mean, standard deviation, and range of the Cobb’s angles at the baseline and post-intervention for each type of curve are shown in Table 1. In terms of the control of the progression of spinal deformity after 6 months of wearing the girdles, a Wilcoxon signed-rank test showed that there was no significant difference between the pre-intervention (mean=13.68±5.32) and post-intervention (mean=13.57±5.91). Nevertheless, it was found that one (10%) subject with a Cobb angle of more than 5°, one subject (10%) with a Cobb angle of more than 20°, 3 subjects (30%) with a Cobb angle of more than 30°, and 4 subjects (40%) with a Cobb angle of more than 40°.

Discussion

This study demonstrates the effectiveness of posture correction girdles to control the progression of scoliosis with a 90% survival rate. More importantly, the statistical analysis further supports that the Cobb’s angle when the girdles are worn is at the 6th month is significantly lower than that of pre-intervention. This shows that there is a post-intervention effect for girdle wear in terms of spinal correction. These results validate the work of Liu et al. (2015) girdle design which is a light-fitting undergarment and reduces localized pressure for controlling scoliosis. The convexity principle of the posture correction girdle for adolescents derived from using main bones and elastic bands with high modulus of elasticity, which create circumferential compressive force onto the body. In addition, the improved design of girdle with elastic bands in the spine curvature area provides additional pressure into the curve region. The convex pressure distribution across the dynamic vertebral to shift forces from convex to the curve side, which are the same as the Cobb’s angle of the spine when the girdle is worn for a given time.
Design and functional bra top for adolescent idiopathic scoliosis

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4. Conference papers


Abstract

A functional bra top is developed with a fabric support system that has 10 degrees of freedom. The garment is trimmed into the traditional 1-needle, 2-needle round neck. The main function of the fabric system is to enhance postural correction of lumbar spine, prevent scoliosis from progressing and provide quality of life for the users. The design of the bra top is based on a functional bra top study that was conducted. The bra top is integrated with a fabric support system that is made of a series of textile structures with varying degrees of freedom. The bra top is designed to provide back support for the users. The design is validated by a Posture Excel system.

Keywords: Bra top, functional bra top, adolescent idiopathic scoliosis, postural correction

Introduction

Adolescent idiopathic scoliosis (AIS) is a progressive deformity of the spine characterized by an abnormal lateral curvature greater than 10° or an angular curve greater than 25°. The condition affects 2% of children and adolescents. The main function of the fabric system is to enhance postural correction of lumbar spine, prevent scoliosis from progressing and provide quality of life for the users.

Methods

The design of the bra top is based on a functional bra top study that was conducted. The bra top is integrated with a fabric support system that is made of a series of textile structures with varying degrees of freedom. The bra top is designed to provide back support for the users. The design is validated by a Posture Excel system.

Results and Discussion

The bra top is integrated with a fabric support system that is made of a series of textile structures with varying degrees of freedom. The bra top is designed to provide back support for the users. The design is validated by a Posture Excel system.

Conclusion

The bra top is integrated with a fabric support system that is made of a series of textile structures with varying degrees of freedom. The bra top is designed to provide back support for the users. The design is validated by a Posture Excel system.
Dissemination and Distribution of Outcomes

4. Conference papers


https://t-summit2018.wixsite.com/home

Functional intimate apparel design for scoliotic spine

Fok Q, Yip J, Yick KL, et al.

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong, Hong Kong

Presentation Mode: Oral

Background

Scoliosis is a complex three-dimensional spinal disorder which features a spinal curvature that is equal or greater than 10 degrees under radiographic examination. Adolescent idiopathic scoliosis (AIS) is a prevalent yet serious spinal deformity found in teens due to its rapid progression. Progressive scoliosis might induce contour deformity, back pain, psychological and social suffering, and even respiratory and pulmonary complaints. Thus, management of the scoliotic spine is critical for AIS patients to maintain quality of life.

Dealing with the application of rigid materials is a traditional and non-invasive treatment of AIS. However, noncompliance is often an issue and there are various drawbacks to the use of hard braces, such as skin irritation, discomfort, aesthetically unappealing appearance, and psychological impacts. On the other hand, the use of textile material and intimate apparel designs have excellent potential for orthotic uses. However, there is little work in the literature on designing functional intimate apparel that features corrective concepts for AIS.

Objective

This study aims to design a functional intimate apparel that controls spinal curvature and posture of individuals with AIS.

Methods

The design process starts from identifying the problems followed by generating design ideas, and developing and evaluating the prototype. The performance of the functional intimate apparel is preliminarily evaluated by 3D body imaging after two hours of wear for contour asymmetry.

Generating design ideas

The designs of the proposed functional intimate apparel consist of 2 corrective mechanisms, which are a three-point pressure system and proprioception. The former is a cumulus system used in orthotics which acts as one principal force that is acting on the apex region and two counterforces acting in the opposite direction located proximally and distally to the principal force. Proprioception is based on the three-point pressure system and allows the reconstruction and restoration of neuromuscular control. Proprioception enables the trunk and pelvis to shift and become properly aligned, thus controlling the scoliotic deformity.

The design of the proposed functional intimate apparel for AIS consists of 5 main ideas which are to: a) provide compression and pulling forces through a tightly fitting pattern, b) support lumbar flexibility with a supporting belt, c) provide transverse forces through a 3-point pressure system, d) redirect the deformed vertebrae in the transverse plane with the use of uneven strips, and e) provide corrective forces that shift the trunk away from areas of induced pressure to control the spinal curvature and posture of individuals with AIS.

Results

A functional intimate apparel for AIS (Figure 1) has been designed, which consists of 3 parts: a bra top, a bottom, and a corrective panel. The bra top covers the spinal area from the underarm to the bottom of the rib cage with front hook and eye openings. The bottom is a high-waist open panel band with a front Velcro opening. The corrective panel is an anisotropic panel with high modulus elastic material and semi-rigid corrective padding to apply three-point pressure onto the body and hence aims to align the spine. Three-dimensional body imaging was carried out and the images in Figure 2 show that the trunk, lumbar and pelvis have shifted after wearing the proposed garment for 2 hours.
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4. Conference papers


http://www.rs.polyu.edu.hk/ppcr2018/

Abstract #18110

A Non-Invasive Method to Assess Control of Body Contours for Spinal Treatment

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1 Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong
2 Hong Kong Community College, The Hong Kong Polytechnic University, Hong Kong

Objective:
This study investigates the application of three-dimensional (3D) profiling of the torso to assess the feasibility of controlling body contours for spinal treatment.

Methods:
Subjects with scoliosis are recruited for a wear trial of a functional intimate apparel (FIA) to treat adolescent idiopathic scoliosis (AIS). They have undergone 3D body scanning prior to the intervention, in which imaging is immediately carried out after donning the FIA, and then after wearing the FIA for 2 hours. The Vivos Smart XXL 3D body scanner (Human Solutions GmbH, Germany) is used to extract the 3D geometry of the body. The asymmetry of the body contours is analyzed by examining the deviations of cloud points between the left and right profiles, and a 3D color-coded map is generated with Geomagic Studio 2012 (Geomagic, Inc.). The orientation of the shoulders and vertebral hump, and trunk alignment are measured based on anatomic landmarks of the 3D image by using SolidWorks 2012 (Dassault Systèmes).

Results:
Deviations of cloud points between the left and right profiles are observed in the upper and lower dorsal, lumbar, and sacrum regions. The 3D color-coded map and direct measurements of the anatomic landmarks show changes in the asymmetry of the torso after intervention with the FIA.

Conclusion:
The 3D profiling of the torso shows asymmetry of the body contours through deviations of cloud points and direct measurements of anatomic landmarks. This study highlights the possibility of using 3D profiling to assess control of the body contours for spinal treatment.

Keywords: Torso profiling, contour symmetry, spinal treatment
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Biomechanical modelling of functional apparel for scoliotic spine

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*Hong Kong Community College, The Hong Kong Polytechnic University, Hou Tin-queen. S.fok@connect.polyu.hk, joanne.yip@polyu.edu.hk, kit-hon.yick@pol
ccpg@hkcc.polyu.hk

Abstract— There is limited studies investigated the effectiveness of flexible brace via biomechanical modeling. The aim of this study is to examine 3D surface, torso, and flexible brace, functional intimate apparel (FIA) models for finite element analysis. Scoliosis model including vertebral body, intervertebral disc, ribcage, and pelvis, torso model, and FIA model were developed. Validation of FIA fabrication was conducted. Preliminary results show that the right thoracic experienced relative high pressure, and the body moved toward upper left. The results coincide the application of corrective padding.

Keywords—Scoliosis, finite element model, flexible brace, functional intimate apparel

I. INTRODUCTION

Scoliosis is a complex three-dimensional spinal disorder with curvature greater than 10 degrees. Rigid bracing is a traditional universal non-invasive treatment for scoliosis. However, noncompliance is often an issue and there are various drawbacks to the use of hard braces, such as skin irritation, discomfort, aesthetically unappealing appearance, and psychological impacts[1-3]. On the other hand, the use of textile material and intimate apparel designs have excellent potential for orthotic uses. Fok et al. developed a functional intimate apparel for scoliotic spine aiming to control the spinal curvature[4].

Due to the concerns of human subjects and the ethical problem of repetitive radiation exposure for the examination of a scoliotic spine, recently, numerical model-based analysis such as finite element modeling (FEM) has emerged to simulate the effectiveness of scoliosis brace. Chou et al. [5] investigated the correction effect of Boston brace with FE models of scoliotic spine, and Boston brace. Pea et al. [6] developed the scoliotic spine, and torso FE model based on a single coronal radiograph, and surface topography, and estimated the effectiveness of rigid brace. Cheng et al. [7] evaluated the correction effect of scoliotic spine under different levels of loading. However, majority of literature investigated the correction performance of rigid brace instead of flexible brace.

The aim of this study was to develop 3D models of skeleton, torso, and the functional intimate apparel for finite element analysis, and to investigate the correction performance of flexible brace.

II. METHODS

A. Patient data

The 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 (Juster [HKL/ HKA EWIB]). One teenager girl (13 years old, Lenke type 3, T5- T11: 25°, T11-L3: 25°) with adolescent idiopathic scoliosis was consented, and was recruited in this study.

The subject underwent a radiographic examination, and 3D body scanning for extracting the skeletal, and torso geometry. The internal spinal geometry was acquired through x-rays from a low dose simultaneous biplanar radiographic system (EOS, EOS imaging, Paris, France). The external torso geometry was acquired using a Vitus Smart X-Scan X-ray system (OneMan Solutions GmbH, Germany). The subject was asked to wear the functional intimate apparel (see Fig. 1), and the interface pressure at the corrective panel region which are right thoracic, left lumbar, right pelvis, and left pelvis was measured. The interface pressures was measured by the Force®-el-16 (-32) system with 6 single sensors.

Fig. 1 Subject wearing the functional intimate apparel

B. Modelling of skeleton with coronal, and sagittal x-rays

Solidworks 2012 x64 Edition (Dassault Systemes SOLIDWORKS Corp., USA) was used to develop the 3D models of vertebral body, intervertebral disc, ribcage, and pelvis based on coronal, and sagittal x-rays (Fig. 2). Due to the concerns of computer capability, and calculation time of numerical simulation, the geometries of vertebral body, intervertebral disc, ribcage, and pelvis were simplified as regular geometric prism shapes. The document units were selected as MMGS system (millimeter, gram, second).

A FEM of vertebral body, intervertebral disc, ribcage, and pelvis was created using Abaqus/CAE 6.14-4 (Dassault Systemes Simulia Corp., USA). The mesh size is set as 40mm. The vertebral body, intervertebral disc, ribcage, and pelvis were represented by 13868 8-node quadratic tetrahedral elements (Fig. 3). The material properties were listed (See Table I).

Table I Material properties of FEM

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Young’s Modulus (GPa)</th>
<th>Poisson’s Ratio</th>
<th>Density (kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>10</td>
<td>0.3</td>
<td>1700</td>
</tr>
<tr>
<td>Cartilage</td>
<td>0.5</td>
<td>0.45</td>
<td>100</td>
</tr>
<tr>
<td>Muscle</td>
<td>2</td>
<td>0.47</td>
<td>1000</td>
</tr>
</tbody>
</table>

C. Modelling of torso

The model of torso was extracted from the 3D body scanning image. Geomagic studi 2012 (Geomagic Inc., USA) was used to uniform the cloud points, remove its noise, and to smooth out the model surface for a better mesh generation in the numerical simulation.

A FEM of torso model was created using Abaqus/CAE 6.14-4 (Dassault Systemes Simulia Corp., USA). The internal geometry of torso model was further modified by cutting the intersect of skeletal model. The mesh size of torso model is set at 40mm. The torso was re-oriented by 37460 8-node quadratic tetrahedral elements (Fig. 3). The material properties were listed (See Table II).

D. Modelling of functional intimate apparel

The model of functional intimate apparel (FIA) was developed based on the torso model. Solidworks 2012 x64 Edition (Dassault Systemes SOLIDWORKS Corp., France) was used to shell the solid torso model. From zipper to the flexible brace model. The FIA is then cut into 4 pieces in order to simulate the fabrication process.

A FEM of FIA was created using Abaqus/CAE 6.14-4 (Dassault Systemes Simulia Corp., USA). The mesh size is set as 10mm. The geometric details (Fig. 3) are defined as follows: left-hip, right-hip, left-thigh, right-thigh, left-leg, right-leg, left-foot, right-foot. The material properties were listed (See Table III).
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4. Conference papers


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5. Silicon Valley International Invention Festival on 24-26 June 2019

The Silicon Valley International Invention Festival (SVIIF), hosted by the International Federation of Inventors’ Associations (IFIA) and organized by Palexpo, Geneva’s Exhibition and Congress Center enjoys the most privileged support from the World Intellectual Property Organization (WIPO), Santa Clara City and Santa Clara University with the collaboration of United States Patent and Trademark Office (USPTO).

Flexible Scoliotic Brace with Shape Memory Alloy Struts

A comfortable functional garment for patients with scoliosis

The innovative scoliotic brace is a functional garment specially designed for adolescents with scoliosis. The shape memory alloy (SMA) and the artificial hinges used in this design apply strategic corrective forces to the spine, providing adequate support to the wearer. Combining clinical practice, materials science, and textile technology, the scoliotic brace of high wearing comfort can control the progression of spinal deformities more effectively and improve patient compliance, thus reducing the possible need for orthotic interventions or surgery.

Special Features and Advantages:

- A multi-disciplinary collaborative project that involves experts in clinical practice, materials science, as well as textile and garment technology
- The superelastic SMA provides adequate support while allowing the wearer to retain certain mobility
- Made of soft materials for enhanced patient compliance
- Light weight with less heat and moisture build-up
- Can be worn as a comfortable underwear

Applications:

- Posture training and controlling spinal deformity for patients with mild scoliosis
- Posture training to general public to improve their movement coordination and daily posture
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5. Silicon Valley International Invention Festival on 24-26 June 2019
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6. Awards

Two awards were received for the project, including:

1) Gold medal of the Silicon Valley International Invention Festival, Santa Clara Convention Center, USA. 23-25 June 2019

2) Special award of Association of Polish Inventors and Rationalizers, 23-25 June 2019
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7. Media and Newspaper reports – Sing Tao Daily, Bay area, USA

發明可動矯形腰背架 香港理工大學獲金獎

Sing Tao Daily Bay area, USA 2019 06 27
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7. Media and Newspaper reports – KTSF Channel 26
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7. Media and Newspaper reports – EDU PLUS HK

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7. Media and Newspaper reports – HK01

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HK01 2019-08 22

https://qrgo.page.link/GL561
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7. Media and Newspaper reports – Sky Post

Sky Post

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7. Media and Newspaper reports – Sing Tao Daily Education News

理大研記形合金腰背架助矯正輕度脊柱側彎

星島日報 教育 2019 08 22

https://qr.go.page.link/vKGUP
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