DEVELOPMENT OF POSTURE CORRECTION GIRDLE FOR ADOLESCENTS WITH EARLY SCOLIOSIS

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Development of Posture Correction Girdle for Adolescents with Early Scoliosis

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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ABSTRACT

Adolescent idiopathic scoliosis is a complex three-dimensional deformity of the spine, which appears and sometimes progresses during periods of rapid growth in apparently healthy adolescents with a higher proportion of girls than boys. In Hong Kong, it was found that the prevalence of scoliosis has an increasing trend. Postural alterations and imbalance problems are commonly found in these adolescents. However, there is a lack of product selection and treatment choice for adolescents with early scoliosis, and many problems are found with the existing products in the market. Therefore, the aim of this study is to provide a tailor-made posture correction girdle for girls who are in the age group of 10-13 with early scoliosis, in order to improve their imbalanced postures by girdling and reduce the possibility of curvature progression in scoliosis.

A systematic framework produced by using a three-stage design process, as well as the functional, expressive and aesthetic (FEA) consumer needs model are used during the design and development process of the girdle. A screening program has been carried out in 7 schools and 21.9% of the screened students possibly have early scoliosis. Nine are recruited in accordance with the inclusion criteria to participate in a 6 month wear trial. A posture correction girdle made of well-performing materials evaluated by physical tests is provided to each subject after two fitting sessions. Padding insertion is one of the key factors that contribute to posture correction by generating point-pressure forces in accordance with the needs in different cases. Acceptable compliance is found in the wear trial and no effects induced by girdling are found to influence heart and pulmonary functions, as well as the sensory levels according to the results of the health tests.

Three dimensional body scanning, direct measuring of shoulder levelness by using the floor as a reference, and motion capturing are carried out to evaluate the possible effectiveness of the girdle on posture correction. The results of shoulder levelness measurement show that wearing the girdle with padding insertion have better effects than without wearing the girdle and wearing the girdle that without padding insertion in both of 0 and 3 months. The results of motion capturing show that

the imbalanced postures of the subjects generally improve after 6-months of girdling. Significant immediate improvements including more even shoulder in frontal plane and horizontal plane during standing, as well as straighter upper back in sagittal plane during sitting; while significant improvements from time-to-time including more even shoulder in frontal plane during standing and walking. Moreover, statistically significant differences of interaction effects of girdling (without girdle, with girdle) and time (0, 3, 6 months) on posture changes including more even shoulder an pelvis in frontal plane during standing, straighter lower back in sagittal plane during sitting, as well as acceptable constrained anterior and lateral bending range.

As well, a radiographic analysis has been carried out to evaluate the effectiveness of the girdle on spinal deformity control. Regarding the results of radiographic analysis (Cobb's angle), 1 subject has improvement, 4 subjects were within control and 2 subjects have further curve progression after 6 months of girdling. Moreover, there are immediate improvements in the spinal curve of the subjects when comparisons are made between wearing a girdle and when a girdle is not worn, i.e. one of the subjects has 83.33% and 75% reductions of the thoracic and lumbar curves respectively after she put on the girdle at 6 months. Additionally, for time-to-time improvements in the spinal curve of the subjects when comparisons are made between 0 month (pre) and 6 months (post) under condition of without girdle, one of the subjects has 26.32% and 20% reductions of the thoracic and lumbar curves respectively. The progression rate could be due to factors such as compliance, growth and curve type which influenced the curve progression of the subjects in this study.

To sum up, the posture correction girdle aims to provide a non-invasive method to control the body posture in order to reduce the possibility of progression of the spinal curve. Patience is needed to see improvement as training of posture needs time. The important thing is that treatment or training should be provided as soon as possible at the right time, i.e. puberty period, as it is more difficult to reverse poor posture or spinal curve deformity if it has already reached a certain level of severity. Although scoliosis is a multi-factorial deformity of the spine that sometimes results due to heredity, waiting to address the issue until it is too advanced is detrimental.

LIST OF PUBLICATIONS

Journal articles

1. **Liu P.Y**., Yip J**.,** Yick K.L., Yuen C.W.M., Ng S.P., Tse C.Y., Law D. (2014) An ergonomic flexible girdle design for preteen and teenage girls with early scoliosis. *Journal of Fiber Bioengineering and Informatics*, 7(2):233-246.

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Patent

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ASIS	Anterior superior iliac spine ……………………………….	69
ATR	Angle of trunk rotation …………………………………….	12
BMI	Body mass index …………………………………………...	53
C7	The 7th spinous process of Cervical Spine …………………	74
CFHD	Center front of the forehead ……………………………….	74
EB	Elastic band ………………………………………………..	89
EVA	ethylene vinyl acetate ……………………………………...	44
FEA	Functional, expressive and aesthetic consumer needs ……..	37
L3	The 3rd spinous process of lumbar spine …………………..	74
L4	The 4th spinous process of lumbar spine …………………..	74
LASI	Left anterior superior iliac spine …………………………..	74
LPSI	Left posterior superior iliac spine ………………………….	74
LSHO	Left acromion ……………………………………………...	74
LSPL	Left inferior angle of scapula ……………………………...	74
LUM	Lumbar ……………………………………………………	123
P & O	prosthetist and orthotist ……………………………………	44
PB	Plastic bone ………………………………………………..	91
PD	Padding ……………………………………………………	53
PN	Powernet …………………………………………………...	89
RASI	Right anterior superior iliac spine …………………………	74
RPSI	Right posterior superior iliac spine ………………………..	74
RSHO	Right acromion …………………………………………….	74
RSPL	Right inferior angle of scapula …………………………….	74
SACR	Sacrum ……………………………………………………..	74
SN	Satinette ……………………………………………………	89
SNCH	Sternal notch ……………………………………………….	74
STRN	Sternum …………………………………………………….	74
T6	The 6th spinous process of thoracic spine ………………….	123
T7	The 7th spinous process of thoracic spine ………………….	74
T8	The 8th spinous process of thoracic spine ………………….	123
T9	The 9th spinous process of thoracic spine ………………….	123
T10	The 10th spinous process of thoracic spine ………………...	123
T11	The 11th spinous process of thoracic spine ………………...	123
T12	The 12th spinous process of thoracic spine ………………...	123
THOR	Thoracic ……………………………………………………	123
TR	Tricot ……………………………………………………….	89
VFS	Velcro tape fastener ………………………………………..	91

CHAPTER 1 - INTRODUCTION

1.1 Background of research

Adolescent Idiopathic Scoliosis (AIS) is a multi-factorial, three-dimensional deformity of the spine that contains lateral curvature and sometimes with trunk rotation. It was found that about 10% of all adolescent have a certain level of spinal curve or deformity after 10 years old (Richards & Vitale 2008). The data obtained from the Department of Health Annual Report showed that there is a growing trend of AIS in Hong Kong (Department of Health Annual Report, 2009/2010). It was mentioned that growth was one of the main causes that affected the progression of spinal curve (Weiss & Goodall 2008) with factors such as developmental destabilization (Goldberg et al. 1997), morphology (LeBlanc et al. 1997), and neuromuscular imbalance (Yamamoto & Yamada 1976). Other risk causes that induced AIS included skeletal immaturity, female gender and large curve magnitude (Reamy & Slakey 2001). The health of patients such as cardiac and pulmonary functions may be affected if their spinal deformity is very serious (Ronald 2003). Hence, the most ideal way is to monitor and control the spinal curvature once the AIS has been found.

In general, patients are suggested to have different types of treatments according to their spine situations and stage of scoliosis, e.g. (1) surgery for patients with spinal curves that are greater than 41 to 50 degrees, (2) bracing for patients with spinal curves between 21 and 40 degrees, and (3) observation with periodical spine re-examination for patients with early scoliosis implying a spinal curve between 6 and 20 degrees (USC Center for Spinal Surgery 2005; Dolan et al. 2007). However, researchers believe that other types of treatments or measures can be provided for adolescents with early scoliosis rather than only observation.

It was indicated that overloaded school bags, poor postural stability control and improper posturing might be the possible factors that further enhance the progression of spinal curves (Chow et al. 2006; Chen et al. 1998; Wong & Wong 2008). As a result, postural controlling and training are considered to be useful in controlling the curve progression of spines during the rapid growth periods. The improvement of the posture or postural alignment for those at risk can be obtained from exercises, physiotherapy, and rehabilitation programs (Weiss & Goodall 2008). “Posture reminders” provided from parents or through training devices for a good posture may also be considered as an acceptable prophylaxis (Wong & Wong 2008). The rationale of posture correction and training is to let patients use their back muscles to keep the spine within the natural curvature. Hence, the corresponding imbalanced posture symptoms may be prevented with awareness of their posture as they may learn good postural habits that can carry over throughout their entire lives (Wong & Wong 2008; Dworkin et al. 1985; Birbaumer et al. 1994).

Although there are different products designed for AIS bracing treatment and posture controlling, there still remain many different concerns, such as the level of comfort, compliance, psychological and health issues etc. Functional garments specially designed for adolescents with early scoliosis are also limited in the market. Therefore, the purpose of this study is to design and develop a posture correction girdle for the preteen and teenage girls aged 10 to 13 who have the early stages of scoliosis. It does not only enhance the physical comfort of patients, but it also considers the psychological comfort and health issues so as to obtain a higher compliance and efficacy rate of the treatment. As a result, the target of posture improvement and spinal curve progression controlling can be achieved. A school-screening program has been carried out to investigate the scoliosis phenomenon of the preteen and teenage girls in Hong Kong by recruiting human subjects for the wear trials. The wear trials have been undertaken to evaluate the effectiveness and practical use of the posture correction girdle mainly by adopting the methods of three-dimensional body scanning, shoulder levelness measurement, three-dimensional motion capture testing (Vicon) and radiographic analysis.

1.2 Problems statement

1) Limited research studies can provide posture control for AIS by using soft girdle

Generally, only observation is suggested for the adolescent with early scoliosis. It is believed that more treatment options should be provided for the adolescent patients and more attention should be paid to them. It is also believed that the number of patients who need surgery throughout the years can be reduced by means of the earlier detection of the spine deformity and treatment in time.

2) Limited products choice in the market and discontented treatment compliance

Bracing and posture correction are important types of treatment for controlling the spinal curve progression in AIS. However, there are two main problems associated with the related bracing treatments and posture corrective garments that influence the treatment efficacy. They are (a) limited product choice and (b) discontented treatment compliance.

a) Limited product choice

There are several types of the related products used for improving posture and controlling spinal curve in the market, e.g. rigid braces and posture corrective garments. However, the corrective mechanisms employed by them are not really fit for the case of early scoliosis. Regarding to the traditional rigid brace treatment, it is mainly used for controlling the spinal curve progression of the patients with the middle stage of scoliosis, i.e. a spinal curves between 21 and 40 degrees. The corrective force employed would be too strong for the patients with early scoliosis, i.e. a spinal curve between 6 and 20 degrees. Although there are few numbers of newer flexible brace products existed in the market, their effectiveness is still controversial. As for the posture corrective garments, most of them are used partly for improving the bad postures such as hunchback and indolent back. As a result, the corrective force employed would be too mild for the patients with early scoliosis. The effective posture correction garments with the specialized design for teenagers are also limited. Therefore, there is an urgent need to specially design and develop a new product, which simultaneously contains the functions of correcting posture and controlling spinal curve progression, for the preteen and teenage girls with early scoliosis.

b) Discontented treatment compliance

The unsatisfactory treatment compliance of the existing products may be due to the garment discomfort, inconvenience induced and aesthetic problems. Rigid brace treatment is taken as an example for explanation. Wearer’s upper torso needs to be compressed tightly by a thick layer of non-breathable plastic material for 23 hours everyday. As a result, skin irritation problem will occur causing discomfort feeling to the wearer. Moreover, the rigid brace nearly applies the entire motion constraint to the upper torso. This may cause inconvenience to the wearer’s daily activities as they cannot bend their body to finish some of the simple tasks, e.g. pick up the things from the floor. The bulkiness of the rigid brace may also give negative image of appearance, and affect the outlook as well as the physical comfort of the wearer. On the other hand, flexible brace treatment available in the market has some disadvantages. For example, the wearer may feel the sensorial discomfort due to the abrasion between the garment and skin. The complicated wearing method and non-detachable garment components may cause inconvenience to the daily activities such as toileting. Some people may feel strange about the asymmetric design of flexible brace and have negative impression on it, thereby reducing the willingness of the patients to undergo the treatment.

The literature has indicated that the compliance of a treatment always affects its efficacy. Therefore, the newly developed product designed for correcting posture and controlling spinal curve progression should consider the above issues and improve the above problems.

1.3 Aim and research objectives

The aim of this study is to design and develop a posture correction girdle for the preteen and teenage girls aged 10 to 13 who have the early stages of scoliosis. This does not only enhance the physical comfort of patients, but it also considers the psychological comfort and health issues, so as to obtain a higher compliance and efficacy rate of the treatment. This also enhances the postural controlling and reduces the possibility of spinal curve progression in scoliosis.

The main research objectives of this study are as follows:

1. To review the strength and weakness of the existing related products, and understand the need, response and behavior of the preteen and teenage girls with early scoliosis, aiming to facilitate the creative exploration step, generate the design ideas and determine the key design criteria for the posture correction girdle.
2. To design and develop an optimal function posture correction girdle for the preteen and teenage girls in the early stage of scoliosis, on the basis of clinical and textile science with a systematic framework, aiming to improve posture, reduce the possibility of spinal curve progression, and satisfy the patients' and psychological needs.

3. To examine the physical properties of the preselected materials used for making the posture correction girdle in order to develop the product with optimal functions and comfort.

4. To conduct a school pre-screening program in order to investigate the scoliosis phenomenon and the spinal posture condition of the preteen and teenage girls in Hong Kong with the recruitment of human subjects who can fulfill the inclusion criteria for wear trial.

5 To undertake wear trials so as to evaluate whether the intended objectives of the posture correction girdle can be achieved, and determine the effectiveness and practical use of the posture correction girdle.

1.4 Project originality and significance

Bracing methods are commonly used in the treatment of scoliosis in order to reduce the possibility of curve progression. The traditional rigid brace treatments are only recommended to the patients with the middle stage of scoliosis, implying the spinal curves between 21 and 40 degrees. For the patients with early scoliosis, i.e. the spinal curves between 6 and 20 degrees, only observation with periodical spine re-examination are recommended to them. It is believed that other types of treatments or measures can also be provided for them rather than only observation. However, the products specially designed and developed for controlling spinal deformity and improving posture of the preteen and teenage girls with early scoliosis are limited. For example, the corrective forces of rigid braces are too harsh for them, while the corrective forces of the primary posture correction garments are too mild for them. Even with the newer flexible braces being invented, their efficacy is still controversial. Besides, the associated problems such as physical and psychological discomfort, inconvenience, aesthetic dissatisfactory and health issues can induce a low rate of patient compliance on the related products like rigid braces, flexible braces and primary posture correction garments. Therefore, the originality of this project is to fill the knowledge gap that exists in the design and development of a suitable product for the preteen and teenage girls with early scoliosis. This does not only provide posture improving and spinal deformity controlling functions with optimal corrective force and mechanism, but it also meliorates the existing problems and concerns that are found from the related products.

The scope of the project includes (1) the preliminary school screening results of the spinal condition of the preteen and teenage girls in Hong Kong, (2) the critical design criteria and features for the posture correction girdle, (3) the physical properties of related fabric materials and accessories, and (4) the employment of the point-pressure system with supportive and compressive forces as an effective way to create corrective forces for improving posture and controlling spinal deformity. This provides useful information for the relative product development, especially in the parts of design criteria determination, material selection and corrective force mechanism employment.

The output of this project can be extended to the development of other posture correction garments or flexible braces, and will advance our knowledge by adding new dimensions to medical clothing for patients. More importantly, the problems and concerns found in the existing related products can be improved by using the newly developed posture correction girdle. Hence, higher compliance and efficacy rate of the treatment can be obtained. Since the style and appearance of the posture correction girdle have been designed with the consideration of the patient’s psychological needs, thus the effect on the patient’s quality of life will be minimized.

1.5 Outline of the report

There are 7 chapters in this report. Chapter 1 covers the background information, concept, rationale, problem statement and objectives of the present study, as well as the project originality and significance. Chapter 2 is the literature review which includes the brief review of scoliosis information and its prevalence in Hong Kong, general treatment types used for scoliosis, associated problems of the existing products for the related treatments, methods adopted for improving posture, researches about the posture correction by interventions on adolescents and research design framework. Chapter 3 describes the thesis research plan and methodology including design and development of posture correction girdle, subject selection, prototype fabrication, clinical trial and evaluation tests. Chapter 4 presents the research results with discussion on the design of posture correction girdle and physical tests of the main materials. Chapter 5 and 6 presents the research results with discussion on subject selection, prototype fabrication, evaluation tests and analysis of wear trial. The last chapter is a general conclusion of the thesis work with suggestions for future research.

CHAPTER - 2 LITERACTURE REVIEW

2.1 Introduction

In this chapter, an overview of scoliosis and different treatment methods is provided. School-screening standard and methods are also reviewed with the prevalence of Adolescent Idiopathic Scoliosis (AIS) in Hong Kong. In addition, the design features, functions, corrective force mechanisms and problems associated with the currently related brace products for treatments and posture correction garments are reviewed. Moreover, psychological concerns for effective scoliosis treatments are also presented in order to understand the need, response and behavior of preteen and teenage girls with early scoliosis. Furthermore, researches about posture correction by interventions on adolescents are reviewed and summarized. Since a systematic design framework is important for researches that are related to product development, thus design process framework and model are also reviewed.

2.2 Brief introduction of scoliosis

2.2.1 Definition and classification of scoliosis

Scoliosis is defined as the 10 degrees or more lateral curvature of spine measured by the Cobb Method based on radiograph (Kane 1997). Idiopathic scoliosis is defined as a structural spinal curve without clear cause (Reamy & Slakey 2001). Adolescent idiopathic scoliosis is defined as the scoliosis occurring to people between 10 years-old and skeletal maturity (Dobbs & Weinstein 1999). It is believed that the rapid growth during the puberty is one of the factors that affect the progression of the curves (Mackenzie 1922; Lonstein & Carlson 1984). This usually occurs to children who are within 10 to 15 years-old (Manuel, Monica and Dino 2010). Since girls with scoliosis tend to progress more often than boys, thus treatments are more needed by the girls than boys (Roach 1999; Pehrsson et al. 1992). A “S” or “C” curve can be found from the spine of scoliosis. If large curves are found on the spine, it will cause uncomforted feeling to the patients.

For the classification of scoliosis, two radiographic scoliosis system including King Classification and Lenke Classification are generally used (Stephens, Daniel & David 2003). In this project, the King Scoliosis Classification has been referenced as it has a higher recommendation level than the Lenke Classification System (Ward et al. 2008).

According to the King Scoliosis Classification System, there were five types of idiopathic scoliosis. The classification was based on the Cobb's Angle as measured by radiographic and the flexibility index was based on the bending radiographs (King et al. 1983). For King Type 1, the S-shaped curve was crossing the midline of the thoracic curve and lumbar curve. When compared, the lumbar curve was larger and more rigid than the thoracic curve with the flexibility index in the bending radiograph being negative. King Type 2 showed that the S-shaped curve was crossing the midline of the thoracic curve and the lumbar curve with the thoracic curve being larger than the lumbar curve. As for King Type 3, the thoracic curve and lumbar curve did not cross the midline. King Type 4 showed a long thoracic curve in which L5 was centered over sacrum but L4 tilted into long thoracic curve. King Type 5 showed a double thoracic curve with T1 being tilted into the convexity of upper curve and the upper curve was on side bending (King et al. 1983). Figure 2.1 shows the five King Types of King Scoliosis Classification (King et al. 1983).

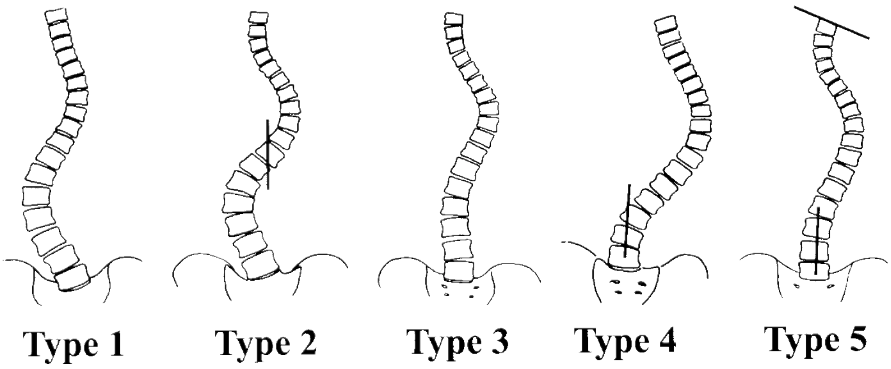


Figure 2.1 The five King Types of King Scoliosis Classification (King et al. 1983)

2.2.2 Identification methods and signs of scoliosis

Sometimes, scoliosis can be noticed easily by the "warning signs" including (1) curved-body, (2) rib prominence at one side, (3) flank prominence at one side, (4) curved head-rib-pelvis line, (5) one side of the pelvis is tilted up, (6) head is not at the direct center above the pelvis, (7) shoulder blade prominence at one side, (8) scapula rotated, and (9) raised and prominent uneven hip (Zaina, Negrini & Atanasio 2009; Bago et al. 2007). Figure 2.2 shows the Walter Reed Visual Assessment Scale for evaluation of the patient with deformity (McCathy 2001). .

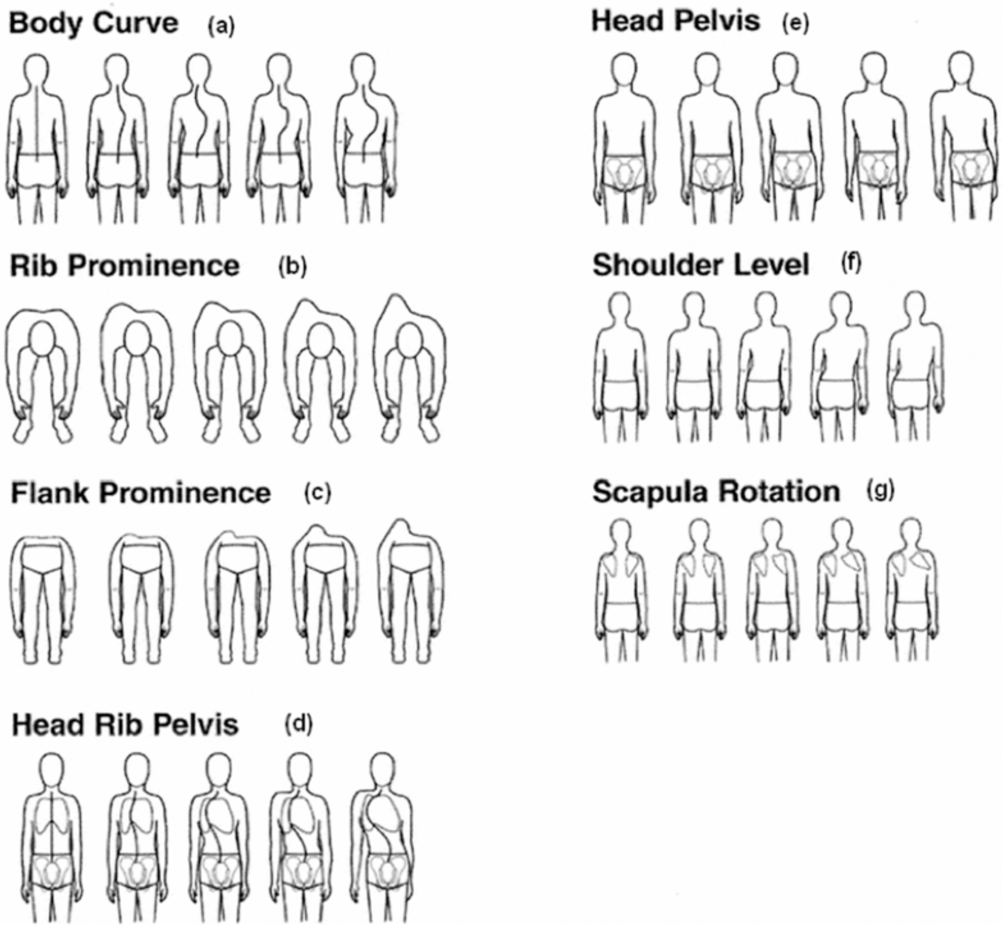
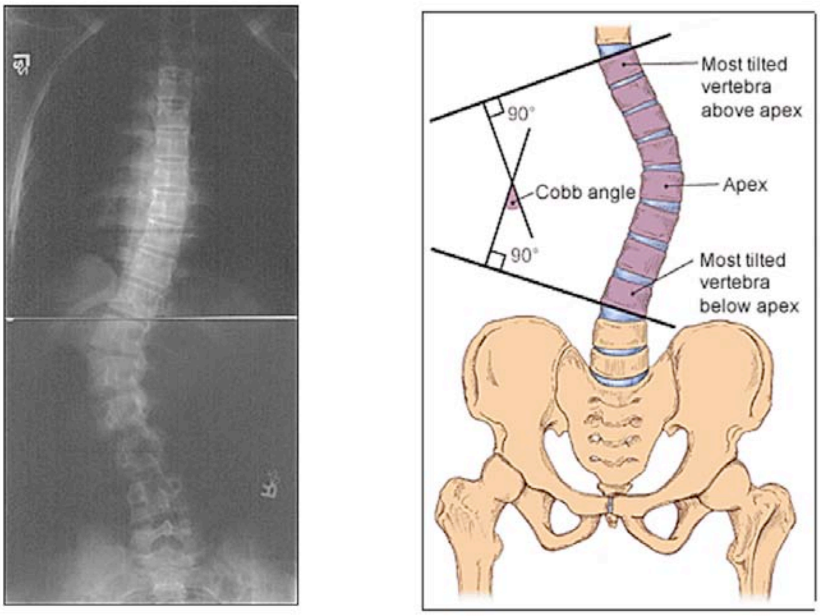


Figure 2.2 The Walter Reed Visual Assessment Scale(McCathy 2001)

More technical and scientific methods used for scoliosis identification including the Adam’s Forward Bending Test (Adams 1882), Natural Bending Test (Scott 2007) and Plumb line test (Neumann 2002, Nordin & Frenkel 2001) can be done by the professionals during body check with the aid of tools like inclinometer (Jonh, Michael & Geald 1984), goniometer and plumb line. The screening tests adopted for scoliosis are mainly used to help notice the potential problem, and they will not present the exact extent of the situation of spinal curve or deformity. Hence, radiographic method will be used once the examiner believes that scoliosis does occur to the patient as X-ray will help obtain a better and clearer look of the spinal situation. The examiner will measure the Cobb’s Angle of the X-ray, which is a method to measure the spinal deformity of coronal plane on antero-posterior plane for determining the type and extent of scoliosis (Cobb 1948; Keynan et al. 2006). Figure 2.3 shows a X-ray sample of a spine with scoliosis and the Cobb's Angle measuring method of a spine with scoliosis (Greiner 2002).



(a) A X-ray sample of a spine with scoliosis:

Posteroanterior radiograph of the spine in a patient with a thoracolumbar spinal curve. Left thoracolumbar curve, T10-L3 (most tilted vertebrae above apex of curve T10, most tilted vertebrae below apex of curve L3). The degree of curvature is 56.

(b) The Cobb's Angle measuring method with a spine with scoliosis:

To use the Cobb method of measuring the degree of scoliosis, choose the most tilted vertebrae above and below the apex of the curve. The angle between intersecting lines drawn perpendicular to the top of the top vertebrae and the bottom of the bottom vertebrae is the Cobb angle.

Figure 2.3 Measuring method of a spine with scoliosis (Greiner 2002)

2.2.3 Prevalence of Asolescent Idiopathic Scoliosis (AIS) in Hong Kong

In Hong Kong, the Department of Health provides the annual comprehensive health assessment for the primary and secondary school students every year through the Student Health Service Centres and Special Assessment Centres. According to the Department of Health Annual Report 2009/2010, the annual comprehensive health assessment was provided for 850,000 primary and secondary school students. There was a total of 737,922 (87.1%) students from 1,233 (98.8%) primary and secondary schools participating in the scheme during the school year 2008/09. Regarding to the results, scoliosis was found as the third most common health problem as shown in

Figure 2.4. It was stated that scoliosis was the most common form of spinal deformity affecting up to 4.5% of the screened population (Department of Health Annual Report, 2009/2010). Moreover, there was an increase of 1.42% in the figure during the period of this ten years time when compared with the figure of 3.08% in 1998/1999. These data showed a growing trend of Adolescent Idiopathic Scoliosis (AIS) in Hong Kong. It was indicated that overloaded school bags and improper posturing might be considered as the possible factors that worsen the spinal deformities. (Wong & Wong 2008; Bessette & Rousseau 2012). It was also mentioned that posture control of the girls with scoliosis was poorer than those girls without scoliosis during backpack carriage in standing posture. (Chow et al. 2006) The girls with scoliosis may have greater risk of fall than those without scoliosis especially with load carriage from the result of compromise in balance that observed in AIS. (Chow et al. 2006). It was believed that the number of patients who needed surgery throughout the years could be reduced by the earlier detection of the spine deformity from the Scoliosis Screening Program (The University of Hong Kong- Faculty of Medicine, 2012).

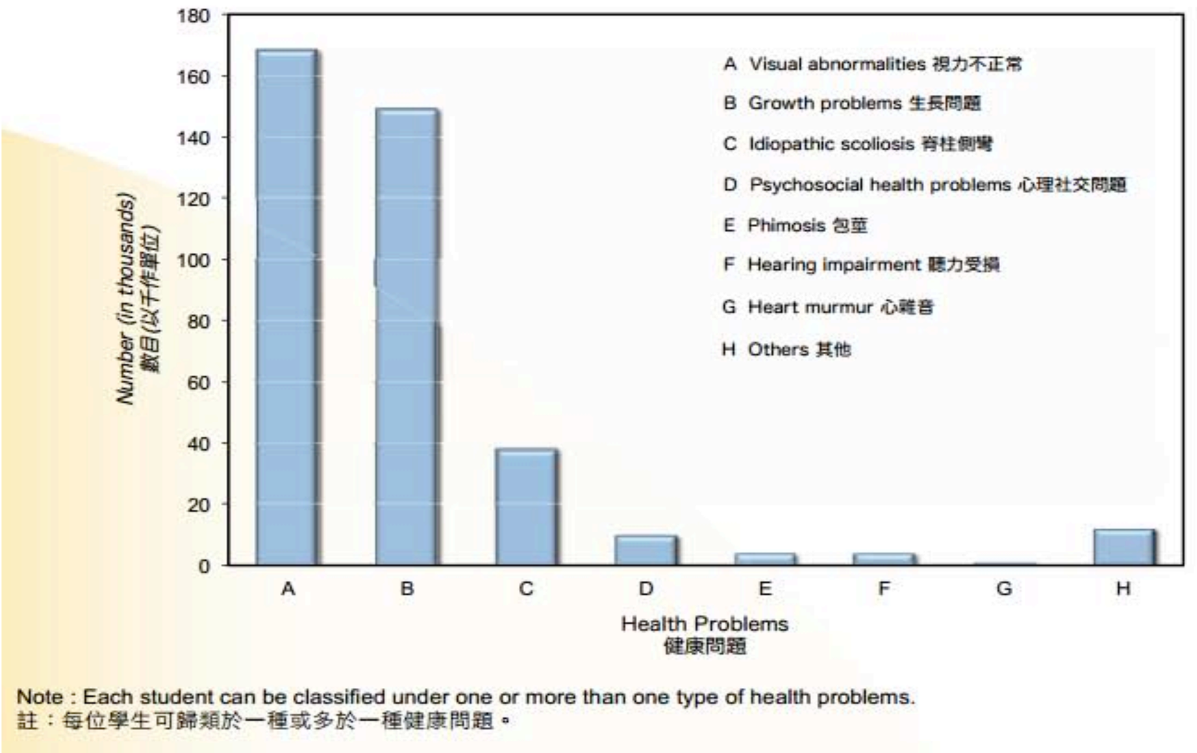


Figure 2.4 Health problems detected at the Student Health Service Centre during the school year of 2008/09 (Department of Health Annual Report, 2009/2010)

2.2.4 School-screening program

2.2.4.1 Protocol of the Hong Kong school-screening program

It was mentioned previsouly that school-screening program was initiated for early detection of adolescent idiopathic scoliosis (AIS) as most of the spinal curves were detectable during adolescence. A study found that there were always over-referral situation in the school-screening programs by referring the student to have follow-up or treatments (Luk et al. 2010). As a matter of fact, it should be provided for those students with more than 20 degrees in Cobb's angle. It was also mentioned that variation of referral processes was likely to occur due to the study design, referral criteria, screening tests used, frequency of screening and duration of follow-up. In addition, it was stated that the protocol of the Hong Kong school-screening program in Figure 2.5 was sensitive and predictive with a low referral rate and was recommended to continue. According to the protocol, the adolescents will perform the forward bending test (FBT) and the angle of trunk rotation (ATR) will be recorded. It was suggested that the organization should provide (1) a biennial screen for those with 0-2 degrees of ATR, (2) yearly screen for those with 3-4 degrees of ATR, more detailed tests including Moiré Topography (MT) test for those with 5-14 degrees of ATR and (4) direct management of spinal deformities obtained from the specialized hospital for those with 15 degrees or above of ATR. This showed that attention was started to pay to the adolescent with the level of 3-4 degrees of ATR, and the attention was increased gradually to the level of 15 degrees or above of ATR (Luk et al. 2010).

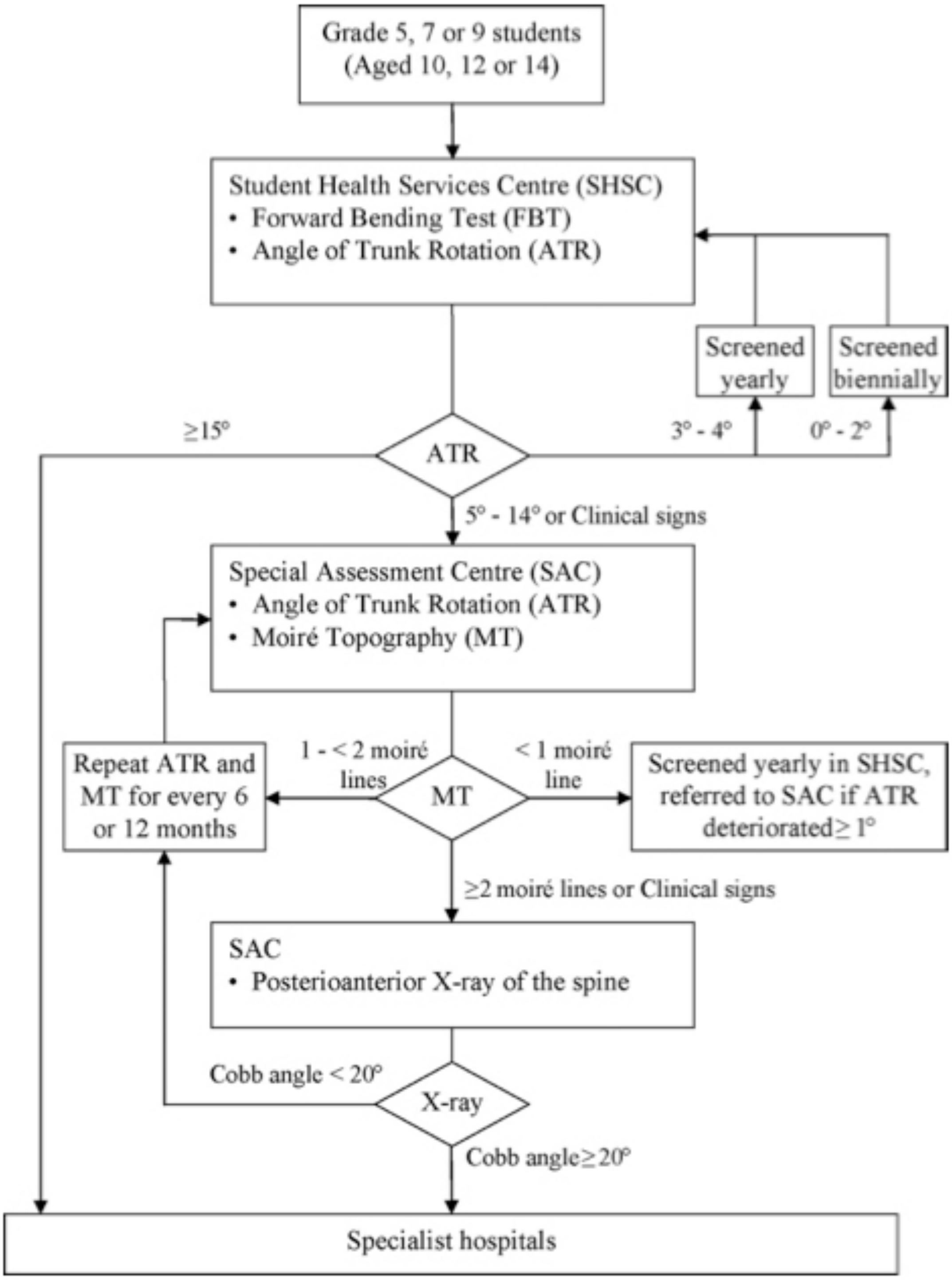


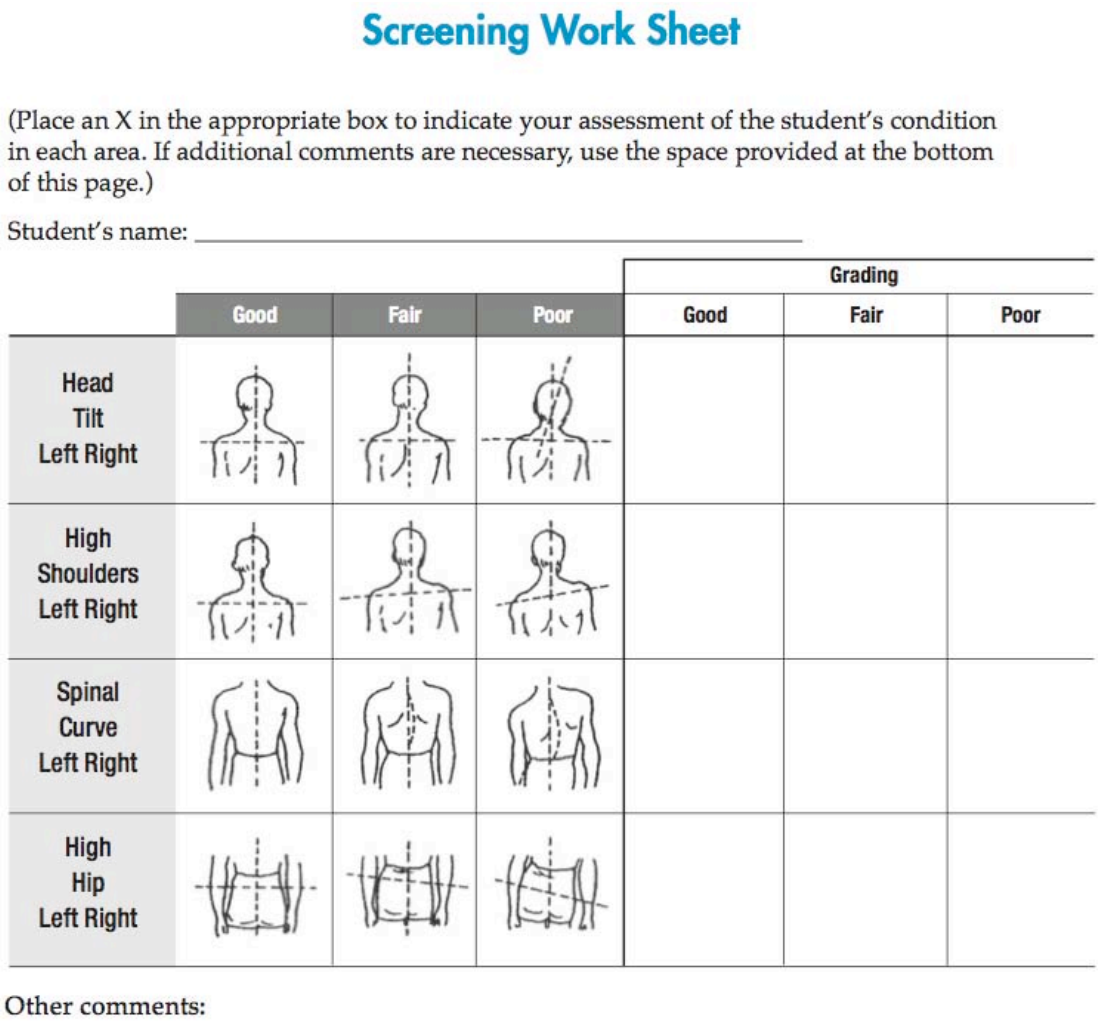
Figure 2.5 Protocol of the Hong Kong school-screening program (Luk et al. 2010)

2.2.4.2 Standards adopted for Scoliosis Screening in California Public Schools

School Screening Program in California Public Schools is aimed at ensuring those who have scoliosis can be identified and referred for medical evaluation before the student has finished growing. The Standards adopted for Scoliosis Screening in California

Public Schools is designed to provide the current best practices for school scoliosis screening. Program implementation, training program standards, screening procedure and checklist for scoliosis screening have been mentioned in the standard (California Department of Education 2007).

It was believed that an education program used for school staff, screeners and students should have an awareness program included in a scoliosis program in order to implement the program. Regarding the training program standards, an in-service training may be conducted by the orthopedic surgeons, physicians, school nurse, physical therapist and chiropractors who have received the specialized training in scoliosis detection. The person administering the program or school staff members should explain the screening procedures, program purpose and preparation of the screening for the students before the actual day of screening day in order to secure the confidence, understanding, cooperation and participation of the students in the screening process. During the screening process, the screening results of standing position (back) and forward bending position (Adams Forward Bend Test) will be assessed and recorded. Figure 2.6 shows the sample of screening work sheet for assessing the standing position (back). After screening, the parental notification should be made. In some cases, rescreening and treatment referral would be provided (California Department of Education 2007).



Screening Work Sheet

(Place an X in the appropriate box to indicate your assessment of the student's condition in each area. If additional comments are necessary, use the space provided at the bottom of this page.)

Student's name: ____________________

	Good	Fair	Poor	Grading Good	Grading Fair	Grading Poor
Head Tilt Left Right						
High Shoulders Left Right						
Spinal Curve Left Right						
High Hip Left Right						

Other comments:

Figure 2.6 Sample of screening work sheet for assessing the standing position of the back view (California Department of Education 2007)

2.3 Tradition treatment for scoliosis

2.3.1 Treatment options

Generally, different treatments are suggested to patients according to the stage of scoliosis with consideration of their spine situation. Surgery is suggested for patients with spinal curves that are greater than 41 to 50 degrees. Bracing is the non-invasive treatment suggested for patients with spinal curves between 21 and 40 degrees. Only observation with periodical spine re-examination is suggested for those with early scoliosis meaning a spinal curve between 6 and 20 degrees (USC Center for Spinal Surgery 2005; Dolan et al. 2007). With regard to bracing treatment, it is believed that if the curvature is detected early while it is still mild, progression may possibly be stopped non-surgically by the use of a scoliosis orthosis (Edmonson & Morris 1977; Blount & Moe 1980). Traditional treatment may also include exercises, physiotherapy and rehabilitation etc. (Weiss & Goodall 2008). However, sometimes only observation is suggested for the adolescent patients with the curve measurement between 20 to 30 degrees, and without any secondary symptoms such as pain. A follow-up examination in six months, one year or two years will be provided depending on the skeletal maturity obtained from the radiographs of the spine and pelvis as assessed by the Risser grading system (Scoliosis Research Society 2012).

<u>Knowledge gap 1:</u>

Generally, only observation is suggested for the adolescent with early scoliosis. It is believed that more treatment options should be provided for them. More attention should be paid to them as the number of patients who need surgery throughout the years can be reduced by the earlier detection of the spine deformity and treatment in time.

2.3.2 Features, functions and corrective mechanisms for bracing products

Bracing is one of the non-surgical treatments for the patients with Adolescent Idiopathic Scoliosis. The basic aim of it is to halt the progression of the curves if they are detected early enough before the skeletal maturity has been reached (Bettijane 1999). It is believed that bracing treatment is medically necessary for three types of patients including (1) those who are still growing with immature skeletal being measured for more than 25 degrees of Cobb's angle; (2) those who have at least two years of growth period left with measurement between 20- 29 degrees of Cobb's angle or a girl, without her first menstrual period being started yet; and (3) those who are still growing with a progressively worsening curve being measured between 20-29 degrees of Cobb's angle (CareAllies 2007).

2.3.2.1 Rigid brace

There are different kinds of rigid brace in the market, with various corrective mechanism and theories in order to reduce the progression of spinal curve. Two types of them will be reviewed in the following.

Thoraco-lumbar-sacral-orthoses (TLSO) brace is one of the most commonly prescribed and used brace. Boston Brace is the most commonly known version as shown in Figure

2.7 (Medical Expo 2013). One of the original brace was invented in the 1970's. Regarding the Boston Brace, it is a plaster cast lined with polyethylene foam materials. It usually contains a back opening that can be extended from shoulder blades to pelvis (Dolan et al. 2007; Wiley et al. 2000; Lonstein 2003). The 3-point pressure system is primarily applied to all TLSO braces in order to make correction of the spinal curve and reduce the curve progression. The plaster cast is tailor-made according to the body shape of each patient. Non-removable internal brace pads are added to the specific points of the brace by the professionals in order to create points of pressure based on the spinal curve of the standing X-ray. Holes are cut to release pressure. The rigid brace also helps to hold the body upright and move it forward in order to obtain better controlling effects (Lonstein 2003; Mac-Thiong et al. 2004).

Cervico-thoraco-lumbo-sacral orthosis (CTLSO) is another common type of rigid brace which is the first modern day brace used to treat spinal deformity. It was also known as Milwaukee Brace as shown in Figure 2.8 (Optec USA 2011). The Milwaukee Brace consists of a plastic pelvic section with an anterior and two posterior uprights being connected to a neck ring with a throat mold anteriorly and occipital pads posteriorly. Plastic contoured low profile neck rings are sometimes applied to the newer designs. Corrective pads are connected directly to the uprights, or suspended from them by the nylon straps (Lonstein 2003). The 3-point force system is also applied in this type of rigid brace. Non- removable pressure pads attached to the metal bars with straps will be placed strategically according to the patient's curve in order to exert additional force to specific point for correcting the spinal deformity. The point that makes this brace different from the Boston Brace is that there is a neck ring helping to keep the head centered over the pelvis and the metal bars help to extend the length of the torso (Lonstein 2003; Mac-Thiong et al. 2004; Wiley et al. 2000).

Figure 2.7 Boston Brace (Medical Expo 2013)

Figure 2.8 Milwaukee Brace (Optec USA 2011)

2.3.2.2 Flexible brace

Apart from the traditioned rigid brace, there are some flexible braces existing in the market although their number is very limited. One of the representative flexible brace used for the patient of scoliosis is called Dynamic SpineCor Brace obtained from The SpineCorporation Limiterd as shown in Figure 2.9 (Ortho-medics 2010). It was introduced in 1993 as a flexible brace for scoliosis treatment (Coillard et al. 2003). It applies to patients who have relatively normal neuromuscular systems. It is a vest-like jacket consisting a pelvic base that is made of three pieces of soft thermo-deformable plastic being stabilized by two thigh bands and two crotch bands, a cotton-made bolero and four corrective elastic bands varying from 0.20 to 1m (Weiss & Weiss, 2005; ScoliCare 2012). All materials used in SpineCor are less than 1.5-mm thick (Hasler, Wietlisbach & Büchler, 2010).

The flexible brace has employed the SpineCor System to do the specific corrective movement of posture and body shape. The theory applied to the SpineCor System is known as Spinal Coupling. It corrects the deformities by reversing the abnormal posture and body shape into their opposite position so that the abnormal alignment of spine can be corrected (Coillard et al. 2003). This controls scoliotic deformities by providing dynamic control to the shoulders, thorax and pelvic girdles in order to limit the adverse movements and modify the 3-dimensional postural geometry while preserving body movement and growth (Corrective Movement© principle) (Wong et al. 2008). As the spinal curves of each patient are different, thus appropriate positions and tensions of the elastics will be placed and adjusted by the professional before the patient wears it.

Figure 2.9 Dynamic SpineCor Brace (Ortho-medics 2010)

2.3.3 Problems of the related products

2.3.3.1 Rigid brace

Health issues caused by the rigid brace treatment are one of the main concerns. During the traditional brace treatment, the wearer may experience physical discomfort. It has been suggested that a patient will need to wear a rigid brace for 23 hours every day. This means that his/her chest wall will bear the weight of the brace, and the brace will press against the abdomen for a lengthy amount of time. Apart from the discomfort and skin irritation, breathing would also be affected (Refsum et al. 1990; Pehresson et al, 2001). It might also further cause sleep disturbance, headaches, nightmares, anxiety and cognitive dysfunction to the wearer (Climent & Sánchez 1999). Furthermore, atrophy of spinal musculature will be caused and the flexibility of spine will also decrease in long-term due to the restricted trunk motion (Berger et al.1983). In some cases, permanent deformation of the ribcage or the soft tissues at pressure points, skin breakdown or allergies and altered gastrointestinal motility are possible to occur due to the constant pressure of the brace (Frontera, Silver & Rizzo, 2008).

With regards to mental health, the rigid brace wearers have a significantly lower mental component of summary scores than the norms of a normal age matched population. Rigid brace, especially the CTLSO type, is often visible under the garment (Bunge et al.

2009). The poor cosmetic appearance is an important problem for the rigid brace treatment (Weiss et al. 2010). Asher and Burton (2006) also found that the self-images of wearers during the rigid brace treatment were negatively affected, and after they finished the treatment, their self-images returned back to normal.

Low compliance is also a concern due to discomfort, unattractive appearance, inconvenience in mobility and psychological effects. Trapping too much heat is one of the main problems as the main body of rigid brace is made of non-breathable plastic (Negrini el al. 2010). The benefits brought about by the rigid brace treatment are reduced when the patients do not follow the wearing instructions and wear the rigid brace for the timeframe that has been suggested (Climent & Sánchez 1999). These results indicate that the wearing compliance of the brace would significantly affect the controlling effect of the treatment.

2.3.3.2 Flexible brace

Dynamic SpineCor brace is a relatively new method used for AIS, but its efficacy is still controversial (Coillard et al. 2003; Weiss 2008). It has been found that the curve progression rate of the group wearing the Dynamic SpineCor Brace is significantly higher than those wearing the rigid brace (Wong et al., 2008). A small number of patients who wore the Dynamic SpineCor Brace even have a spinal curve progression that exceeds those that have been normally found historically (Weiss 2008; Lonstein & Carlson 1984). It is believed that the ineffectiveness of the flexible brace may be caused by the shifting of the elastic bands. The elastic bands present on the brace are not fixed to the wearer's body, and may easily shift to other areas during movement. Hence, the corrective force will no longer be exerted onto the correct position for posture and body shape correction.

Apart from the effectiveness, the acceptance of the Dynamic SpineCor Brace is also one of the concerns due to the issues encountered when going to the bathroom. The results of a study conducted by Wong et al. (2008) showed that there was no difference between wearing the flexible brace and the rigid brace in terms of skin irritation, pressure sores, breathing, sports participation, walking, sleeping and dressing. However, when going to the bathroom, the former was deemed most unacceptable. The difficulties of going to the bathroom while wearing the Dynamic SpineCor Brace may be due to its design since there is a plastic shell at the pelvis level, meaning that the wearer cannot easily bend down.

2.3.4 Comparison of rigid brace and flexible brace

There are rigid brace and flexible brace for the patients to choose for the bracing treatment. These two types of brace have different features, wearing methods, outlook and possible problems. Table 2.1 shows the comparison of rigid brace and flexible brace. Milwaukee brace was chosen as the example of rigid brace, while SpineCor® was chosen as the example of flexible brace in the following comparison.

Table 2.1 Comparison of rigid brace and flexible brace

	Rigid brace : Milwaukee brace	**Soft brace : SpineCor®**
Invention period	- 1940s	- Early 90s
Aims	- To halt the curve progression	- To halt the curve progression
Corrective mechanism	- 3-point pressure system	- Spinal Coupling
Main materials used	- Rigid plastic, metal and paddings	- Soft thermo-deformable plastic, bands, cotton-made bolero and elastic bands
Features	- Rigid and heavy - Plastic pelvic section with an anterior and two posterior uprights being connected to a neck ring with a throat mold anteriorly and occipital pads posteriorly	- Soft and light. - A pelvic base made of three pieces of soft thermo-deformable plastic is stabilized by two thigh bands and two crotch bands, a cotton-made bolero and four corrective elastic bands
Ease of movement	- Hardly move	- More flexible
Ease of Wearing	- Difficult to wear and take off - Self-wearing is impossible	- Easy to wear and take off - Self-wearing is possible
Outlook with clothes	- Bulky, strange and rare	- More natural and invisible
Possible physical and psychological effects/ problems	- Skin irritation, breathing disturbance, atrophy of spinal musculature may be caused - Permanent deformation on the ribcage or the soft tissues may occur in some cases - Hindering of sports participation - Lower self-esteem, more fatigue and lower compliance	- Skin irritation, pressure sores and slightly breathing disturbance - Slight hindering of sports participation - Difficulties during toileting - Less disturbance on self-image, less fatigue and higher compliance - Efficacy is still controversial

2.3.5 Psychological concerns for effective treatments

2.3.5.1 Compliance

Bulkiness of orthosis will distract youngster's appearance and affect their self-esteem especially during the period that they think outward appearance is very important (Dworkin et al. 1985; Fallstrom, Nachemson & Cochran 1984; Myers, Friedman & Weiner 1970; Wickers, Bunch & Barnett 1977). However, cosmetic acceptability is one of the main factors that affect the patient's compliance to the treatment (Wickers et al. 1977). This social stigma may affect some children psychologically as they may think that orthosis is the symbol of dissimilarity. Psychosocial issues including peer pressure at school, social relations and low family support are commonly found from the adolescent patients. It is believed that these issues are always triggered by individual psychological and negative predictive determinants such as lack of vitality, low expectation, anxiety about failure, low self-esteem and poor body image.Hence, compliance behavior is being affected (Lindeman, & Behm 1999; Korovessis et al. 2007; Morton et al. 2008; Tones, Moss & Polly 2006).

2.3.5.2 Behavioral methods used for compliance enhancement

Compliance can be enhanced by physical aesthetics and education aspects. With regard to the physical aesthetics method, scoliosis patient is usually aware of the asymmetries of trunk and wants to improve it. Hence, providing the immediate improvement of physical aesthetics, i.e. trunk remodeling, can help improve the patient's compliance by making them more committed to what he or she is doing (Zaina, Negrini, Fusco & Atanasio 2009). Health provider can also instruct patients to observe themselves in a mirror in order to eliminate the obviously bad posture created by the patient's consciousness (Dworkin et al. 1985). As for the education method, it is important to educate the adolescent patients and their parents about the background of scoliosis including its natural history, the estimated risk of curve progression, consequences and possibilities brought about by scoliosis (Hasler et al. 2010). The patient's involvement is also one of the key factors that affect the success of treatment (Wong et al. 2001). Therefore, questions about the orthosis wearing time should be asked and the importance of compliance should be emphasized at each visit (Hasler et al. 2010). As a result, compliance can hopefully be enhanced with consciousness and conscientiousness.

2.4 Posture correction

2.4.1 Definition of posture

Posture is defined as the orientation or alignment of body segments while maintaining an upright position (Raine & Twomey 1994). The effect of gravity, muscle tension and integrity of the bony structures are the factors that affect body alignment (Raine & Twomey 1994; Newton & Neal 1994). Static posture is defined as the state of muscular and skeletal balance within the body and this creates stability by the orientation of the constituent parts of the body. Dynamic posture is defined as the state such that the segments of the body adopt when undertaking movement (Eston 2008). Ideal alignment in vertical posture is related to the gravity line which is a vertical line that passes through the center of gravity of the body (Eston & Reilly 2008; Penha, Baldini & João 2009). In addition, good posture is a state of muscular and skeletal balance which protects the body structure against injury or progressive deformity and is independent of whether the structure is working or resting (Penha et al. 2005). Poor posture is defined as any prolonged deviation from the "neutral spine" (Wong & Wong 2008; Dworkin et al. 1985, Birbaumer et al. 1994). Spinal deformity modifies the shape of the trunk and changes the relations between body segments (Goldberg et al. 2001; Masso & Gorton 2000; Mubarak et al. 1984; Sakka et al. 1995; Sawatzky, Tredwell & Sanderson 1997; Stokes 1994). Therefore, postural alterations including the orientation of the head, shoulders, scapula, and pelvis in all three planes are commonly found in adolescents with scoliosis, while the rotations of body segments in the horizontal plane are particularly more (LeBlanc 1997).

2.4.2 Methods used for improving posture

The methods used for improving the posture or postural alignment for those at risk include exercises, physiotherapy and rehabilitation programs (Weiss & Goodall 2008). "Reminders" for a good posture may also be an acceptable prophylaxis [8], which can be obtained from parents or training devices. According to the proposed therapeutic approach of posture correction training, the rationale is to train the patients to keep the spine within the natural curvature by using the back muscle. Hence, the corresponding symptoms may be improved and prevented with the awareness of their posture as adolescents may learn good postural habits that can carry over throughout their entire lives (Wong & Wong 2008; Dworkin 1985; Birbaumer 1994).

2.4.3 Posture correction garments

Posture correction garments or posture supporting products are semi-rigid or soft structured as they are aimed at supporting and improving the posture by elastic force. They always contain the design elements of large elastic belts, abdominal binders and back braces etc. Poorer body image is resulted from the rigid brace treatment (Sapountzi-Krepia et al. 2000) and the awareness of keeping good posture is now arising from people even though they do not have spinal deformity problems. These types of supportive garments have a likely achieved marketability due to their flexibility and more acceptable appearance.

2.4.3.1 Features, functions and corrective mechanisms of the related products

Three related products including (1) Babaka U9 Posture Corrective Corset, (2) Women's Posture Corrector and (3) The S3® Scapular Stabilization Brace have been chosen as examples for describing their design elements, materials and corrective force mechanisms. They are popular in the market as they show different corrective mechanisms with design to cover the upper torso rather than only one part of the body.

Babaka U9 Posture Corrective Corset from Babaka is a corset and vest liked garment for improving the wearer's indolent posture of upper torso as shown in Figure 2.10 (Babaka 2011). It is aimed at improving the body alignment, reducing the problem of hunchback, alleviating the pressure at the back, and protecting the waist of the wearer. The whole garment is made of fabric with little pores in order to obtain a high breathability. The main feature of Babaka U9 is that there is a double-Y liked straps design for holding the shoulder to a better position which is fixed by the adjustable Velcro tape design at the front after the straps across the back and the sides of the wearer in opposite direction. Resin bones are also applied to the garment for a better support. The main opening is a pair of adjustable Velcro tape at the front which is used to make the garment fit to different body size. (Babaka 2011)

Figure 2.10 Babaka U9 (Babaka 2011)

Women's Posture Corrector from Underworks® is a vest-liked garment for correcting the wearer's indolent posture of upper torso as shown in Figure 2.11 (Underworks® 2013). It is aimed at keeping the wear's upright and standing tall by pulling the shoulders back with its strong shaped straps, alleviating the stress from the spine and stimulating muscle response for the balanced support of the upper body weight. The whole garment is made of durable Lycra® spandex and nylon fabrics. The double reinforced bands tighten the mid-section of the wearer in order to stimulate the contraction of the abdominal muscles while the metal staying on the back counters the pressure. The tightness of the reinforced bands can be adjusted by the hook and eye front closure by means of three levels (Underworks® 2013).

Figure 2.11 Women's Posture Corrector (Underworks® 2014).

The S3® Scapular Stabilization Brace obtained from AlignMed is a jacket-liked garment with short sleeves used for improving posture, enhancing the muscle strength, facilitating joint motion, reducing pain and increasing range of motion in the shoulder and spine as shown in Figure 2.12 (AlignMed 2013). It has been mentioned that the garment can also help to prevent thoracic osteoporosis, provide pre-rehabilitation and rehabilitation for the shoulder and scapular parts. The garment is made of thin elastic fabric with the moisture management function and Touch-Tension Neuroband™ Technology being applied as well as the aid of strapping to target and re-educate the muscle firing patterns. It provides a full cover for the upper body and contains adjustable elastic straps across the back. It passes through the sides and is finally fixed at the front by Velcro tapes. A zipper acts as the main opening of the garment at the front (AlignMed 2013).

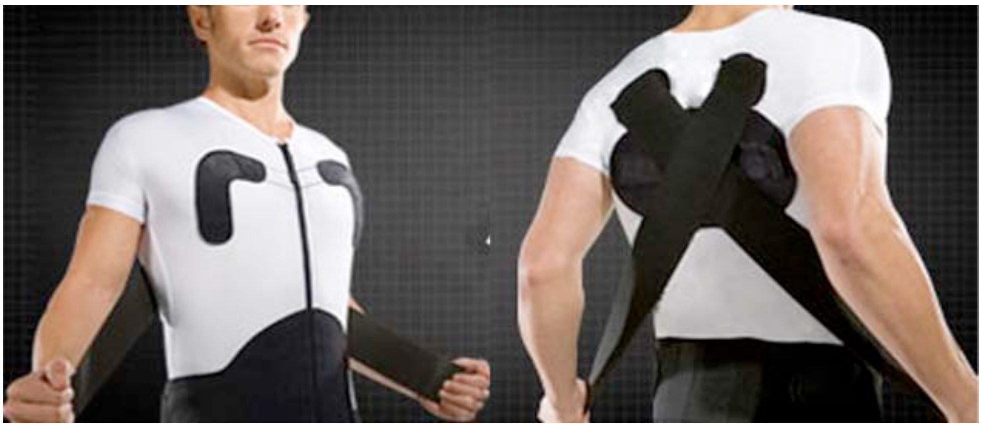


Figure 2.12 The S3® Scapular Stabilization Brace (AlignMed 2013)

2.4.3.2 Problems of the related products

As forthe Babaka U9 Posture Corrective Corset obtained from Babaka, it is commonly believed that the functions of the Babaka U9 are exaggerated (Tainfu Morning Post 2006). The garment may help improve poor posture like hunchback, but does not seem to be able to improve the serious posture problems or spinal deformities. The lack of effectiveness of the Babaka U9 may be due to its design features and the materials applied. In terms of the design features of the Babaka U9, the double-Y shoulder straps are difficult to fit to different body shapes smoothly and closely. Since gaps are always found between the double-Y shoulder straps and the shoulder, especially for the slim wearers, thus this may affect the corrective force exerted to the body. In addition, the resin bones applied to the lower back are not long enough, resulting in inadequate corrective forces exerted by this feature. Moreover, the strength and recovery of the elastic bands and fabrics are found in poor quality (Tainfu Morning Post 2006), which directly affect the corrective force exertion and the life of the product. Furthermore, the length of Babaka U9 is not enough to cover the pelvis for providing a more stable corrective force to the upper body of the wearer.

With regard to the Women's Posture Corrector obtained from Underworks®, the length of the shoulder straps cannot be adjusted. Hence, it is difficult to fit different body shapes closely and affects the corrective forces exerted to the shoulder part. If the shoulder straps are getting looser after repeated wearing of the garment, there will be no way for the wearer to adjust the length of the shoulder straps as to obtain the optimum corrective force. Since the length of the bones at the back only covers the area from shoulder to underbust level, and no bones are found at the lower back or waist, thus the supportive force of the garment is controversial. Furthermore, the length of Women's Posture Corrector is not enough to cover the pelvis to provide more stable corrective force for the upper body of the wearer.

In the case of the S3® Scapular Stabilization Brace obtained from AlignMed, only a visible zipper is found at the main opening without other accessories for tension adjustment of the jacket base. This may affect the fitting of the garment and at the same time there are no means for the wearer to obtain the optimum fit after the garment is getting looser due to repeated wearing. In addition, only one set of Velcro strapping system may not be able to provide enough corrective forces for achieving the mentioned functions. Moreover, a study has found that there are no significant differences in the S3® treatment group as compared to the sham group used for FHRSP or EMG activity in any muscles (Cole 2008). This indicates that the specific strap application might not provide enough force for obtaining the changes and improvements in posture and EMG activity (Cole 2008).

2.4.3.3 Comparison between the related products

There are different types of posture correction garments for people to choose for posture correction or training. Different types of posture correction garments have different functions, corrective mechanisms, design features, wearing methods, outlook and possible problems. Table 2.2 shows the comparison of 3 different types of posture correction garments including Babaka U9, Women's Posture Corrector and The S3®.

Table 2.2 Comparison of Babaka U9, Women's Posture Corrector and The S3®

	Babaka U9	Women's Posture Corrector	The S3®
Brand	- Babaka	Underworks®	- AlignMed
Aims	- To improve the body alignment - To improve hunchback - To alleviate the pressure at the back - To protect the waist	- To keep wear's upright and standing tall - To alleviate the stress from the spine - To stimulate muscle response for balanced support of the upper body weight	- To improve posture - To improve the muscle strength - To facilitate joint motion - To reduce pain - To increase range of motion in the shoulder and spine - Rehabilitation
Corrective mechanism	- Pulling back forces exerted by double-Y liked shoulder straps design - Resin bones supporting	- Pulling the shoulders back with strong shaped straps - Double reinforced bands tighten the mid-section - Metal bones on the back counter the pressure	- Touch-Tension Neuroband™ Technology - Strapping applications
Main materials used	- Stretchable fabric with little pores - Resin bones - Velcro tapes	- Durable Lycra® spandex and nylon fabrics - Metal bones - Hook and eye	- Thin elastic fabric with moisture management function - Velcro tapes - Elastic bands - Visible zipper
Special design features	- Double-Y liked shoulder straps design - Resin bones	- Double reinforced bands - Metal bones	- Touch-Tension Neuroband™ Technology - Strapping applications
Ease of movement	- Flexible	- Flexible	- Flexible
Ease of Wearing	- Easy to wear and take off - Self-wearing is possible - Main opening: Velcro tapes	- Easy to wear and take off - Self-wearing is possible - Main opening: hook and eye	- Easy to wear and take off - Self-wearing is possible - Main opening: visible zipper
Outlook with clothes	- Invisible	- Undetectable under clothing	- Natural and invisible
Possible problems	- Fitting of double-Y shoulder straps - Resin bones are not long enough - Garment do not cover pelvis - Effectiveness exaggerated	- Non-adjustable shoulder straps - Metal bones do not cover the lower back and waist - Garment do not cover pelvis	- Lack of tension adjustment methods for the jacket base - Only one set of Velcro strapping system - No significant difference to prove the specific strap application which can provide enough force to obtain the changes and improvements of posture in a study

Knowledge gap 2a: Limited product choice

Hard brace treatment is too harsh for the adolescent with early scoliosis due to high corrective force which is nearly the constraint for all of the movements.

Flexible brace treatment is an alternative option for the adolescents with early scoliosis. However, its efficacy is still controversial.

The posture correction garments with the specialized design for teenagers are limited and a large part of them can only provide a part of the improvement for the bad postures such as hunchback.

Knowledge gap 2b: Discontented treatment compliance

Hard brace treatment has a low compliance due to the problem of discomfort and psychological issues like rare outlook and bulkiness of it.

Flexible brace treatment has a low compliance due to the problems of discomfort, inconvenience and strange designs.

2.4.4 Summary of researches about posture correction by interventions on adolescents

In order to know more about the researches concerning posture correction by means of interventions on adolescents done in the past, a systematic review of it was carried out. Firstly, the literature was searched from the electronic databases based on the pre-determined keywords related to posture correction by means of interventions on adolescents. Secondly, the abstracts were screened and the irrelevant articles were rejected based on the exclusion criteria. Thirdly, the full articles were retrieved if the abstracts were not rejected. Those articles that did not meet the inclusion criteria were rejected. Finally, the relevant and important studies were included in the review summary (Cook, Mulrow & Haynes 1997).

A broad and thorough literature search obtained from most updated electronic database was performed with a cut-off date of 1 May 2014. The search terms comprehensively covered the following keywords: adolescents, posture correction. Only eligible articles published in English would be analyzed. Most English articles were retrieved from the Google Scholar using university links. Regarding to the selection criteria, original full papers in English on posture correction of adolescents, any time up to 1 May 2014 were included. Letters, comments, narrative reviews, books, patents, animal studies, and unpublished thesis were rejected. The review included the objective studies like experimental and survey types, but rejected the subjective studies like observation and case study types. Adolescent is defined as a person between 10-19 years of age and during the period from puberty to legal adulthood (Canadian Paediatric Society 2003). Therefore, only the relevant publications that contained human subjects within the age range 10-19 ±2 would be considered.

Figure 2.13 outlines the systematic review process of a study attrition diagram. The initial electronic database research identified 117 citations for screening. In these citations, 98 were rejected in the first scan. After screening the abstracts, 5 citations were excluded. Of the remaining 14 articles, 1 did not provide sufficient information for further analysis. Therefore, a total of 13 publications satisfied the selection criteria and were eligible for detailed review.

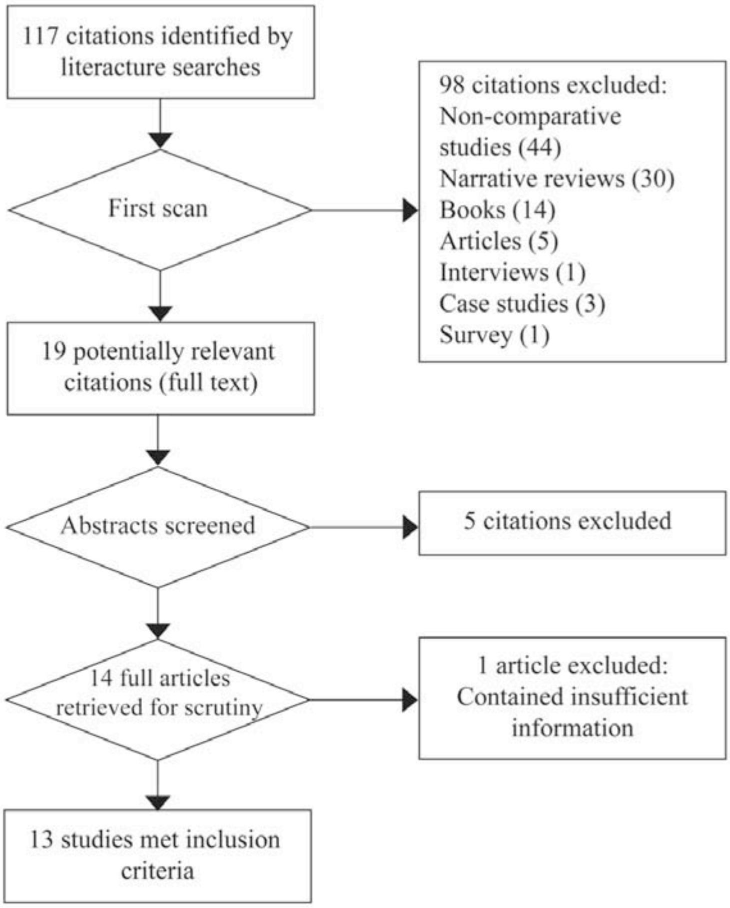


Figure 2.13 Study attrition diagram

The study characteristics were compared by means of publication year, discipline, subject age and type, study position, intervention type, study aim and duration. Table 2.3 shows the summary of researches about the posture correction by means of interventions on adolescents.

According to the table, the numbers of subjects in the studies varied from 4- 334 and half of them contain less than 50 subjects. The number of subject that recruited in the studies might affect by the complexity of the experiment and the prevalence of the target subjects. The study positions of body posture are mostly focused on the spinal regions and the back, in order to evaluate the improvements on posture, musculoskeletal problems and spinal angles. Generally, most of the studies have positive outcomes. In addition, the intervention methods include mostly the exercise or physical therapy, but the studies are seldom intervened by the wearable device like functional garments. Hence, publications concerning the study on posture correction which was intervened by wearable device like functional garments should be encouraged.

Table 2.3 Summary of research about posture correction by interventions on adolescents

Author(s), Year	No. Of subjects	Age	Type of subject(s)	Study position(s)	Intervention(s)	Aim(s)	Result (s)	Duration
Birbaumer et al, 1994	27	6-14	Patients of Scoliosis or Kyphosis	Spinal region	Posture biofeedback; Behavioral treatment developed by Dworkin & Miller; wearing posture training device made of thin nylon cord	To find out effective non-surgical treatment for Scoliosis & Kyphosis patients	With kyphosis patients the PB treatment resulted in rapid straightening of the spine and removal of structural deformities of Scheuermann's disease	4-39 months
Moynahan, 1995	4	17-19	Subjects with spinal cord injury (SCI)	Arms	Establish the arm as a postural limb in subjects; 'personal strategies' for postural control	To examine whether repeatable responses are elicited in the arm muscles of subjects with SCI while standing & performing cued arm raises; to investigate whether the muscle activity results in adequate postural correction as compared to able-bodied standers	The results of the trials establish the arm as an active postural limb for subjects with spinal cord injury who stand with braces or with FNS	2-20 months
Wong et al., 2001	16	9-14	AIS patients with progressing or high-risk curves	Spinal region	Audio-biofeedback device	To investigate the possibility of using learned physiological responses in control of progressive adolescent idiopathic scoliosis (AIS)	69% (or 56% for worst case analysis) of the cases were successfully under control in the first 18 months of application	18 months

(continued)

Author(s), Year	No. Of subjects	Age	Type of subject(s)	Study position(s)	Intervention(s)	Aim(s)	Result (s)	Duration
Białek, M'hango, & Kotwicki, 2007	64	13.9 ± 1.9	Girls with scoliosis (mean Cobb angle 30.6 ± 14.7 degrees, Risser sign median 2.0)	Spinal region	Functional Individual Therapy for Scoliosis (FITS) physiotherapy	To assess angle of trunk rotation (ATR) in primary scoliosis and in secondary curvatures in a cohort of adolescent girls during Functional Individual Therapy for Scoliosis (FITS) physiotherapy	Intensive in-patient FITS physiotherapy reduced primary curve rotation measured in a relaxed posture & PCR angle decreased in actively corrected posture	14 days; 14 girls were followed for 1 year
Robbins, Johnson& Cunliffe, 2009	71	11-12	Secondary school students	Body posture when using computer	Posture training delivered by teachers at school; intervention group also received automated on-screen reminders (posture warnings and tips) on their personal computers	To improve bad posture & reduce Musculoskeletal problems	The overall incidence of musculoskeletal problems in the intervention group showed a greater trend towards reduction, falling significantly from 32.4% to 5.4% compared with the control group	1 week
Raikova, Tahtakov & Chakarov, 2011	1	12	Girl with thoracolumbar scoliosis I-II degree	Back & spinal muscles	Technical device with sound & vibration signal for biofeedback-type pupil teaching of dynamic stereotype for right posture maintenance	To create a dynamic stereotype for correct body position maintenance; to avoid further health problems; to present one simple feedback type technical device for prevention of spinal column disorders (scoliosis); to elaborate a protocol; to test different techniques for EMGs processing and graphical presentation for diagnostic purposes	The device can be used as a simple tool for biofeedback-type pupil teaching of dynamic stereotype for right posture maintenance & the developed software for EMGs processing can be used for tracing the effect of using the device	N/A

(continued)

Author(s), Year	No. Of subjects	Age	Type of subject(s)	Study position(s)	Intervention(s)	Aim(s)	Result (s)	Duration
Hanfy, Awad & Allah, 2012	50	13-18	Girls after puberty complained from postural kyphosis from preparatory and secondary schools	Back & shoulder	Exercise program	To correct female's postural kyphosis after puberty & determine the effect of exercise on postural kyphosis in female after puberty	A statistically highly significant decrease in thoracic kyphotic angle after performing the exercises & it could be concluded that the exercise is very effective in correcting female's postural kyphosis after puberty	6 months
Zouita et al., 2012	100	14-15	Young footballers	Body muscles	Postural muscle strengthening & toning exercise program	To detect possible effects of toning physical performance of young footballers	A statistically significant improvement was found between tests T1 and T2 in the experimental group & compared with the control group	8 weeks
Calvo-Muñoz, Gómez-Conesa & Sánchez-Meca, 2013	334	6-18	Subjects with low back pain which excluded serious spinal patholo- gies or deformities, neurological conditions which alter motor tone	Back	Physical therapy treatments for low back pain with back education	To investigate the effectiveness of the physical therapy treatments for low back pain in children & adolescents.	The average effect size of the treatment groups was statistically & clinically significant, whereas the control groups had negative average effect sizes that were not statistically significant	Average 12 weeks

(continued)

Author(s), Year	No. Of subjects	Age	Type of subject(s)	Study position(s)	Intervention(s)	Aim(s)	Result (s)	Duration
Cheon et al., 2013	16	16.4±1.84	Adolescent students with scoliosis having >10° Cobb's angle but did not need or have surgery & did not have neurological symptoms	Lumbar muscle	Chiropractic & lumbar exercise program	To evaluate the program effect on lumbar muscle strength and Cobb's angle in patients with scoliosis	A positive effect was found on lumbar muscle strength & Cobb's angle in patients with scoliosis after the program & therapy	12 week
Mahnaz & Olena, 2013	52	8	Children with posture violation in the frontal plane and 1st & 2nd Degree Scoliosis	Spine & body	Physical rehabilitation course with application of exercises on restoration of vestibular function	To correct existing posture defect and scoliosis; to increase physical exercise of the school children for improving their physical development	The program containing the methodological & organizational approaches to the scoliosis correction, which takes into account quantitative traits of a posture disorders, contributes to a more effective correction of the body spatial organization & to neutralize the negative impact of school risk factors	80 weeks

(continued)

Author(s), Year	No. Of subjects	Age	Type of subject(s)	Study position(s)	Intervention(s)	Aim(s)	Result (s)	Duration
Mahnaz, 2013	165	6-8	Primary school age children who got the incorrect posture in the frontal plane, and scoliosis in 1st & 2nd degree	Back muscles	Rehabilitation programs for the correction & prevention of scoliosis	To study the effect of physical rehabilitation programs for primary school age children with incorrect posture in the frontal plane	The method have contributed to leveling of the functionality of the back muscles on either side of the spine, which affected the increase in the level of development in main group children	10-15 minutes daily (homework exercises); 2 times per week in school hours for 45 minutes (Therapeutic exercises lesson)
Torlakovic et al., 2014	70	11.9±2.3	Girls in the second phase of intense growth & development	9 variables of the body & an overall posture	Kinesiology treatment	To improve posture & prevent health problems that might arise later in life	The models which complement the experience and practical application of expert health professionals and kinesiology knowledge is a very effective tool for improving posture of girls in the second phase of intensive growth and development	28 weeks

2.5 Research design framework and model

Nowadays, textiles industries increase the use of team format to solve problems and develop the products in more complex way. As a result, a clear outline of work attached to a time-line will make teamwork run smoothly. Hence, two design frameworks including Three-Stage Design Process, Functional, Expressive and Aesthetic Consumer Needs Model (FEA) will be described in the following.

2.5.1 Three-Stage Design Process

Three-stage Design Process was suggested by LaBat and Sokolowsiki in 1999 as shown in Table 2.4. There are three stages in the design process including (1) Problem definition and research; (2) Creative exploration; and (3) Implementation.

Table 2.4 Three-stage Design Process (LaBat & Sokolowsiki 1999)

I. Problem Definition & Research	**II. Creative Exploration**	**III. Implementation**
A. Initial Problem Definition - Client definition	A. Preliminary Ideas - Expansive, all realm of possibilities	A. Production Refinement - Cost to produce - Time to produce - Methods of production - Sales potential
B. Research - User needs (function, aesthetic, economic) - Market (assess current products, competitive analysis, economic conditions)	B. Design Refinement - User constrains (function, aesthetic, economic) - Production Constrains (cost to produce, time to produce, methods of production, sales potential)	B. Phase1: Immediate Production - Changes in product or production that can be accomplished immediately
C. Working Problem Definition - Defined by industry client & university designer - Design criteria established	C. Prototype(s) Development - Meshing design criteria and constraints to develop workable ideas	C. Phase2: Improvement/ Refinement - Further development may be delayed
	D. Evaluation of Prototype - Preliminary: by university designer - Final: by university designer and industry client	

With regarding to the first step related to problem definition and research, the preliminary problem was defined by the target group based on their needs. The design researcher had a further research on the users' needs and characteristics of the current products such as materials, silhouette, posture corrective mechanism or methods, and functions. The design criteria for the new product were then set based on the finding. As for the second step related to creative exploration, the possible preliminary ideas were explored. The design ideas were then refined with the consideration of user's constrains including the functional needs and production methods. The prototypes were further developed and evaluated by the subjects and research team. In the case of the third step related to implementation, the reality production of the product was discussed. The product was finally refined into immediate production and further development of the product would be considered (LaBat & Sokolowsiki 1999).

It is believed that the structured design process framework will enhance the communication and planning of a project between the team and the target subjects or clients. Moreover, effective communication between the team members within the team from different background will help collect the knowledge from different specialized areas affluently. This is good for design and development of a new product or applying the professional knowledge to improve the exiting products. The target subject or clients will also put pressure on the team to present a new product or improve the product to meet the needs and exceed competition (LaBat & Sokolowsiki 1999).

2.5.2 Functional, Expressive and Aesthetic Consumer Needs Model (FEA)

The Functional, Expressive and Aesthetic Consumer Needs Model (FEA) is a user-centred model devised to recognize the clothing needs of the end consumer as shown in Figure 2.14 (Lamd & Kallal 1992). It is aimed at acting as a teaching tool to help student designers to conceptualize the design process originally. It is also applied to the relative areas of functional design research including the hospital gowns (Cho 2006) and sailing apparel (Bye & Hakala 2005).

Figure 2.14 The Functional, Expressive and Aesthetic Consumer Needs Model (Lamd & Kallal 1992)

A previous study has mentioned that congruency with the target customer's culture, i.e. adolescent culture, leads to the success design (Stokes & Black 2012). Functional considerations should include the ability of product to perform the tasks required by the customer. Expressive considerations of a product should include the customer's status and self-image in order to be purchased and worn. Aesthetic considerations should include style and design. It has been found that adolescents with disabilities are concerned with all functional, expressive and aesthetic considerations with a higher number being found in functional considerations (Stokes & Black 2012).

In addition, it has been illustrated that the relationship of body and garment is a complex combination of functional, expressive and aesthetic considerations (Stokes & Black 2012). It is believed that there is a need to expand the role of the relationship of body, garment and near environment, in order to create the successful designs. Hence, a revised FEA model has been developed as shown in Figure 2.15. This revised version emphasizes the interrelationship of functional, expressive and aesthetic considerations when compared with the previous one. The solid lines separating the functional, expressive and aesthetic considerations in the previous version have been replaced by the dotted lines in the revised version (Stokes & Black 2012).

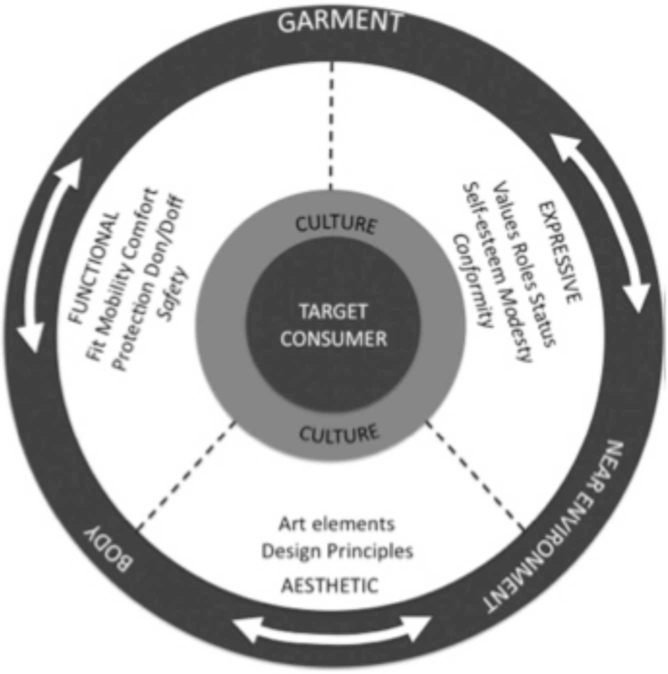


Figure 2.15 Revised version of Functional, Expressive and Aesthetic Consumer Needs Model (Stokes and Black 2012)

2.6 Chapter summary

Adolescent Idiopathic Scoliosis (AIS) is a multi-factorial, three-dimensional deformity of spine and trunk which can appear and sometimes progress during any of the rapid growth periods of the apparently healthy children. It is believed that the rapid growth during the puberty is one of the factors that affect the progression of the. This usually occurs to the children who are within 10 to 15 years-old. Since girls with scoliosis tend to progress more often than boys, thus treatments are more needed by the girls than boys. Scoliosis can be noticed easily by the posture symptoms and identified by the Adam's Forward Bending Test. The screening tests adopted for scoliosis are mainly used for helping the patients to notice the potential problem. School-screening program has been initiated for early detection of AIS as most of the spinal curves are detectable during adolescence. Moreover, there was an increase of 1.42% in the figure during the period of this ten years time when compared with the figure in 1998/1999 from the assessment that provided by Department of Health in the school year 2012/13, which shows a growing trend of AIS in Hong Kong. It was mentioned that heavy school bags and poor posture might be considered as part of factors that induced and worsened the spinal deformities. Moreover, it was believed that the number of patients who needed surgery throughout the years could be reduced by the earlier detection of the spine deformity obtained from the Scoliosis Screening Program and treatments in time, and the attention should be started to pay on the adolescent who have more than 3-4 degrees ATR. The Standards for Scoliosis Screening in California Public Schools is designed to provide current best practices for school scoliosis screening. Hence, this will be referenced for the school-screening program in the present study. Therefore, girls who are age at the range 10-13 with more than 3-4 of degrees of ATR in the school screening program being carried out in the present study will be invited to participate in the radiographic analysis. Once they have the Cobb's angle between 6-20 degrees, they will be invited to be the human subjects for the wear trail after obtaining the informed consents from them and their parents.

Generally, different treatments are suggested to patients according to the stage of scoliosis with consideration of their spine situation. The treatments include surgical, medical and orthotic interventions as well as the and back muscle-strengthening exercises. Mostly, only observation with periodical spine re-examination is suggested for those with early scoliosis, meaning a spinal curve between 6 and 20 degrees. However, researchers believe that other types of treatments or measures can be provided for the adolescents with early scoliosis rather than only observation. Although there are different types of bracing products and posture correction garments in the market, yet the products that are really fit to the case of adolescents with early scoliosis are limited. Rigid brace treatment is too harsh for the adolescent with early scoliosis due to high corrective force which is nearly a constraint for all of their movements. Flexible brace treatment is an alternative option for the adolescents with early scoliosis. However, its efficacy is still controversial. The posture correction garments with the specialized design for teenagers are limited and a large part of them can only provide partly with the improvement of the bad postures such as hunchback. Furthermore, discontented treatment compliance of these products is also induced by the problem of discomfort, inconvenience and psychological issues like rare outlook and bulkiness of it. In order to improve the posture and reduce the possibility of curve progression, there is a need to design and develop a posture correction girdle which is specialized for the adolescents with early scoliosis. In addition, a systematic review of the researches concerning the posture correction by means of interventions has been carried out. The intervention methods include mostly the exercise or physical therapy, but the studies are seldom intervened by the wearable device like functional garments. Hence, publications concerning the study on posture correction, which was intervened by wearable device like functional garments should be encouraged.

As a clear outline of work attached to a time-line will make research run smoothly, thus two design frameworks including Three-Stage Design Process, Functional, Expressive and Aesthetic Consumer Needs Model (FEA) have been reviewed. Regarding to Three-Stage Design Process, three stages including (1) Problem definition and research; (2) Creative exploration; and (3) Implementation, are contained in the design process. It is believed that the structured design process framework will enhance the communication and planning of a project between different parties, which make the tasks and procedures in a project run more efficiently. Regarding to FEA, it is believed that functional, expressive and aesthetic considerations are important to make a successful product that satisfies the customers' needs and meet the functional purpose. Hence, a revised version of FEA has been suggested, which emphasizes the interrelationship of functional, expressive and aesthetic considerations, and expands the role of the relationship of body, garment and near environment. Since a smooth research process with considerable design criteria is a must for a successful study, thus both the Three-Stage Design Process and FEA model will be referenced in the present study.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, the research plan of the present study would be illustrated in the part of overall experiment design. The methods that employed in (1) design and development of the posture correction girdle, (2) subject selection, (3) fabrication of the posture correction girdle, as well as (4) wear trial and evaluation tests would also be descripted.

3.2 Overall experiment design

In this project, within-subject experimental design with 6 months intervention was employed as the research type. Ethic approval was obtained from the Human Ethics Committee of the University. Figure 3.1 shows the research plan of the present study expressed in the form of a flow chart diagram.

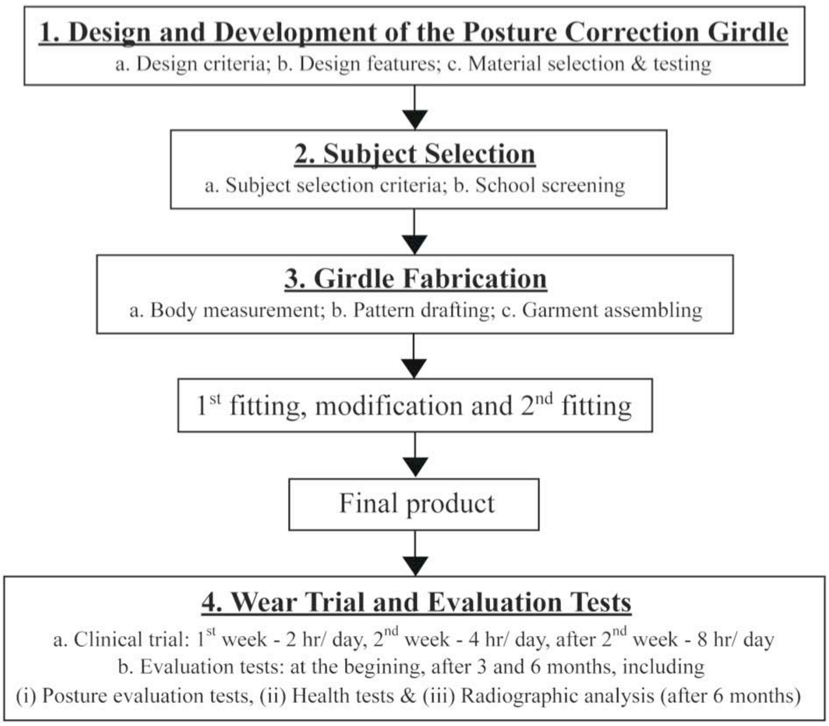


Figure 3.1 Research plan and flow of the present study

According to the studies, problem of AIS is more common on females and usually gets worse during the puberty (Roach 1999; Pehrsson et al. 1992; Mackenzie 1922; Lonstein & Carlson 1984), so female adolescents aged 11-13 that fulfilled the inclusion criteria (see chapter 3.4.1) were recruited as human subject for the wear trial in this project.

With regard to the sample source, the subjects for wear trial were recruited in the school-screening program of the present study and after the doctor consultation. All subjects were assigned into the experimental group. It was indicated that improper posturing might be considered as the possible factors that worsen the spinal deformities. (Wong & Wong 2008; Bessette & Rousseau 2012). Therefore, tailor made vest-liked posture correction girdles were provided to the experimental group as the intervention. The fit checking and placement of padding insertion were approved by professional prosthetist and orthotist (P&O).

In regard to the textiles materials and accessories that needed in the present study for girdle making including: 1. Fabrics with knitted structures and different compositions; 2. Fastening accessories, e.g. elastic bands, zippers, Velcro tapes, etc.; 3. Supporting materials, e.g. EVA foam pads, plastic bone, etc.; 4. Sewing tools. In regard to the equipment and measuring tools that needed in the present study for data collection on posture change including: 1. Scoliometer for ATR measuring; 2. digital Sphygmomanometer, Peal Flow Measure and Touch-Test Sensory Evaluator for health tests; 3. 3D body scanning system with body markers by Human Solutions for 3D body scanning; 4. Tape ruler and setsquare for shoulder levelness measuring; 5. Vicon 612 motion capturing system by Oxford Metrics Ltd and reflective markers for motion capturing.

In order to examine the possible effect of girdling on the posture change of the subjects, measurements of posture change of the intervention group were collected at 3 time points including 0 month (pre-girdling), 3 months and 6 months (post-girdling) in the wear trial for postural change evaluation. Moreover, in order to examine the possible effect of girdling on the change of spinal curves of the subjects, Cobb's angles of the intervention group were measured on the radiographs that took at 0 months (pre-girdling) and 6 months (post girdling) for comparison.

3.3 Design and development of posture correction girdle

3.3.1 Design process framework

In the present study, the design process framework proposed by Labat and Sokoloeski (1999) was referenced as the design process stage framework for the design and development of posture correction girdle. On the other hand, the revised version of FEA model proposed by Stokes and Black (2012) was referenced during the consideration of design criteria. According to the literature review, several adjustments have been made in order to form a more suitable design process framework for the present study. Figure 3.2 shows the framework of Three-Stage Design Process including (1) Problem definition and research, (2) Creative exploration, and (3) Implementation, for the design and development of a posture correction girdle for AIS in this study (Liu et al. 2014).

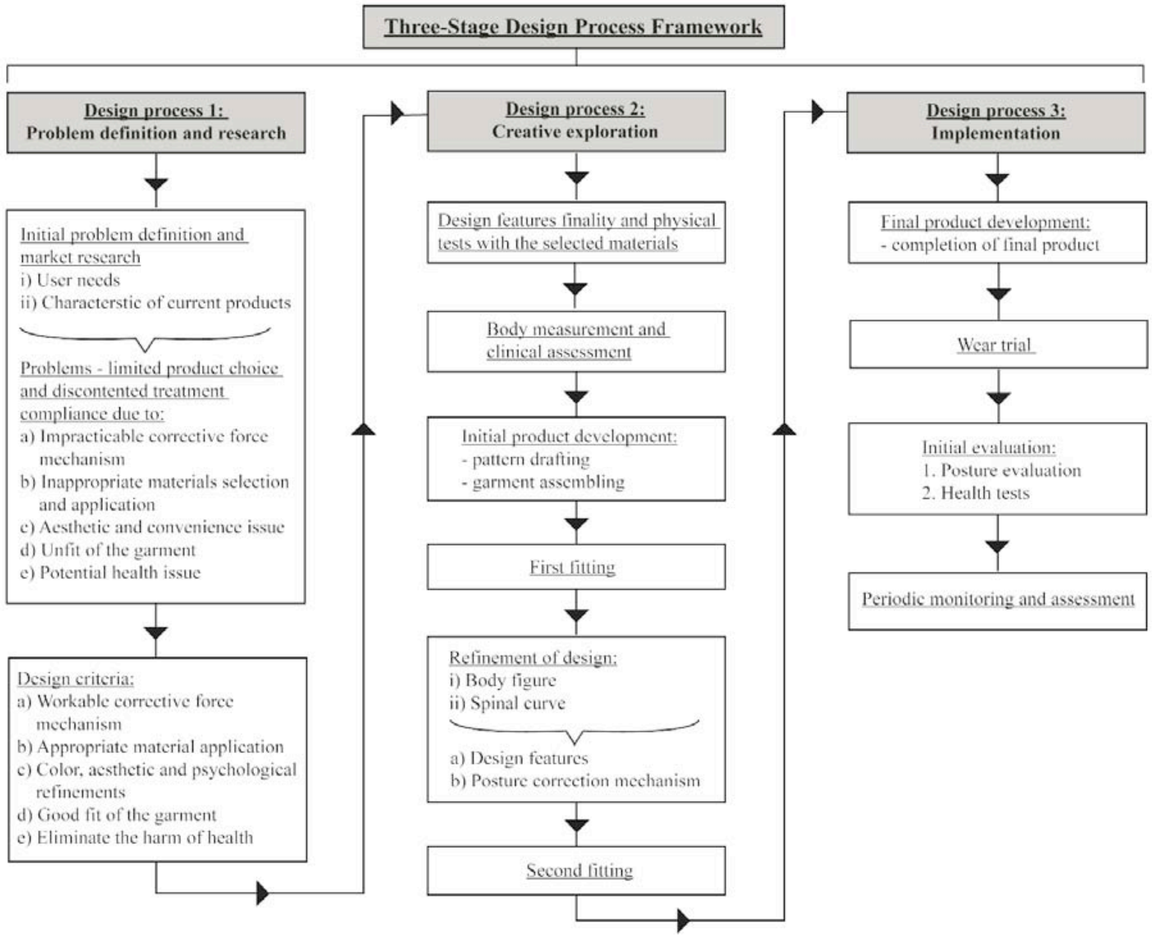


Figure 3.2 Three-Stage Design Process for this present study

3.3.2 Material selection and physical testing

3.3.2.1 Main fabric selection criteria

The selection criteria of materials used for making the posture correction girdle are high strength, high recovery and high breathability.

Warp knit fabric made of synthetic fiber is preferable due to its sustainable rigidity (Ramakrishna 1997), which helps facilitate the corrective function and provide the durability of the garment. Few samples of warp knitted fabrics were pre-selected according to their appearance and stretchability. Several physical tests were performed in order to evaluate their performance and select the most suitable materials for making the girdle.

The outermost fabric forms the basic framework of the garment shape. Since it is necessary to have a smooth surface and better hand feel, thus tricot will be chosen as the shell fabric. Shape retention of the girdle is considered as one of critical element used for posture correction, as the garment shape can restrict the trunk to form a proper shape (Clin et al. 2010). The fabric must be flexible but firm enough to hold the trunk without excessive pressure. Hence, half tricot (stabilizer) and satinette have been chosen as the middle layer of fabric that can sandwich between the shell fabric and lining located at the part of center back and sides accordingly. They are strong enough to stabilize the garment dimension by eliminating the distortion due to fabric stretch so as to facilitate the force exertion and supporting function of the garment. Lining is the inner layer of fabric that will directly contact to body. The lining works as the pockets to insert the semi-rigid paddings for providing corrective forces. With the aid of top-stitching on the lining fabric, a variety size of pockets can be divided. In order to perfectly adapt to the thickness of the inserted padding, elastic fabric with good recovery should be used. With the consideration of improving air permeability, the powernet or mesh with good hand feel has been chosen as the lining fabric. Table 3.1 lists the functions of different main materials used for the posture correction girdle.

Table 3.1 The functions of main fabrics used for the posture correction girdle

Functions	**Fabric Type (structure)**	**Description**
1. Forming the shape of the garment	Tricot (Warp knit)	A basic kind of warp knit fabric popularly used for women's underwear with lightweight and sheer properties. The longer free-floating underlap yarns contribute the pleasant touch and good extensibility of the fabric. The cohesion of the structure decreases the snagging problem of the fabric (Spencer 2001).
2. Stabilization of garment	a) Half Tricot (stabilizer) (Warp knitted)	A simple warp knit structure that contributes a fine and rigid fabric. The filament yarns result in a fine sheer net fabric without elasticity. It has a rather poor cover than the tricot fabric (Spencer 2001).
	b) Satinette (Warp knitted)	A kind of fabric similar to powernet as it also allows two-way stretch with warp direction and performs a slightly higher stretchability. With the pleasant hand feel on the technical back, it is more dimensionally stable than the powernet.

3. Pocket lining for corrective padding	a) Powernet (Warp knitted)	Normally used for foundation garment such as all-in-one and girdle. It is mostly made of nylon or polyester blended with spandex which can perform an excellent elasticity and recovery. It is a two-way stretch fabric with the warp direction being more stretchy.
	b) Mesh (Warp knitted)	A two-way stretch net fabric with lots of mesh openings. Due to the mesh openings structure, the fabric is more lightweight and air permeable than most of the warp knit fabric.

3.2.2.2 Accessories selection criteria

Apart from the main fabrics, accessories such as elastic straps and fastening materials are also needed for girdle making. As the tension of elastic straps is critical for facilitating the exertion of corrective force to improve the improper posture (Périé et al. 2003), thus their properties of them will be examined. Moreover, Schiller et al. (2010) stated the importance of Velcro strap used for fitting of scoliosis brace. In order to obtain the optimum fit of the garment, the Velcro strap should be able to attach the ends of elastic straps so as to adjust the desirable tightness. Since fastening is the closure of the garment, thus the length and size of the fastening should suit the opening part of the garment. It should be durable enough to withstand tensional wear. Table 3.2 lists the function of different accessories used for the posture correction girdle.

Table 3.2 The functions of accessories used for the posture correction girdle

Functions	**Accessories**	**Description**
1) Posture corrective material	a) Elastic strap	A flexible strap is made with elastomeric fiber. Unlike the common elastic straps used in normal girdle. It is wide and able to encircle the body to provide pushing force from padding to spine.
	b) Velcro fastening strap	A hook-and-loop fastener allows repeatedly opening and closing by attaching two surfaces together. Although it does not directly take part in posture correction, it is the device used to hold the elastic band in the corrective position.
	c) Plastic bone	It is made of lightweight and flexible plastic and is popularly used for supporting the shape of a girdle or corset.
2) Fastening	Plastic zipper	A common fastening device is used to attach two edges together by teeth and sliding tab.
3) Comfort enhancement	a) V-fold (fold-over) elastic strap	It is used as edge binding to avoid hem or edge discomfort. It can be applied without seam allowance.
	b) Spacer fabric shoulder pad	A three-dimensional flexible textile structure made by the warp knitting technique. It gives a cushioning effect and good air permeability.

3.3.2.3 Materials conditioning and testing

All the purchased materials obtained from the market were evaluated and tested in order to identify their constructions, densities, weights, fiber contents and thickness. The corrective force adjusted for the posture correction girdle is one of the important factors that used to prevent the progression of spinal curvature. Different physical tests were carried out in order to determine the mechanic properties, comfort and durability. All the materials were store in the standard testing conditions (21± 1°C, 65±1% Relative humidity) for 24 hours before the tests.

With regard to the measurement of the mechanical properties, CRE (constant rate of extension) machine was used for stretch and recovery test. It is able to extend the specimen with a constant load or extend the specimen to specific length by increasing the load (Saville 1999). Comfort properties were investigated by measuring the air permeability and moisture vapor transport, and the dimensional stability was tested by the washing test. Table 3.3 shows a summary of tests performed in the present study.

Table 3.3 Physical and comfort tests conducted on different materials used for the posture correction girdle

		Mechanical Properties		**Comfort Properties**		**Durability**
Material(s)	**Test(s)**	**Strength Test** (BS4952; ASTM D5169-98; ASTM D5170; Chatillon Push/Pull tester)	**Stretch and Recovery Test** (BS4952)	**Air Permeability Test** (KES-F8 Air Permeability Test)	**Moisture Permeability Test** (ASTM E96)	**Washing Test** (AATCC Test Method 135)
1) Fabrics	a) Tricot	✓	✓	✓	✓	✓
	b) Powernet/ Mesh	✓	✓	✓	✓	✓
	d) Satinette	✓	✓	✓	✓	✓
2) Accessories	a) Elastic strap	✓	✓	✓	✓	✓
	b) Velcro fastening strap	✓	X	X	X	✓
	c) Plastic bone	✓	X	X	X	X

3.3.2.3.1 Strength test

Strength is one of the properties related to the resistance to stretching, pulling and compressing forces. Mac-Thiong et al. (2010) mentioned that the mechanical counterforce imposed by the garment could retard the growth of spine curvature. Hence, strength tests were conducted on the materials including the fabrics, elastic bands, Velcro fastening straps and plastic bones.

With regard to the strength test used for fabrics and elastic bands, the BS 4952 standard (Methods of test for Elastic fabrics) was referenced in order to investigate their tensile strength. Fabrics and elastic bands were cut into the size of 5cm in width and 15cm in length respectively for preparation with the actual test length being 10cm. 3 sets of fabric specimens in both of the warp and weft directions, and 3 sets of elastic specimens in the warp direction for each chosen material were fixed separately in a CRE (constant rate of extension) machine, Instron Tesion Tester, with the upper jaw moving at 300mm/min. Elastic bands were tested under a higher force than fabrics as Mac-thiong et al. (2010) had mentioned that the optimal force applied by the strap was around 40N. The force applied and data recorded are shown in Table 3.4.

Table 3.4 Test specification required for fabrics and elastic bands

Material		**Maximum Force Applied**	**Data Recorded at Point of**
1) Fabrics	a) Tricot b) Powernet/ Mesh c) Satinette	10N	2N, 4N, 6N, 8N and 10N
2) Accessories	Elastic bands	40N	5N, 10N, 20N, 30N and 40N

In the case of the strength test used for Velcro fastening straps, the ASTM D5169-98 standard was adopted for examining the shear strength in order to estimate the secure force when the subject wore the posture correction girdle. In this test, 4 pairs of Velcro straps were prepared with 4 inch length and 1 inch width with the closure of loop and hook part for 2 inch in the middle. The actual test length of this test is 3 inch. The specimen was mounted on the clamps of Instron tension tester for extension until it broke. Each specimen was required to complete the same process for 4 times. The results were reported as the mean value of breakage force, which was also the mean of the maximum force applied to all pairs of the Velcro strap.

Moreover, the standard test method ASTM D5170 ("T" method) was also adopted for examining the peel strength of Velcro strap in order to determine the separation force of the straps during the normal wear. In this test, 4 specimens of the chosen material were prepared in the form of 1 inch x 8 inch. The loop and hook part would be engaged by the 4lb flat plate and secured by 5 cycles of back and forth motion generated from 5kg cylindrical roller. The end of the specimen would be separated by hand for 1 inch to create two free ends. The free ends were mounted relatively to the clamps with the separation speed of 300mm/min. The peeling strength was estimated by the mean of the 5 highest values obtained from the stretch-strain curve which was also known as "average of five highest peaks" method.

The strength test used for plastic bones was performed by the Chatillon Push/Pull tester which measured the pushing for bending the elastic bones into a standard angle or depth. This test helped to investigate the bending rigidity of the bones. In the test, the bones were cut in 10cm length and mounted on the clamp. The measurement was shown on the monitor after a metal finger pushed the mounted plastic bone.

The measurement is calculated as,

$$N/mm^2 = \text{Force Applied (N)/area (mm)} \qquad (1)$$

3.3.2.3.2 Stretch and recovery test

The aim of conducting this test is to determine the stretch, growth and recovery properties that posture correction girdle made with the fabric tested may be expected to exhibit during use.

The specimens were prepared in 5cm x10cm testing size. A specific load would be applied to the specimens in the strength test with the standard testing method BS4952. 10N and 40N forces were applied to the fabrics and elastic bands respectively. The length of the specimen was recorded when the load was applied to extend the specimen. After completing two cycles of stretch with respect to specific load, the specimens was then removed from the clamps, and the specimen length was measured immediately after the load was released. The result was achieved by calculating the percent of elongation at extension and after load released in which

% Elongation at Extension = (B-A)/A x 100% (2)

% Elongation after Load Released = (C-A)/A x 100% (3)

where A= initial length,

B= length at extension, and

C= length after load released.

3.3.2.3.3 Air permeability test

Kilinc-Balci (2011) mentioned the significance of air permeability in terms of comfort properties of textile. Hence, air permeability test was conducted on the fabrics and elastic bands as they closely contacted the wearer’s body.

In the test, KES-F8 Air Permeability Tester was used to measure the ability of transferring air from inside to outside of the materials. It calculated the rate of flow air passing through a given area of materials under the standard compressing pressure (Hes & Williams 2011). 5 specimens of 10cm x10cm size tested individually for each chosen material were locked between the pressure chamber and a metal plate. After sending air at a constant flow rate, the airflow resistance value was measured. The test results were expressed as the mean of each type of specimen in kPa. s/m. The larger the number, the higher the ability of fabric to resist the penetration of more air will be. This also means that it has a lower air permeability.

3.3.2.3.4 Moisture permeability test

Moisture permeability is one of the methods used to determine the thermal comfort properties (Kilinc-Balci 2011) as there is a need for evaporating the secreted sweat to the outside environment (Huang & Qian 2008).

Standard test method ASTM E96 was adopted to investigate the performance of transmitting moisture from inside to outside of the materials. 12 small test dishes and 16 large test dishes were prepared for elastic bands and fabrics. Each material was cut in pair. The specimens were prepared by cutting according to the outer rim of the test dish edge. All the test dishes were then filled up with distilled water in 3/4 level with the glue being spread evenly on the edge dish. After labeling all the specimens, they were placed on the top of each test dishes without contacting the water inside. The back side (skin-contact side) of all materials was faced downwards into the water in order to simulate the vapor transfer from skin to environment.

The weight of each test dish together with the specimen was recorded and weighed every 24 hours for 5 days. The change in weight was recorded and plotted on a graph. The mean value of Water Vapor Transmission (WVT) of each specimen was then calculated according to the formula of WVT:

$$WVT = G/tA \qquad (4)$$

where G= weight change in grams

T= time duration when G occurred in hours

A= test area of test dish in m^2

3.3.2.3.5 Washing test

Dimensional change of posture correction girdle is a critical problem as the shape is one of the factors that influences the degree of posture correction (Aubin et al. 1999). Therefore, washing test was performed to observe the dimensional changes of materials after repeated laundering of garment. This is a common practice at home in order to keep hygiene.

AATCC Test Method 135 (Dimensional Changes of Fabrics after Home Laundering) was adopted during the test. 3 specimens of 50cm x 50cm with 25cm bench mark in the weft direction. Another 3 specimens in the warp direction were also prepared for each chosen material. The washing temperature and drying conditions were selected at 41°C for normal washing cycle and tumble drying. The rinsing temperature was set for less than 29°C automatically. 90g of AATCC Standard Detergent 124 were added to the washing machine. The test specimens and adequate dummy pieces used for making 1.8kg load were placed inside the washing machine. After competing the washing procedure, the specimens were removed, separated and dried by tumble-drying machine carefully. The dimensional change after laundering and drying cycle were estimated as follows:

$$\% \text{ Dimensional Change} = (B-A)/A \times 100\% \qquad (5)$$

where A= original dimension of the bench mark

B= dimension of bench mark after laundering

3.3.3 Padding selection and pressure measurement

3.3.3.1 Padding selection criteria

Apart from the main fabrics and accessories, padding also plays an important role in the posture correction function of the girdle by means of pressure exertion (Périé et al. 2003). It was mentioned that a removable polyethylene pad worked as the direct rigid force to reduce the abnormal spine curvature (Clin et al. 2010). It could be flexible, semi-rigid and rigid according to the cell structure. In the present study, padding was used for exerting point-pressure to the specific body. A semi-rigid type padding that provided the satisfied pressure exerting effect and within thickness of 1 cm would be chosen, in order to minimize the thickness and reduce the bulkiness of the girdle after padding insertion. During the padding selection process, apart from the professional opinion obtained from P&O, the opinion obtained from human subject would also be considered due to the consideration of level of comfort.

3.3.3.2 Pressure measurement

Pressures exerted by hard brace and posture correction girdle with or without different padding insertions imposed on human body were measured in order to understand the pressure distribution of them. The Pliance® equipment with 3x3 pressure sensor as shown in Figure 3.3 and the Pliance-x16 Expect SD card System were used to measure and process the data. A 10 years-old female subject with 36.5kg in weight, 142.5cm in height and 17.97 BMI was invited to be the human subject wearing the tailor made hard brace and posture correction girdle with or without different padding insertions during the measurement process. The pressure data were obtained respectively under 6 different scenarios including (1) wearing of a hard brace; (2) wearing of the posture correction girdle without inserted padding; (3) wearing of the posture correction girdle with padding PD1 inserted (thinner and less rigid); (4) wearing of the posture correction girdle with padding PD2 inserted (thinner and more rigid); (5) wearing of the posture correction girdle with padding PD3 inserted (thicker and less rigid); and (6) wearing of the posture correction girdle with padding PD4 inserted (thicker and more rigid).

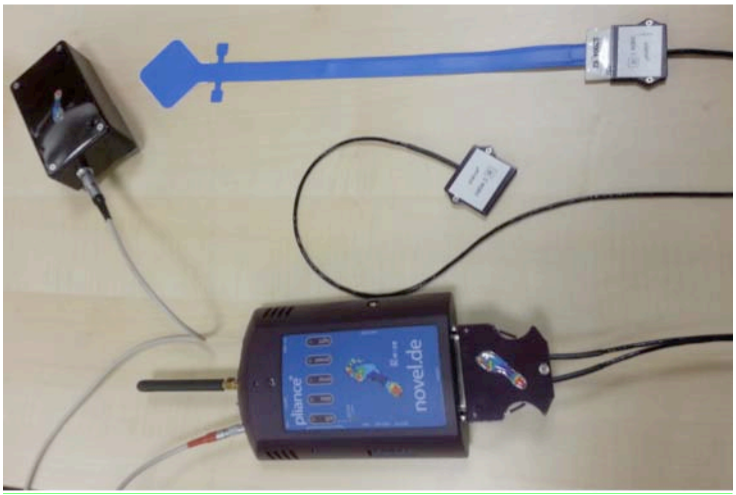


Figure 3.3 Pliance® with 3x3 pressure sensor

Under each scenarios, the subject needed to perform (i) standing, (ii) sitting and (iii) walking tasks during pressure measurement process in order to obtain the data more comprehensively. The subject needed to perform each task for 5 minutes, and the pressure measurement was taken in the middle of the process for 1 minute. The pressure sensors were located at 6 placements that were concentrated along the sides during the measurement process. Since the pressure exerted from the devices were mainly concentrated at these parts, thus the placements of pressure sensor in each scenarios were the same in order to make comparison. Figure 3.4 shows the 6 placement points of the pressure sensor during the measurement process. As for the scenarios of 3-5, paddings were inserted into the girdle at 6 different placements accordingly in order to minimize the “hold-up” effect caused by the paddings at other placements. Furthermore, 30 minutes of adaptation time were given to the subject after putting on the brace or girdle in order to obtain more accurate data. The whole process was done in a relaxed and comfortable environment. The room temperature was controlled at 25°C (±1°C) which was not too hot or cool for the human subject. After obtaining the data, the mean of the data under each scenario of every placement was calculated for comparison. The results obtained were considered as one of the references during the padding selection used for the posture correction girdle.

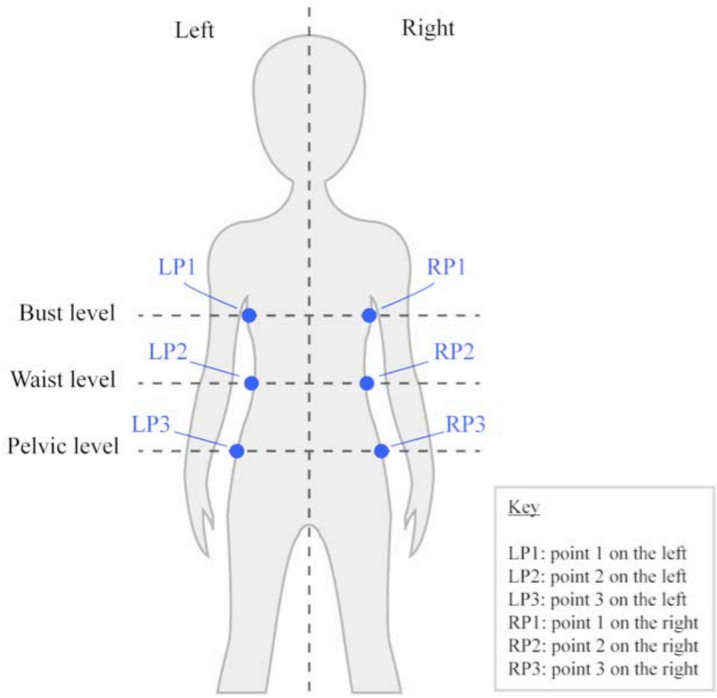


Figure 3.4 The 6 placement points of the pressure sensor during the measurement process

3.4 Subject selection

3.4.1 Inclusion criteria for subject recruitment

Human subjects were selected based on the inclusion criteria. Adolescent was defined as a person of 10 to 19 years of age or during the period from puberty to legal adulthood (Canadian Paediatric Society 2003). Curve progression usually occurs to children who are from 10 to 15 years old due to rapid growth (Manuel, Monica and Dino 2010). In the present study, some female subjects aged 10 to 13 years old were diagnosed as Adolescent Idiopathic Scoliosis (AIS) in the early stage, i.e. their spinal deformities were within the Cobb's angle of 6 to 20 degrees. The Risser grade of the iliac crest should be ≤ 2, implying skeletal immature with a good spinal flexibility and a high risk of spinal curve progression. The subjects should be pre-menarchal or post-menarchal is less than 1 year. Moreover, the subjects should be able to adhere to the girdle protocol both physically and mentally. They should be able to read and speak English or Chinese for effective communication.

All the selected subjects had the consensus to participate in the study as voluntaries. They also agreed that their personal data including all measurements collected and research data could be used for in data analysis and research purpose.

3.4.2 Exclusion criteria for subject recruitment

Any subject who had the history of (1) previous surgical or orthotic treatment for AIS, (2) contraindications for x-ray exposure or pulmonary tests, (3) recent trauma, (4) mental disorder, (5) skin allergy, or (6) fail to compliant to wear the posture correction girdle would not be recruited.

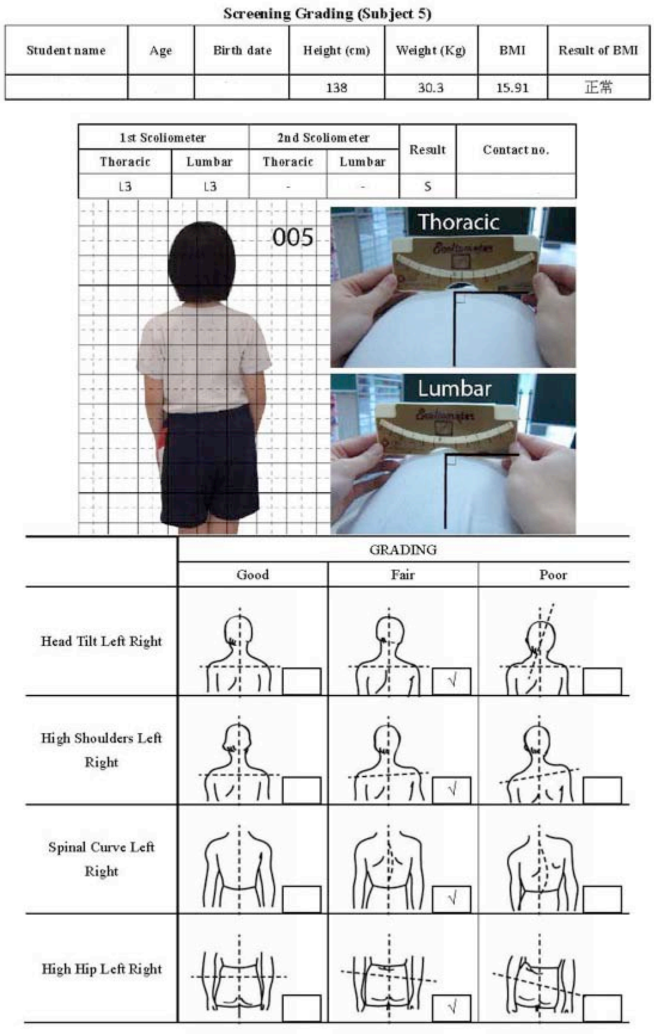
3.4.3 School-screening program

3.4.3.1 Screening method and procedures

School-screenings were carried out in the primary and secondary schools in order to provide a simple spinal examination service for females aged 10 to 13 years old who are interested to participate in the present study. The spinal examination was performed by the professional Prosthetist-Orthotist (P&O) and the well-trained research team. Information sheet of the study was given to them with the written consent forms being obtained from their parents before their participation. Figure 3.5 shows the poster designed for the school-screening program.

Figure 3.5 Poster designed for the school-screening program

The standards used for Scoliosis Screening in California Public Schools (2007) were designed to provide the current best practices for school scoliosis screening. Hence, it was referenced and used for the school-screening program in the present study. During the examination process, the participants were invited to perform the Adam’s forward bending test and the P&O which would measure the angle of the trunk rotation (ATR) with the aid of a scoliometer. It was found that angle of trunk rotation (ATR) which also called angle of trunk inclination (ATI) has sensitivity of 84.37% in the Adams forward-bending test for detecting scoliosis. (Karachalios et al. 1999) It was also mentioned that using inclinometer to measure lateral flexion have satisfied criterion-related validity by comparison with X-ray measurements. (Tyson 2003) Apart from the ATR reading, the participant’s age, body height, weight, photograph image of the back and signs of the poor posture/ scoliosis had also been recorded. Figure 3.6 shows the information and data record form used in the school screening. Figure 3.7 shows the measurement method using a scoliometer in the Adam’s bending test.


Screening Grading (Subject 5)

Student name	Age	Birth date	Height (cm)	Weight (Kg)	BMI	Result of BMI
			138	30.3	15.91	正常

1st Scoliometer		2nd Scoliometer		Result	Contact no.
Thoracic	Lumbar	Thoracic	Lumbar		
L3	L3	-	-	S	

	GRADING		
	Good	Fair	Poor
Head Tilt Left Right		√	
High Shoulders Left Right		√	
Spinal Curve Left Right		√	
High Hip Left Right		√	

Figure 3.6 Information and data record form used for school screening program

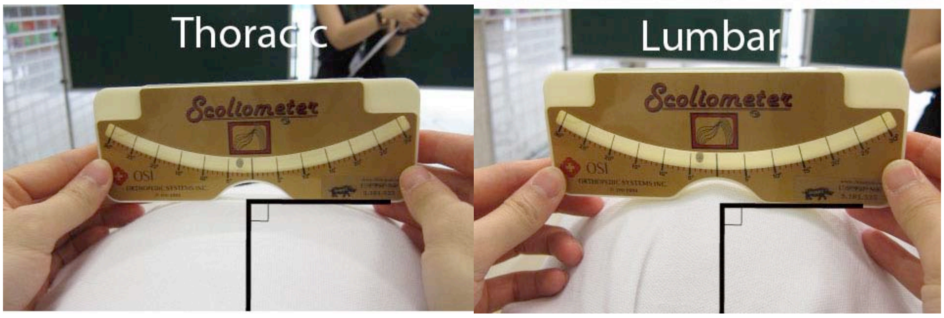


Figure 3.7 Measurement method using a scoliometer in the Adam's bending test

With regard to the photograph taking of the back for each subject, 3 clinical photographs were taken at the back and in the frontal plane. The digital cameras mounted on the tripods and placed at a standard distance of 2 m away from the area where the subject was positioned at a height of 1 m (Akel et al. 2008; Penha, Baldini & João2009). The subjects were requested to stand in front of the sheet of grids (Simetrografo) which containing 5cm X 5cm metric grids with visible plumb lines for reference (Watson & Mac Donncha 2000). 2 markers were stuck at the highest point of the clavicles on both the left and right sides which showing the shoulder elevation of the subject. The subjects were then asked to stand straight with their arms placing by their sides (Akel et al. 2008). In order to minimize the error of data collection, the research team had received a comprehensive training so as to ensure the correct placement of the anatomical markers, positioning of the subject and camera placement (Penha, Baldini & João2009).

It had been indicated that teenagers who had the ATRs of 3°, 4° or above in the screening program needed to be re-screened more frequently and given more attention as an ATR of 3° might be the early sign of the start of scoliosis (Bunnell 1984). Hence, the subjects with an ATR of 3° or above were defined as possible subjects in the present study. After the school-screening program, all the possible subjects were invited to take a radiograph for further evaluation of their spinal conditions. Those possible subjects with the spinal deformity shown in the Cobb's angle of 6 to 20 degrees obtained from the radiographic analysis were defined as the potential subject and recruited as the human subject in the present study if they were willing to participate in the wear trial.

3.5 Fabrication of the posture correction girdle

3.5.1 Key body measurement items and methods

After clinical assessment, the body measurement of the human subjects needs to be obtained before pattern drafting and garment making. As the fit of posture correction girdle is important, 27 body measurement items were identified for making the posture correction girdle as shown in Table 3.5. The measurement methods of these items are shown in Figure 3.8. Direct measurement was performed with a measurement tape.

Table 3.5 Body measurement items

Type	No.	Measurement Items	Remark
Length	1	Center back length	Measure from nape to hip level vertically.
	2	Nape to bust	Measure from nape to bust level vertically.
	3	Nape to underbust	Measure from nape to underbust level vertically.
	4	Nape to waist	Measure from nape to waist level vertically.
	5	Nape to pelvis	Measure from nape to pelvis level vertically.
	6	Center front length	Measure from neck base to hip level vertically.
	7	Shoulder to left scapular	Measure from shoulder seam to scapular level vertically at the back (left side).
	8	Shoulder to right scapular	Measure from shoulder seam to scapular level vertically at the back (right side).
	9	Shoulder to chest	Measure from shoulder seam to chest level vertically in the front.
	10	Shoulder to bust	Measure from shoulder seam to bust level vertically in the front.
	11	Shoulder to underbust	Measure from shoulder seam to underbust level vertically in the front.
	12	Crotch depth	Sit on a firm chair, feet flat on the floor. Measure from waist to chair seat.
	13	Crotch length	Measure from waist in back, through legs to waist in the front.
Girth	14	Chest	Measure chest circumference horizontally.
	15	Bust	Measure bust circumference horizontally.
	16	Underbust	Measure underbust circumference horizontally.
	17	Waist	Measure waist circumference horizontally.
	18	Pelvis	Measure pelvis circumference horizontally.
	19	Hip	Measure hip circumference horizontally.
	20	Thigh	Measure thigh circumference horizontally.
	21	Armhole	Measure around the armhole.
	22	Neck	Measure around the neck base.
Width	23	Neck to shoulder	Measure from neck base to shoulder point.
	24	Across back	Measure directly across the back from left underarm to right underarm horizontally.
	25	Left scapular to right scapular	Measure from left scapular to right scapular horizontally.
	26	Left scapular to center back	Measure from left scapular to center back horizontally.
	27	Right scapular to center back	Measure from right scapular to center back horizontally.

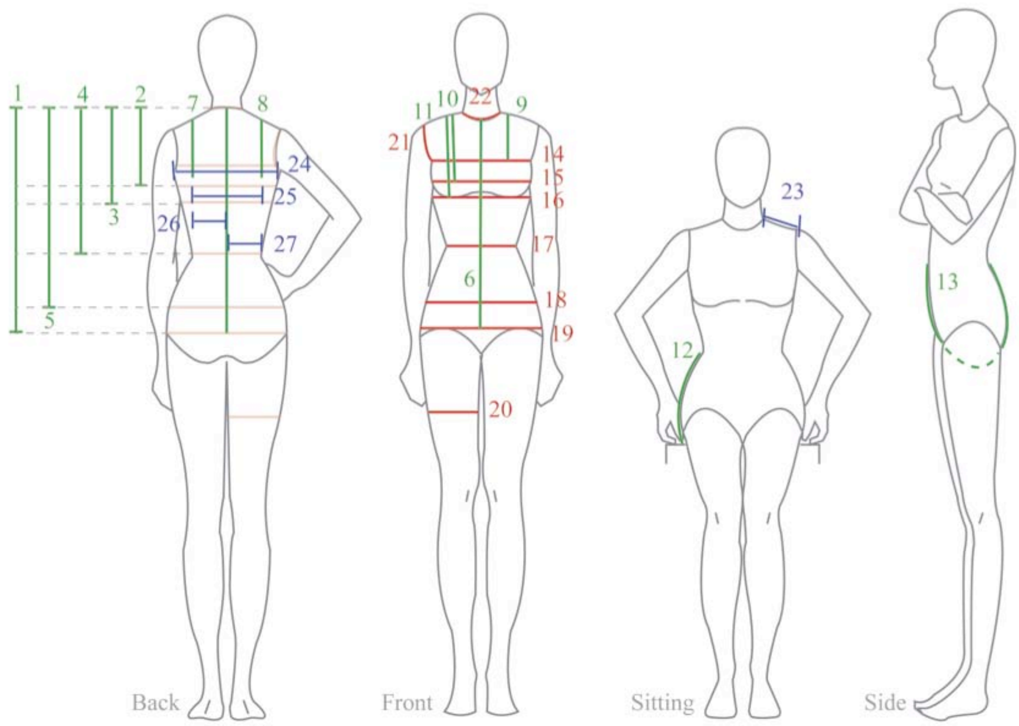


Figure 3.8 Measurement methods

3.5.2 Pattern making

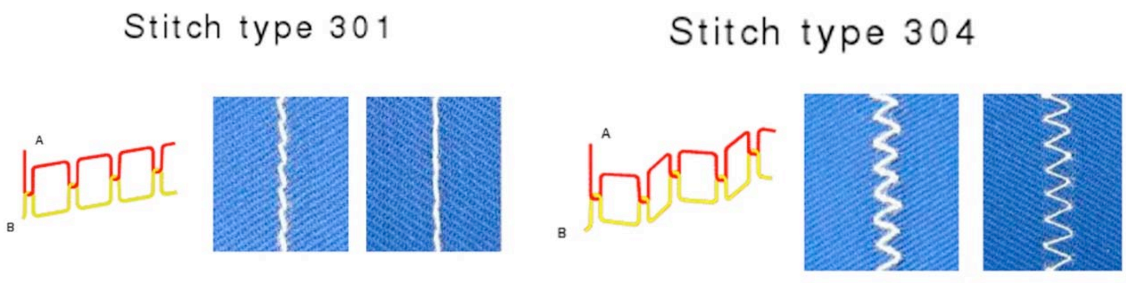
Firstly, the bodice basic block of the subjects was constructed according to the subject' body measurements. After developing the back part, the front part was then developed. The side seams of front and back part should be matched and the darts should be applied to the suitable place with the correct widths. In order to get a close-fit basic block, the original basic block was shaped (Rohr 1967). The straight lines of the darts were curved outward by about 3mm and the extra ease allowances were also trimmed by about 10mm on each side. After the construction of basic block, the style lines were added according to the design and style needs.

In the present project, the fabrics selected for girdle making were stretchable warp knitted fabrics. Hence, the extra ease allowance would be trimmed away according to their elasticity and extensibility properties. This process could help make the posture correction girdle more fit for the subject's body figure, in order to facilitate the supporting and corrective force exerting function of the girdle to the body. Generally, 10-15% of the elastic fabric needed to be trimmed away for the tight-fit garment at the circumference part (Keith 2008). The ease allowance could be trimmed at the side seams, center front and center back. After trimming away the extra ease allowance, style lines of the girdle were marked according to the design and style needs.

3.5.3 Garment assembling

As the posture correction girdle would touch the skin tightly, thus the seam allowance should be minimized to 0.6 cm in order to reduce the bulkiness of the seam and on the other hand reduce the weight of the garment. Moreover, all the seam allowance would be covered and parceled between the shell-support layer and pocket lining layer. As a result, the problems of abrasion and skin irritation induced by the seams protrusion would be reduced.

With regard to the stitch application, two types of stitch including (1) stitch type 301-chain stitch as shown in Figure 3.9a and (2) stitch type 304 - zigzag stitch as shown in Figure 3.9b were applied to the posture correction girdle. Chain stitch was mainly applied to the vertical seam stitching and straps attachment as these parts were not necessary to stretch. On the other hand, zigzag stitch was mainly applied to edge binding and horizontal seam, as these parts were necessary to stretch and it could help to minimize the effect on the material stretch ability.



(a) (b)

Figure 3.9 Stitch type used for the posture correction girdle

3.5.4 The first and second fittings

After the initial product was made, the first fitting session was carried out in order to eliminate the fitting problem that might affect the function of the girdle. The area used for padding insertion was determined by the P&O according to different cases. The second fitting session was then carried out after the garment refinements. Paddings were inserted during this fitting section in order to ensure that there were no problems found from the fit and function of girdle. If no more problems were found from the girdle, final product would be given to the subjects for wear trial.

3.6 Wear trial and evaluation tests

The period of wear trial would be lasted for 6 months for each subject. A clear wearing instruction was given to the subjects before the wear trial. Compliance monitoring was continually implemented throughout the whole wear trial period by using the temperature loggers. The evaluation tests based on the health effects of the posture correction girdle, i.e. performance of heart function test, pulmonary function test and sensory level measurement, would be carried out at the beginning of the wear trial. In addition, the evaluation tests conducted on the function of the posture correction girdle would be carried out at the beginning, after 3 months and at the end (after 6 months) of the treatment. It was performed by different methods including the 3D body scanning, direct measurement of shoulder level from floor, and motion capture (Vicon).

3.6.1 Wearing instruction and compliance monitoring

The period of the wear trial was 6 months for each subject, and the suggested duration of girdle wear for each day was 8 hours. An adaptation period of two weeks was given to the subjects before the wear trial in order to provide enough time for them to get used to their girdle. During the adaptation period, the suggested duration of girdle wear for each day was 2 hours in the first week and 4 hours in the second week. Before the commencement of wear trial, it was necessary to ensure that the subjects understood the wearing method of the girdle and wore it correctly.

Temperature logger (Thermocron) as shown in Figure 3.10 was inserted into the girdle to monitor the wear practice of the subjects. The temperature logger was set to record the data every 5 minutes. 30 °C was chosen as the indicative line of girdle wearing as it was the average normal human skin temperature which would “build-up” gradually due to the protection of clothing by hindering the heat loss (Benedict, Miles & Johnson 1919). Therefore, the temperature higher than 30 °C would be counted as girdle wearing time.

Figure 3.10 Temperature loggers

3.6.2 Health tests

Health tests were carried out at the beginning of the wear trial (0 month) in order to ensure that the posture correction girdle had no health effect on the human subjects. Three health tests including the heart function, pulmonary and touch tests were chosen.

Firstly, the health tests were conducted on the subjects before they wore the posture correction girdle. The subjects were then required to wear the girdles for 2 hours continuously. Subsequently, the health tests were conducted on the subjects again in order to compare the test results of “after wearing the posture correction girdle” with those obtained “before the girdle wear”.

3.6.2.1 Heart function test

Since the posture correction girdle is a type of the compressive garment, thus blood circulation as well as the blood pressure and heart beat rate might be affected. Heat function test was aimed at ensuring no negative effect on the heart function which would be induced by wearing the posture correction girdle. The test was performed by a digital Sphygmomanometer as shown in Figure 3.11 in order to obtain the data of the wearer’s blood pressure and pulse.

Figure 3.11 Digital Sphygmomanometer

During the test, the subject was required to roll up the sleeve of the left hand and the subject's hand should be at the same level of her heart. It was necessary to make sure that the subject was in a relax mode and there was no extra stress on her hands during the testing process. The test was performed three times in order to obtain the reliable data, and the left arm would be given 1 to 2 minutes of relief between each measurement.

3.6.2.2 Pulmonary function tests

Since the posture correction girdle is a type of the compressive garment, thus the rib cage might be compressed and thus the breath ability might be affected. Pulmonary function test was aimed at ensuring no negative effect on the breath capacity which would be induced by wearing the posture correction girdle. The test was performed by a Peak Flow Meter as shown in Figure 3.12 in order to obtain the data of the wearer's Peak Expiration Flow (PEF) in unit of L/min.

Figure 3.12 Peak Flow Meter used to measure Peak Expiration Flow (PEF) in unit of L/min

During the test, the subject was required to take a maximal respiration by using the mouth to surround the mouthpiece of the Peak Flow Meter without gap followed by exhaling with a maximal effort. The test was performed 3 times in order to obtain the reliable data and there would be 1 to 2 minutes break between each measurement.

3.6.2.3 Sensory level measurement

Since the posture correction girdle is a type of the compressive garment, thus the upper torso and underarm would be compressed. This might cause the bad circulation of the hands, resulting in numbness, tingling and prickly feeling which might be induced. Touch test was aimed at ensuring no effect on the sensory level of hands which would be induced by wearing the posture correction girdle. The test was performed by a Touch-Test Sensory Evaluator (North Coast) as shown in Figure 3.13, which contained different evaluator sizes including 2.83, 3.61, 4.31, 4.56 and 6.65.

Figure 3.13 Touch-Test Sensory Evaluator (North Coast)

During the test, subject was required to paste her hands on a stable table surface and cover her eyes by means of an eye mask. The operator then introduced the testing procedures to the subject, i.e. to say “yes” when she feeling the stimulus occurring to the hands. Different sizes of the filament contained in the evaluator were flipped out and pressed on the skin until it bowed at 90 degrees from the finest size to the thickest size. The “pressing” action was held for 1.5 seconds and then removed. The test was performed at (1) the palmar surface, figures and thumb in order to test the median nerve function; (2) the hypothenar and little finger in order to test the ulnar nerve function; and (3) the dorsum in order to test the radial nerve. Figure 3.14 shows different test sites of hand. The operator applied the stimulus using the evaluators with different filament sizes at the same location for 3 times with respect to a response. However, for the filament of 4.31, 4.56 and 6.65, stimulus was applied once only. If the subject had no response to the stimulus, the operator would change the next larger filament to perform the test and this process was repeated until the end.

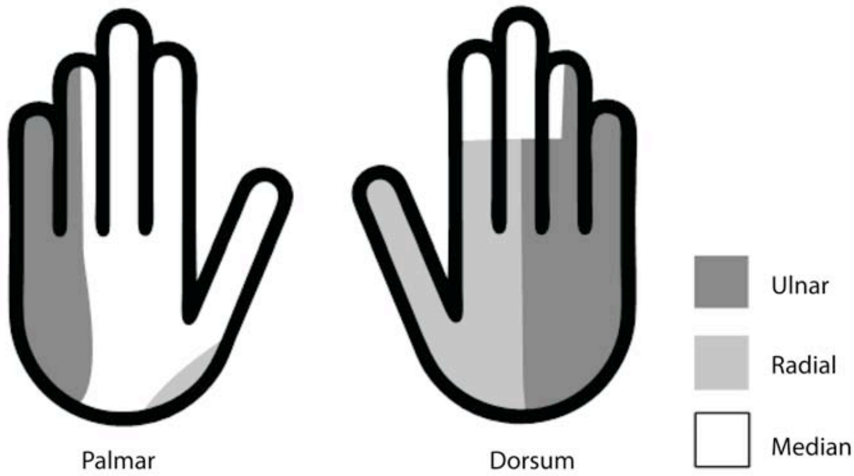


Figure 3.14 Test sites of hand

3.6.3 Evaluation tests of posture change

3.6.3.1 Three dimensional (3D) body scanning

The aim of carrying out the 3D body scanning is to obtain the image of outside surface of the human subjects in order to evaluate the change of body posture from time to time during the period of clinical trial. This method was specially used for evaluating the standing posture, i.e. hunchback, forward or backward tendency and protruding neck etc. The first scanning was done at the beginning (0 month) of the clinical trial. The other scannings were performed after 3 months and at the end (after 6 months) of the clinical trial for each human subject in order to have a fair comparison of their posture change. 3D body scanner is one of the optical systems that have been developed as non-invasive imaging techniques for assessing posture or surface metrics of scoliosis. The angle that measure by this method is a type of deformity indices measured on the transverse plane, and the method is similar to the one that suggested by Jaremko et al. in 2002 which correlated well to the Cobb angle in 88% of cases.

3.6.3.1.1 Method of scanning

In the present project, the 3D body scanning sessions were performed by the 3D body scanner using the Anthroscan System developed by Human Solutions and installed at The Hong Kong Polytechnic University as shown in Figure 3.15. The whole 3D body scanning system was composed of a dark area surrounded by curtain with the laser scanners being linked to a computer. The body scanner's optical triangulation process conducted by the Human Solutions is currently one of the most accurate methods of measurement in the world. It enables the contact-free and fully-automated acquisition of more than 140 body dimensions with an exact three-dimensional image of the human body. The scan time per person from head to foot lasts for less than 10 seconds (Human Solutions 2014).

Figure 3.15 3D body scanner with Anthroscan System

With regard to the scanning procedure, a simple calibration was done before the scanning. In order to obtain a better scanning image, the subjects were generally required to wear the close-fitted thin clothing with shorts in plain light color (Cynthia and Hwang 2001). Moreover, the subject's hair should be tied up in order to avoid the problem of scanning interference, i.e. neck covered by hair. In the present study, both the 3D body images related to the subject wearing and without wearing the posture correction girdle were captured every time for record and comparison. Firstly, the 3D body image of the subject wearing close-fitted thin clothing but without wearing the girdle was captured. The subject was then requested to wear the posture correction girdle directly on top of the thin clothing for 2 hour in order to get used to it. The 3D body image of the subject wearing the girdle was also captured after the adaptation time.

During the scanning process, the female subject should stand straightly without any stress. Her feet should step apart according to the footprint indication shown on the floor. She should hold her hands straightly away from the body at both sides, and her head should uplift a bit with the eye level parallel to the floor. Markers were stuck on the subject's body, i.e. the left and right acromion, as well as the left and right pelvis (ASIS), in order to locate the reference points for evaluation. Once the subject was standby, the operator who stood besides the scanner would start the scanning process through the software installed in the computer. The scanning process was performed twice to reduce the risk of data missing. For a successful scan, the body segmentation, the silhouette of the body shape, and a full image of the outside surface of the human subjects were thus generated by the processed cloud points as showed in Figure 3.16.

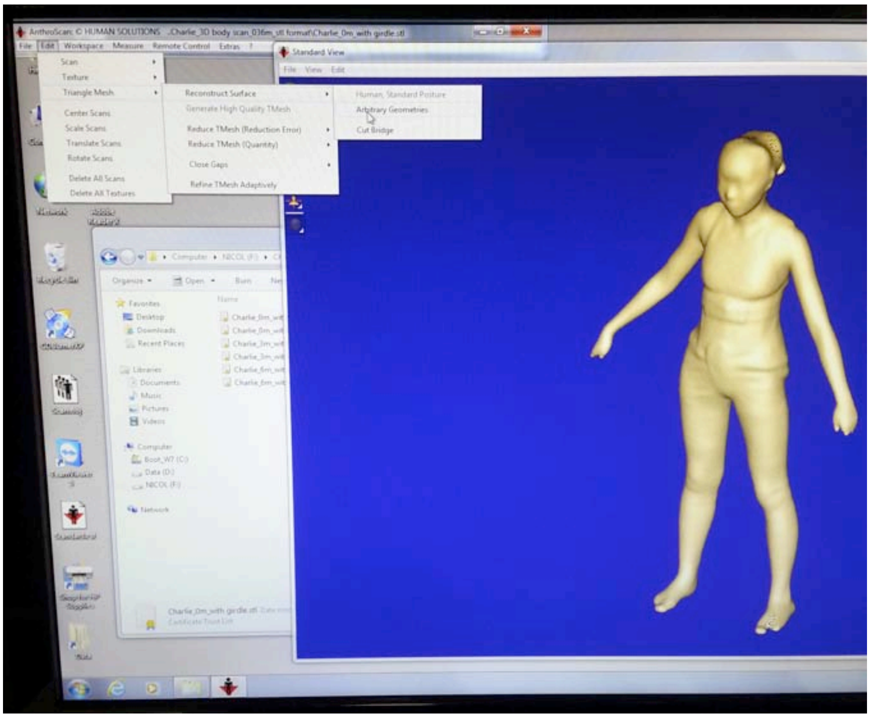


Figure 3.16 Successful scanned output

The data obtained from the 3D body scanning were processed by using the software including MatLab 2013a and Window Excel 2007. In the analysis, the absolute angle of the rotation between shoulder and pelvis levels in the horizontal plane during standing was considered and used to describe the change of rotation of shoulder and pelvis rotation against to the body center line.

3.6.3.2 Direct measurement - shoulder levelness from the floor

Uneven shoulder is one of the signs of scoliosis and it may be caused by poor posture. The balance of shoulder could be indicated by the measurement of the left and right shoulder levels from the floor. It was mentioned that direct methods such as measuring the distance between bony landmarks with specific devices or tape measurement have been used to assess the resting position of the head, shoulder, pelvic and scapula postures or positions. (Fortin et al. 2011) Some studies used tape ruler to measure the distance from a point to floor to assess the posture which have good reliability, for example, measure the iliac spines to the floor (Gajdosik et al. 1985) and pelvic to a wooden base on floor (Alviso et al. 1988).

3.6.3.2.1 Measurement method

During the shoulder level measurement process, the subject should stand straightly without any stress alone the wall. Her feet should step apart according to the footprint indication shown on the floor, and her head should uplift a bit with the eye level parallel to the floor. Shoulder level from the floor meant that the shoulder height from the floor was measured by a tape ruler. Figure 3.17 shows the shoulder height measurement method and also the method of finding the shoulder height differences.

In the analysis, the measurements of the differences between the shoulder levels of the left and right from the floor during standing was considered and used to describe the change of shoulder balance in the frontal plane.

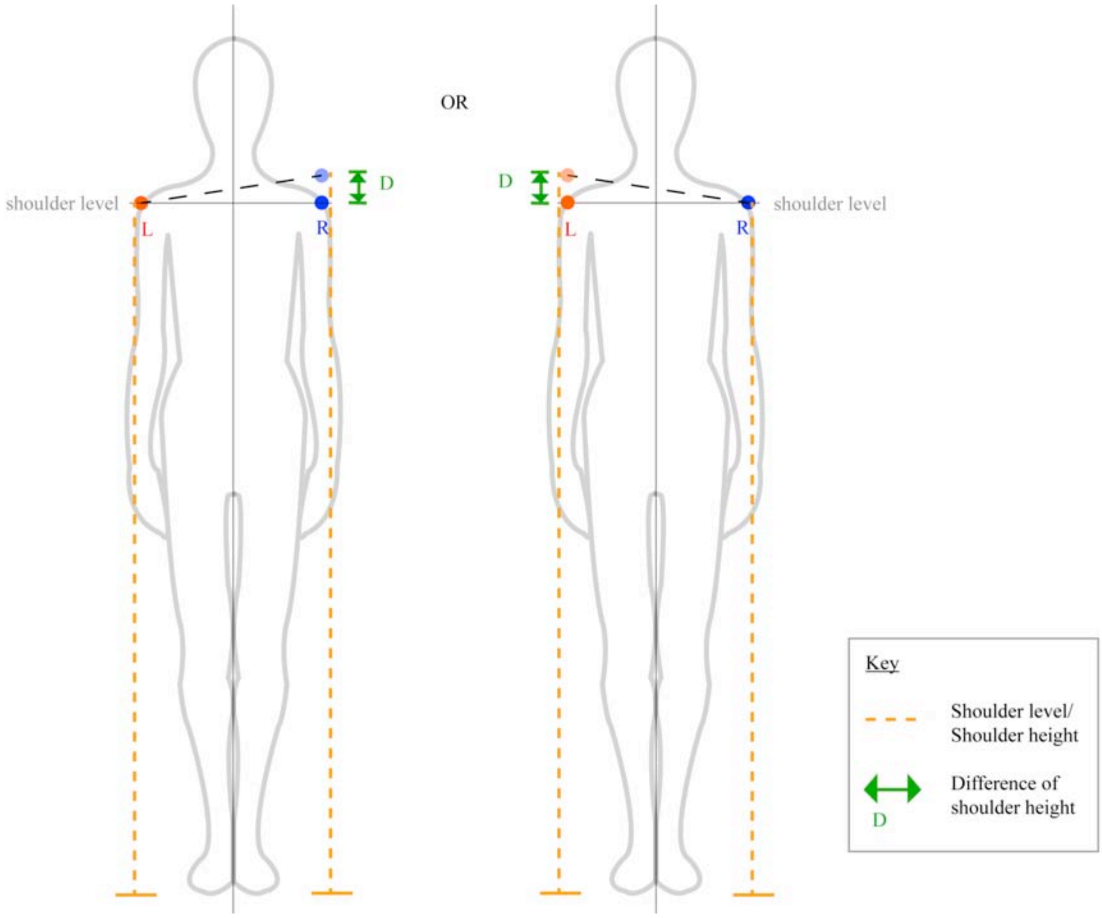


Figure 3.17 The measurement method of left and right shoulder levels from floor

3.6.3.3 Motion capturing System (Vicon)

The aim of carrying out the motion capture is to obtain the data of a series of movement in dynamic and static phases of posture with and without the presence of posture correction girdle. 3D posture analysis systems such as Vicon are commonly used to quantitatively assess posture. (Fortin et al. 2011). Motion capture sessions in the present project were performed by the 3D optoelectronic motion capture system, Vicon 612 (Oxford Metrics Ltd, Oxford, UK) installed at The Hong Kong Polytechnic. The system contains a data-station, six wall-mounted video cameras equipped with infrared sources, and a workstation PC. Figure 3.18 shows the setting of the motion capture system. The infrared light-emitting diodes of each camera have a flash rate in 60 Hz, and the system can obtain the 3D co-ordinates generated from each marker by means of the 3D reconstruction method.

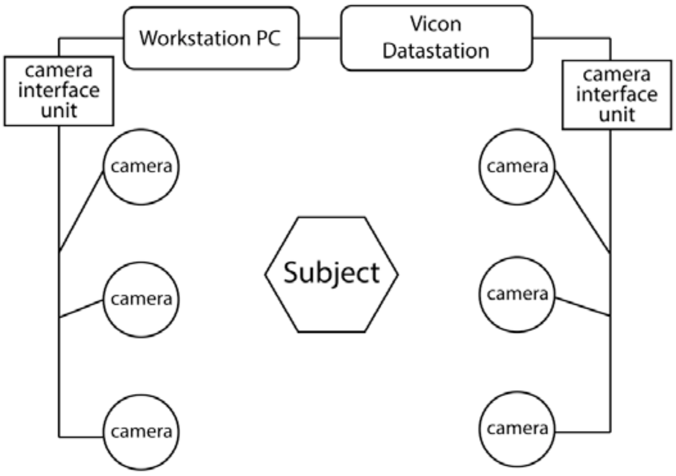


Figure 3.18 Setting of the motion capture system

With regard to the procedure, Figure 3.19 shows a flow chart of the motion capture sessions in the present study. The whole process was done in a relaxed and comfortable environment. The room temperature was controlled in 25°C (±1°C) which was not too hot or too cool for human subject.

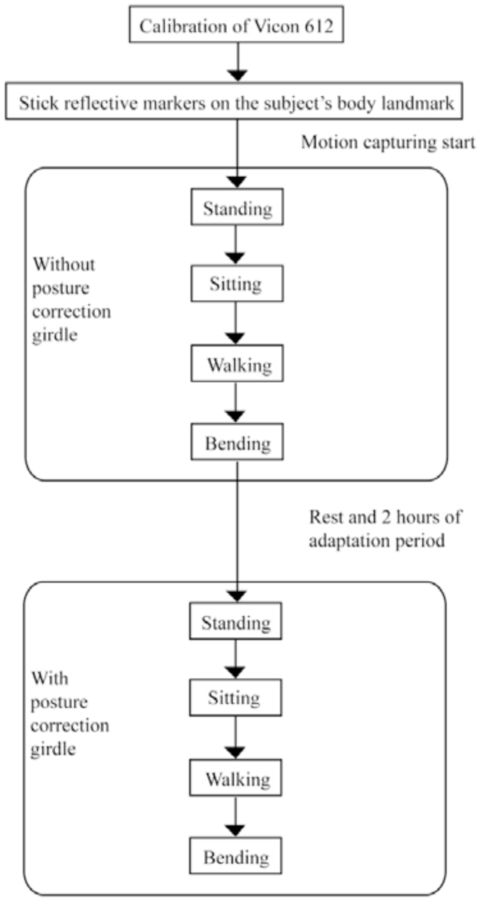


Figure 3.19 Flow chart of the motion capture session

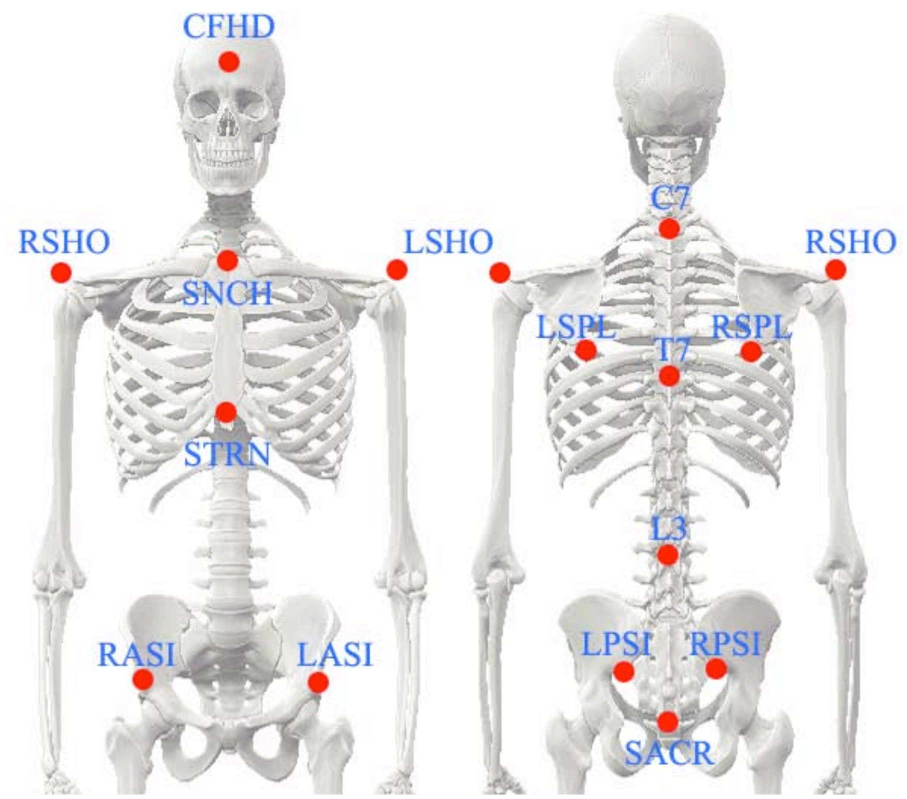
Calibration was done before the motion capturing in order to find out the desirable position and orientation of six cameras with respect to the origin and different set of axes. As for the static calibration, it was performed by the clinical L-frame that was fitted to the marked area on the floor within the desirable position and direction. 4 pieces of 25mm reflective markers were mounted on the L-frame separated with a known distance and height. X-axis was determined as the medial-lateral direction, while y-axis was determined as the anterior-posterior direction and z-axis was determined as the vertical direction. In the case of dynamic calibration, it was performed by a wand, which contained 2 spherical retro-reflective markers with a distance of 500mm. The wand was randomly swept inside the whole motion capturing volume with the captured separation distance being checked regularly to ensure the capturing accuracy.

The subjects were required to wear thin bra tops and tight fitting shorts during the motion capturing process in order to obtain the results more accurately. After the calibration and before the commencement of capturing, the landmarks were marked on the body of the subjects using a washable marker. Totally, 16 reflective markers were placed on the body of the subjects according to the specific landmarks. The reflective marker on the left arm acted as the reference point which provided a easy location of the body direction in the software program. The other 15 locations of the reflective markers are shown in Table 3.6 with their abbreviations. To ensure the accuracy of data, the holes with a diameter of 2cm were cut from the clothing including the posture corrective girdles worn by the subjects during the motion capturing process in accordance with the 15 body landmarks as shown in Table 3.6. Hence, the reflective markers could be directly placed on the skin so as to eliminate the error induced by the shifts of clothing. It was proved that there was almost no difference in the posture correcting effectiveness of the girdle between those with the holes cut and those with no holes through the preliminary motion capturing test.

The data obtained from the 3D motion capture were processed by using the BodyBuilder software and Window Excel 2007.

Table 3.6 Location of reflective markers

Location of Markers with Respect to Skeleton



Anatomical region	Location	Abbreviation
Head (1 marker)	- Center front of the forehead	CFHD
Neck (1 marker)	- Sternal notch	SNCH
Bust (1 marker)	- Sternum	STRN
Shoulder (2 markers)	- Left acromion	LSHO
	- Right acromion	RSHO
Spine (4 markers)	- The 7th spinous process of cervical	C7
	- The 7th spinous process of thoracic spine	T7
	- The 3rd spinous process of lumbar spine	L3
	- Between two posterior superior iliac spines (Sacrum)	SACR
Pelvis (4 markers)	- Left anterior superior iliac spine	LASI
	- Right anterior superior iliac spine	RASI
	- Left posterior superior iliac spine	LPSI
	- Right posterior superior iliac spine	RPSI
Scapula (2 markers)	- Left inferior angle of scapula	LSPL
	- Right inferior angle of scapula	RSPL

In the present study, both the static and dynamic phases of posture were evaluated (Eston& Reilly 2008). During the motion capturing process, a series of tasks including: 1) standing, 2) walking, 3) sitting and 4) bending that were designed in accordance with the daily life activities were performed by the subjects (as shown in Figure 3.20).

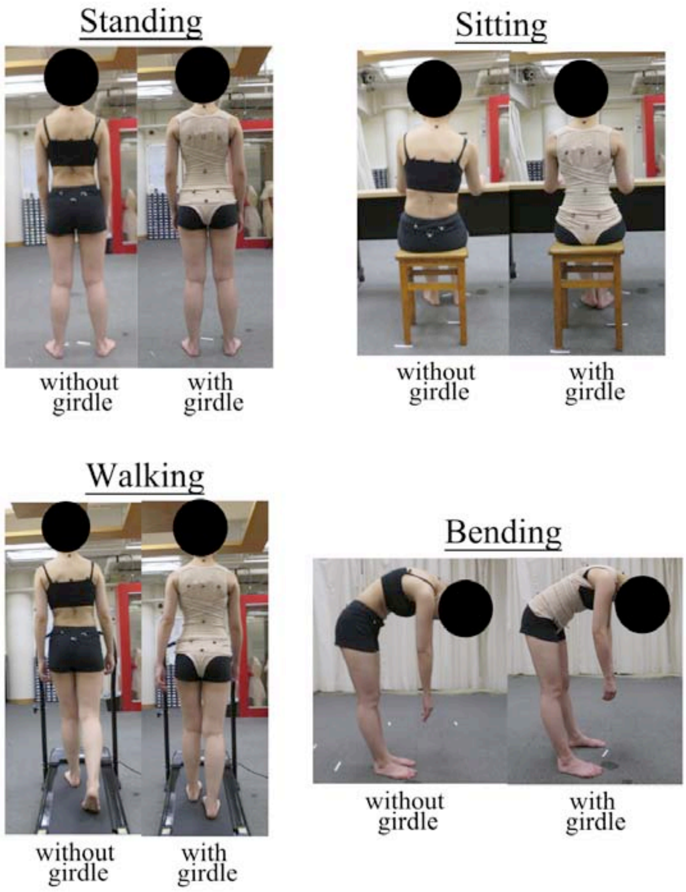
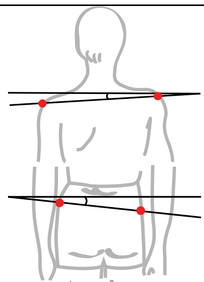
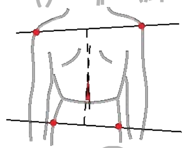
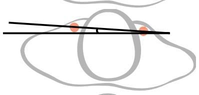
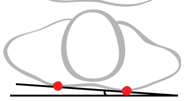
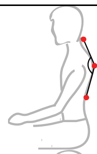
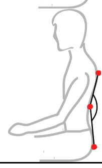
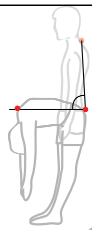
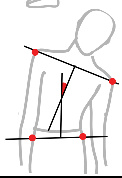


Figure 3.20 Different postures of the subject with or without the posture correction girdle during the tasks

The subjects were required to carry out each task 3 times with or without the presence of posture correction girdle. After finishing the capturing of the part without girdle and before commencing the capturing of the part with girdle, 2 hours of break was given to the subject in order to provide sufficient time for the subject to get used to the girdle. Digital camera was used to record different postures for reference. The room temperature was controlled at 25°C (±1°C) which was not too hot or too cold for the participants. After collecting the data, the posture parameters as shown in Table 3.7 were analyzed.

Table 3.7 Posture parameters analyzed in study

Activity	Plane	Measure		Marker	Reference
Standing	Frontal	1	Acromion (°)	LSHO, RSHO	
		2	Pelvis (°)	LASI, RASI	
		3	Acromion/pelvis (°)	LSHO, RSHO, LASI, RASI	
	Horizontal	4	Acromion (°)	LSHO, RSHO, SNCH, C7	
		5	Pelvis (°)	LASI, RASI, SNCH, C7	
		6	Scapula (°)	LSPL, RSPL, SNCH, C7	
		7	Scapula/Acromion (°)	LSPL, RSPL ,LSHO, RSHO	\
		8	Acromion/Pevis (°)	LSHO, RSHO, LASI, RASI,	\
Sitting	Sagittal	9	Thoracic Angle (°)	C7, T7, L4, SACR	
		10	Lumbar Angle (°)	C7, T7, L4, SACR	
Walking (value in range)	Frontal	11	Acromion (°)	LSHO, RSHO	\
		12	Pelvis (°)	LASI, RASI	\
	Horizontal	13	Acromion (°)	LSHO, RSHO	\
		14	Pelvis (°)	LASI, RASI	\
Bending	Frontal	15	Max. Anterior Bending (°)	C7, SACR	
	Horizontal	16	Max. Lateral Bending (°)	LSHO, RSHO, LASI, RASI	

3.6.3.3.1 Standing with girdle or without girdle

As for the standing test, the subjects were asked to stand up in a straight posture for 3 minute without stress in accordance with the footprint marker placed on the floor for both the “without girdle” and “with girdle” sessions as shown in Figure 3.21a and 3.21b.

(a) Front view (b) Back view

Figure 3.21 Motion capture of subject with girdle or without girdle during standing

3.6.3.3.2 Walking with girdle or without girdle

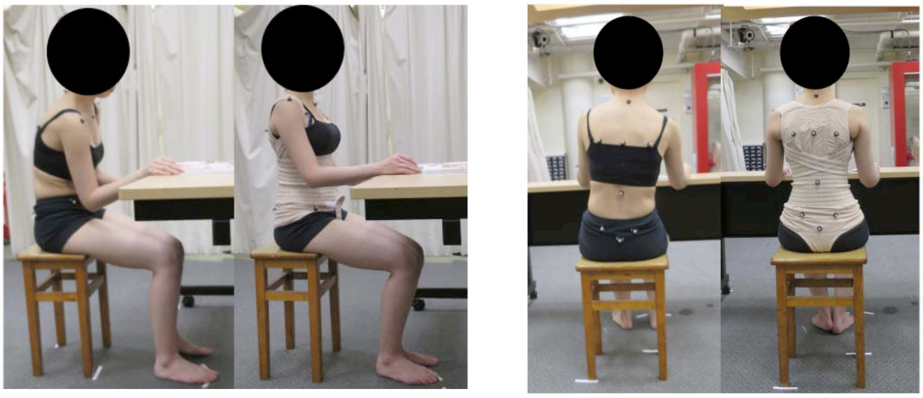
In terms of walking, the subjects were asked to walk on a treadmill with bare feet at their normal speed for 5-10 minutes in the “without girdle” and “with girdle” sessions as shown in Figure 3.22a and 3.22b. The first 5 minutes were considered as the warm-up time. Once the subject was walking smoothly without any problem, the capturing and recording would be started. The capturing and recording times were lasted for around 1-2 minutes depending on the subject performance.

(a) Lateral view (b) Back view

Figure 3.22 Motion capture of the subject with girdle or without girdle during walking

3.6.3.3.3 Sitting with girdle or without girdle

With regard to sitting, the subjects were requested to sit on a chair and read the book placed on a school desk for 15 minutes in the “without girdle” and “with girdle” sessions as shown in Figure 3.23a and 3.23b. The digital camera and motion capturing system would be started to capture the data simultaneously once the subject was relaxed and concentrated on the writing exercise. The capturing and recording times were lasted for around 1-2 minutes depending on the subject performance.



(a) Lateral view (b) Back view

Figure 3.23 Motion capture of subject with girdle or without girdle during sitting and writing

3.6.3.3.4 Bending with girdle or without girdle

In terms of bending, the subjects were asked to perform the maximum anterior and lateral bending. The whole process was carried out in a relaxed and comfortable environment. The subject would be required to bend slowly forward and sideward respectively. After holding seconds the subject returned to original posture. In order to obtain the reliable data, each of the forward bending and side bending tasks was repeated 3 times for both the “without girdle” and “with girdle” sessions as shown in Figure 3.24a and 3.24b.

(a) Front view (b) Lateral view

Figure 3.24 Motion capture of subject with girdle or without girdle during standing and bending

3.6.4 Evaluation method of spinal deformity

3.6.4.1 Radiographic analysis

Traditionally, the radiographic method is considered to be the most accurate method used to observe the changes in bone structure. The radiographic measurement of Cobb’s angle is considered the golden standard for detecting scoliosis. (Patias et al. 2010) It was also mentioned that the radiological images are mostly used to verify the bony structure or spinal alignment. (Fortin et al. 2011). Generally, Cobb’s angle will be measured and the change of spinal curve will be recorded by the professional during the assessment. However, the radiographic method is invasive and cannot be used for repeated measures of body segment posture within a short period of time (Fortin, Ehrmann Feldman, Cheriet & Labelle 2011). Hence, the spinal conditions of the subjects were evaluated by the radiographic method only before wear trial (0 month) and after wear trial (6 months) in the present study. The measurement method of Cobb’s angle on a spinal curve can be referred to Chapter 2.2.2, “Identify methods and signs of scoliosis” in the present study.

It had been reported that a significant number of idiopathic curves were actually improved during the follow-up period. According to the studies in the past, curve progressions were determined once more than 5° or 7° Cobb’s angle increases were happened to the curvy spines of the subjects (Wong & Tan 2010; Brooks et al. 1975; Soucacos et al. 1998; Rogala Drummond & Gurr 1978). In these studies, different progression rate were found with various inclusion criteria of Cobb’s angle, i.e. 5% with

5° or more, 14.7% with more than 10° and 6.8% with 6° or more. Table 3.8 shows the comparison of inclusion criteria, definition of progression and progression rates reported by the studies of curve progression of idiopathic scoliosis. Moreover, it was mentioned that there were 25% and 10% progression rate for the children aged 10 to 12 and 13 to 15 years old respectively with a curve magnitude of <19°.

Table 3.8 Comparison of inclusion criteria, definition of progression and progression rates on curve progression on idiopathic scoliosis

Authors (year)	**Number of Children**	**Inclusion Criteria (Cobb's angle)**	**Definition of Progression**	**Progression Rate (%)**
Brooks et al. (1975)	474	5° or more	Average of 7°	5
Soucacos et al. (1998)	839	More than 10°	5° or more	14.7
Rogala Drummond & Gurr (1978)	603	6° or more	5° or more	6.8

With reference to the past studies, the curve progression would be defined as 5° or more in the present study. The spinal curve was said to be under control if the increase of Cobb's angle was <5° after 6 months wear trial. Apart from the comparison of the Cobb's angle measured at the beginning (0 month) and after 6 months of wear trial, the comparison of the Cobb's angle between wearing and without wearing the posture correction girdle was also carried out. It was said that there was an immediate improvement of the spinal curve induced by girdling if the decrease of the Cobb's angle was >1° after putting on the girdle.

3.7 Statistical analysis

In connection with the results of school-screening program in the present study, distribution of age and BMI of the participants were analyzed by using IBM SPSS Statistic Version 20 with the method of Chi-square test, in order to identify any abnormal distribution of age and BMl among the subjects with and without suspected scoliosis. The alpha level of significance was set as p=0.05.

Concerning the ATI and Cobb's angle information of the recruited subjects, Pearson correlation test in IBM SPSS Statistic Version 20 was conducted in order to examine the relationship between these two variables. In the case of possible relationship, the correlation coefficient will be closer to 1; while in the case of negative relationship, the correlation coefficient will be closer to -1 If the p value is lower than the conventional 5% ($p<0.05$) the correlation coefficient is called statistically significant.

In regard to the results of health tests including blood pressure, pulse, peak expiration flow and sensory level on the subjects, the data were compared before and after wearing the girdle at 0 month by using IBM SPSS Statistic Version 20 with the method of repeated measures ANOVA, in order to evaluate the health effects that might induce by girdling. The level of significance was set at $p=0.05$.

With regard to the postural change on the human subjects with 6 months intervention (girdling), the data that obtained from 3D body scanning, direct measurement (shoulder levelness) and 3D motion capturing, were analyzed by using IBM SPSS Statistic Version 20. In order to examine the possible effect of girdling on the posture change of the subjects, measurements of posture change of the subjects were collected at 3 time points including 0 month (pre-girdling), 3 months and 6 months (post-girdling) in the wear trial for postural change evaluation. The data collected were analyzed by using SPSS with the method of 2-ways repeated measures ANOVA. The independent variables included the girdling (with girdle and without girdle) and month (0 month, 3months and 6 months); while the dependent variables were the measurements obtained in different posture evaluation methods (3D body scanning, shoulder levelness measurement and motion capturing). The level of significance was set at $p=0.05$.

As regards the change of spinal curve on the human subjects with 6 months intervention (girdling), the data that obtained by radiographic method (Cobb's angle) were also analyzed by using IBM SPSS Statistic Version 20. In order to examine the possible effect of time on the change of spinal curves of the subjects, Cobb's angles of the subjects were measured on the radiographs that took at 0 months (pre-girdling) and 6 months (post girdling) for comparison. The data collected were analyzed by using SPSS with the method of paired t-test. The level of significance was set at $p=0.05$.

Finally, in regard to the data obtained from 3D body scanning, direct measurement (shoulder levelness), 3D motion capturing and radiographic analysis (Cobb's angle) that used to quantify the changes of posture and spinal curve on the subjects, test-retest reliability tests were conducted in order to evaluate the reliabilities of these measurements. The measurements would be reported as reliable if $r>0.7$.

3.8 Chapter summary

The design process frameworks proposed by Labat and Sokoloeski (1999) and FEA model proposed by Stokes and Black (2012) were referenced for the design and development of the posture correction girdle. After the research problem was defined, the research steps and key design criteria including (1) workable corrective force mechanism, (2) appropriate material application, (3) aesthetic and psychological refinements, (4) good fit of the garment, and (5) elimination of the harm of health were determined. The physical tests of strength, stretch and recovery, air permeability, moisture permeability and dimensional stability were carried out on the main materials by referring to the standards. Pressure measurement (Pliance®) was also carried out on (1) the hard brace, (2) the posture correction girdle without padding insertion, and (3) the posture correction girdle with different padding insertions. This was aimed at investigating the amount of pressure exerted by them on the human body and selecting the suitable padding for point-pressure created to optimize the corrective function.

Meanwhile, inclusion and exclusion criteria were determined for subject selection. School-screening program was carried out in order to investigate the spinal condition of the female participants aged between 10 and 13 from the primary and secondary schools. After the school-screening program, those possible subjects with an ATR of 3° or above and with the spinal deformity in Cobb’s angle of 6 to 20 degrees obtained from the radiographic analysis would be defined as the potential subject. The potential subject would be recruited as the human subject if they were willing and able to participate in the present study.

With regard to girdle fabrication, 27 body measurement items were identified for making the posture correction girdle as the fit of posture correction girdle is important. After obtaining the body measurements of the subject by means of a tape ruler, the pattern was be drafted by the method of basic block alteration. 10 to 15% of the elastic fabrics were trimmed from the girdle at the circumference part as the usual practice in order to make it more tight-fitted. Chain stitch and zigzag stitch were applied to garment during the assembling process and the seam allowance was minimized to reduce the garment weight. The first fitting and second fitting sessions were carried out in order to eliminate the fitting problem. Garment refinements by inserting the paddings to the specific placements were carried out according to different cases in order to obtain the optimum corrective function of the girdle.

Finally, there would be 6 months long clinical trial of the posture correction girdle for each subject. Wearing instruction would be given to the subjects before the trial, and compliance monitoring was carried out by inserting the Thermocron Temperature Loggers. Health tests including the heart function, pulmonary and touch tests were carried out at the beginning of the wear trial (0 month) in order to ensure that the posture correction girdle had no health effect on the human subjects. Moreover, the evaluation tests conducted on the function of the posture correction girdle were carried out at the beginning, after 3 months and at the end (after 6 months) of the treatment. It was performed by different non-invasive methods including the 3D body scanning, direct measurement of shoulder level from floor, and motion capture (Vicon). The data obtained from these methods were analyzed by the statistic method in order to compare the posture parameters obtained from tests and evaluate the posture changes of the subjects. Furthermore, the spinal conditions of the subjects were also evaluated by the radiographic method before wear trial (0 month) and after wear trial (6 months) in the present study. With reference to the past studies, the spinal curve was said to be under control if the increase of Cobb's angle was <5° after 6 months of wear trial. It was also said that there was an immediate improvement of the spinal curve induced by girdling if the decrease of the Cobb's angle was >1° after putting on the girdle.

CHAPTER 4 - DESIGN AND DEVELOPMENT OF POSTURE CORRECTION GIRDLE

4.1 Introduction

In this chapter, design sketches will be presented, and the application of corrective forces, material selection and testing of the girdle will be discussed.

4.2 Design sketches and description

Figure 4.1 shows the front and back views of the design features of the posture correction girdle. The girdle is an underwear-like garment with a vest-like upper part. The girdle is close-fitting and shoulder to top-hip in length which help to facilitate support and control of the body from the shoulders to the top of the hips. It also contains a pair of shoulder straps and a waistband. The shoulder straps and waistband are used to exert the primary corrective forces.

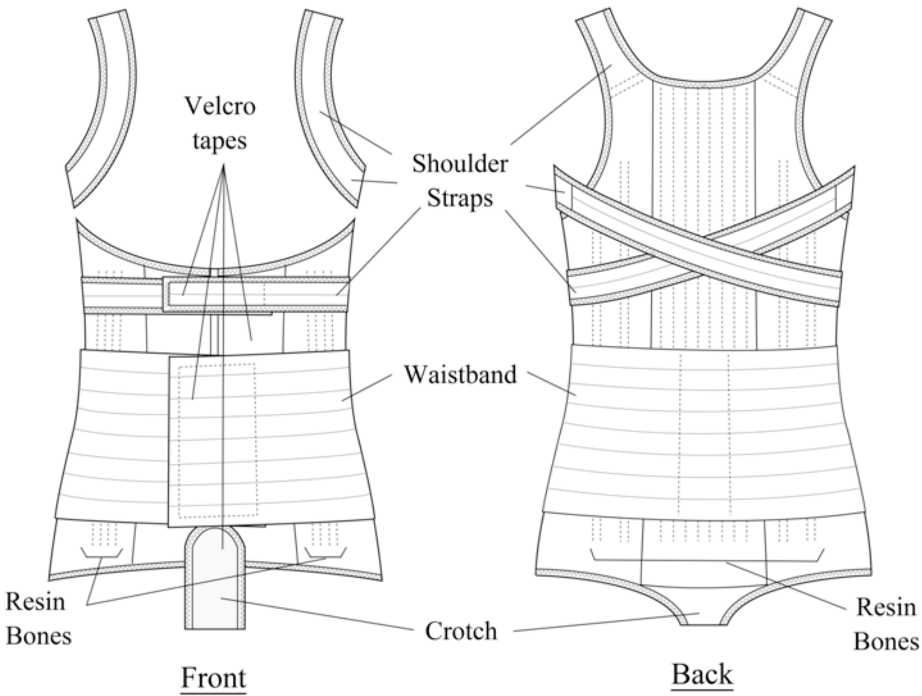


Figure 4.1 Front and back views of the posture correction girdle

Figure 4.2 shows a view of the inside of the posture correction girdle. The girdle contains six partitioned internal pocket linings which are used for padded insertions in order to reinforce corrective forces through the creation of point-pressures. The paddings which are inserted into certain locations will exert secondary corrective forces onto the patients.

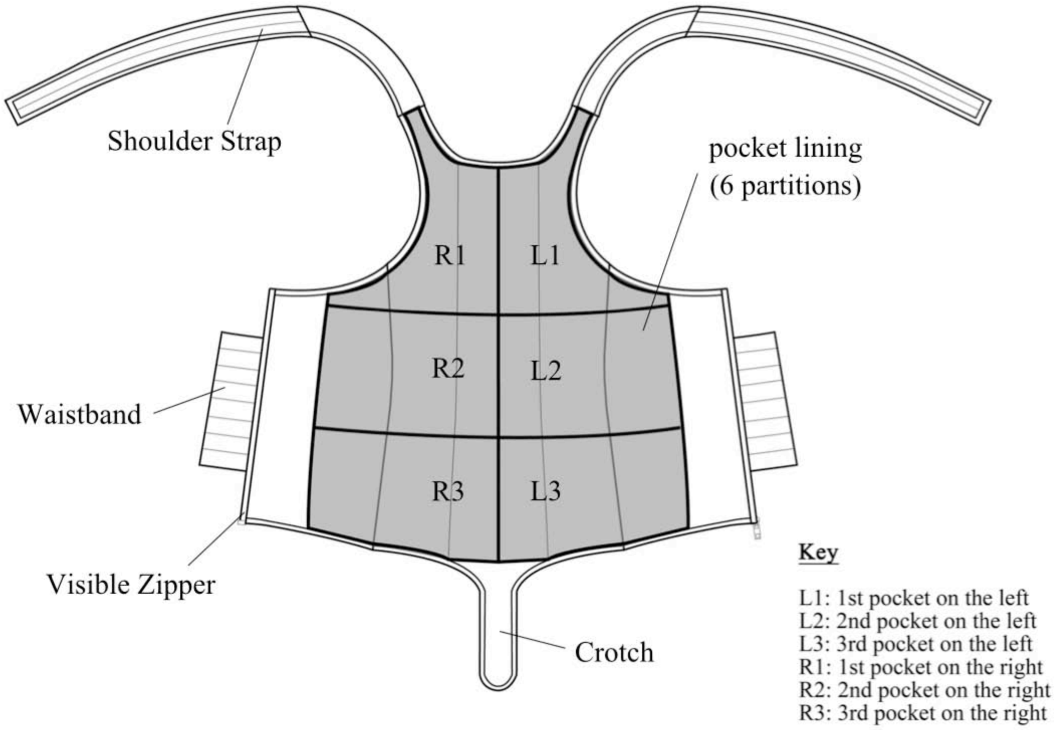


Figure 4.2 Inner view of the posture correction girdle

The shoulder straps of the garment wrap around the shoulders of the wearer and across the back to the opposite side, then wrap around the ribs and are finally fixed in the front by Velcro tape. The waist straps of the garment wrap around the waist and the straps also cover the waist and pelvis. The tension of the straps can be adjusted by adjusting the Velcro tape. These straps help to exert corrective forces onto the body when they are in tension. A visible zipper is applied as the means of the main opening at the front for convenience of putting-on and taking-off the garment. Furthermore, the adjustment area for the straps is concentrated at the center front panels and therefore easier for the wearer to put on the garment by herself.

Resin bones are fixed onto the garment and mainly concentrated vertically at the back and side, in order to provide support to the waist and spine. This support facilitates the posture correction process and increases the effectiveness of the corrective forces onto the body. A bone is applied onto each shoulder in order to reduce wrinkles and curling during wear. Weft knitted spacer fabric is used for the shoulder part in order to reduce pressure onto the shoulders. Removable ethylene vinyl acetate (EVA) foam paddings are inserted into the partitioned pocket linings depending on the needs of different individuals, in order to reinforce the corrective forces onto particular areas and enhance the function of the girdle.

The garment will not cover the chest in order to reduce any effects on breast development. The length of the garment is longer at the back but shorter in the front, in order to reduce the lift-up and roll-up of the edges during walking and sitting when wearing the garment. The design of the crotch also helps to reduce the problem of shifting and up-lifting of the garment during movement. The Velcro tape opening in the front of the crotch provides convenience for bodily functions.

V-fold elastic binding is applied to the edges of the garment, in order to ensure that the edges fit the body more closely, thus reducing the problem of shifting and also for a better finishing.

4.3 Application of corrective forces

In regard to the primary corrective force exertion of the posture correction girdle, the warping and elastic extension of the shoulder straps and waistband may generate corrective forces onto the torso. The brace design which is flexible, close-fitting and shoulder to top-hip in length would help to facilitate support and control of the body from the shoulders to the top-hip. The resin bones that are attached to the girdle base are mainly to support the torso while the elastic straps are mainly to exert corrective forces onto the torso. The shoulder straps hold the shoulders and pull them backward, in order to allow better posture and straighten them by reducing forward bending tendencies. The corrective force exerted by the elastic waistband reduces side-bending of the waist. The compressive forces also help to reduce imbalance, extra movement or tilting of the waist, pelvis and so, the spine, in order to enhance the corrective effects. Figure 4.3 shows the exertion of the primary corrective forces of the posture correction girdle.

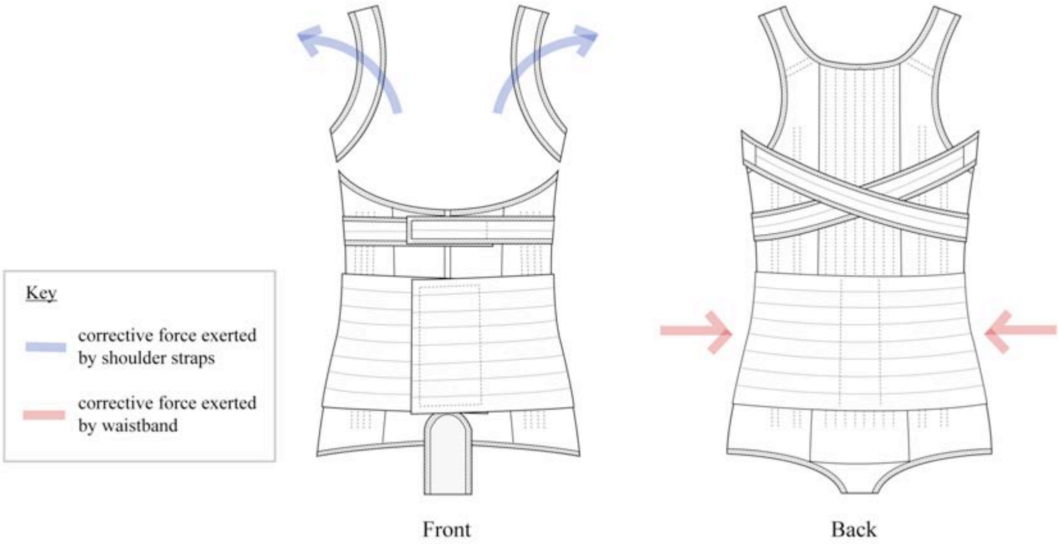


Figure 4.3 Primary corrective force exertion

In regard to the exertion of secondary corrective forces by the posture correction girdle, point-pressures through a support system are used. Semi-rigid EVA foam paddings are inserted into specific partitioned internal pockets of the girdle in accordance with the needs of different individuals so as to create point-pressures for areas that require them. Figure 4.4 shows examples of padding insertion as a point-pressure system in the posture correction girdle. The additional semi-rigid EVA foam paddings are inserted into various partitions of the pocket linings from the bottom to the top step by step, as the wearer's spine will often shift for balance when corrective forces are applied onto the lower section. For most of the cases, 2 semi-rigid pads are enough for correction by placing them opposite to one another. Some cases might need 3 or more pads while others only 1 pad for correction. In Example 1, the patient has right thoracic and left lumbar S-type scoliosis, and the pads should be inserted into the R1, L2 and L3 pockets to exert the appropriate corrective forces onto the body. In Example 2, the patient has a larger curve on the right thoracic and mild curve on the left thoracic, therefore, pads should be inserted into the R1, R2 and L1 pockets.

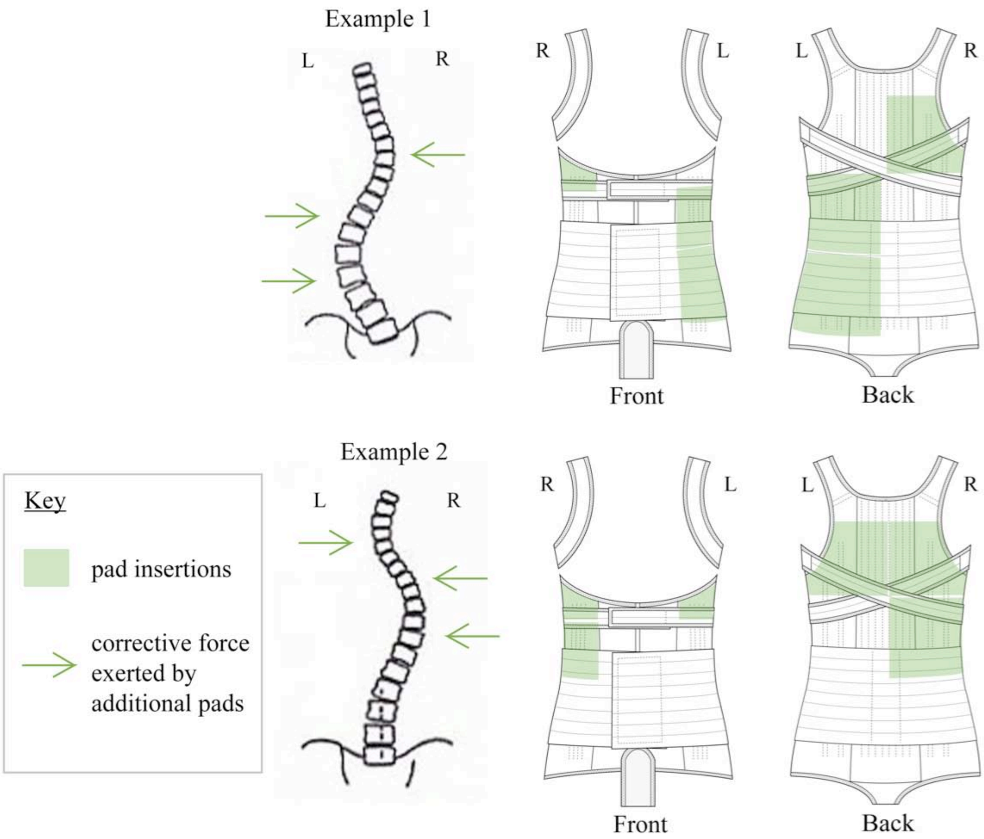


Figure 4.4 Examples of padding insertion method in point-pressure system

This posture correction girdle which uses a point-pressure support system is different from the three-point pressure system used in the traditional rigid brace. Traditional rigid braces compress and nearly constrain all body movement of the covered area with high tension. This method is considered to be a passive corrective method by using intense external compressive force on scoliosis patients as it might weaken the function of the muscles near the spine since it would no longer need them to hold, control and balance the spine once a “hard frame” is worn (Danielsson, Romberg & Nachemson 2006). It is believed that it would be too demanding on patients who are in the early stages of scoliosis with a Cobb’s angle of 6-20 degrees. So, a gentler method with an active-training concept was developed, which resulted in the new flexible girdle with a posture correction function. The point-pressure support system applied to this new flexible girdle would reduce the range of body bending by using moderate compressive force instead of fully constraining the movement of the torso by intensive compressive force. This helps to maintain good posture for the wearer during her daily activities in order to reduce the possibility of spinal curve progression. Meanwhile, the girdle is considered to have the ability to train the muscles that are near the spine in holding, controlling and balancing the spine by using point-pressures.

4.4 Material testing

It was indicated by previous research that comfort and human ergonomics could be highly affected by the mechanical properties and weight of materials (see Barker 2011), and moisture and air permeability are the determinants of the properties of comfort (Kilinc-Balci 2011). Therefore, the physical, mechanical and comfort properties of the materials used in the girdle were tested.

4.4.1 Selection of main fabrics and accessories

The most common fabrics and accessories used in shapewear are warp knitted fabrics, narrow fabric elastic straps and plastic bones. The main criteria for material selection are their mechanical and physical properties. In this study, warp knitted fabrics were selected as main materials due to they have good stretch and recovery properties. Three different tricot fabrics (TR1-3), two satinettes (SN1-2) and three powernets (PN1-3) that are commonly used in shapewear were preselected for mechanical and physical testing in order to choose the most suitable materials which satisfy both of the functional need and comfort need for the girdle.

Narrow fabric elastic straps are used to hold the garment in the right position and provide pulling or correcting forces. Six different types straps were pre-selected for mechanical and physical tests.

For Velcro tape, the thinnest one was preselected with the consideration of level of comfort. For the plastic bone, two different bones with common width and thickness that use in the industry were preselected. Tables 4.1 and 4.2 show the specifications of the main fabrics and accessories that preselected for further testing.

Table 4.1 Specifications of fabrics

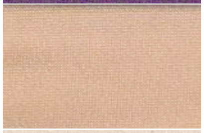
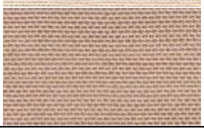
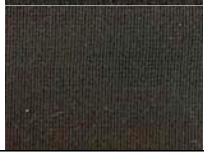
Component	Material	Name	Supplier & Cost	Photo	Width/ Size
1) Shell fabric	Tricot	TR1	Best Pacific Textile (Hong Kong) Ltd. HK$ 10/yd		57”
		TR2	Best Pacific Textile (Hong Kong) Ltd. HK$ 15/yd		60”
		TR3	Sham Shui Po Fabric Market HK$ 12/yd		58”
2) Supportive fabric	Satinette	SN1	Pacific Textiles Ltd. HK$ 10/yd		60”
		SN2	Pacific Textiles Ltd. HK$ 10/yd		60”
3) Pocket lining	Powernet	PN1	Sham Shui Po Fabric Market HK$ 10/yd		60”
		PN2	Pacific Textiles Ltd. HK$ 10/yd		58”
		PN3	Pacific Textiles Ltd. HK$ 10/yd		53”

Table 4.2 Specifications of accessories

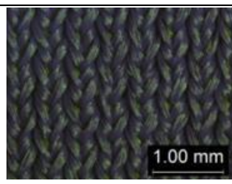
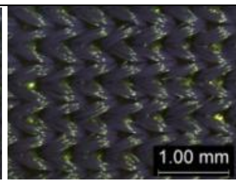
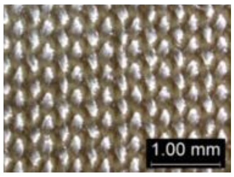
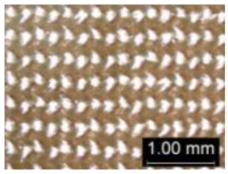
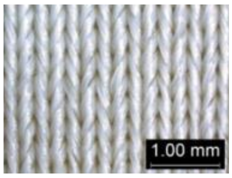
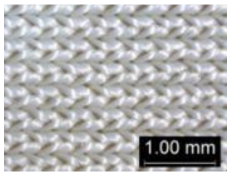
Component	Material	Name	Supplier & Cost	Photo	Width/ Size
1) Corrective strap	Elastic strap	EB1	Wing Fung Industrial (Hong Kong) Ltd. HK$ 12/yd		2”
		EB2	Wing Fung Industrial (Hong Kong) Ltd. HK$ 12/yd		1.5”
		EB3	Wing Fung Industrial (Hong Kong) Ltd. HK$ 100/yd		6”
		EB4	Wing Fung Industrial (Hong Kong) Ltd. HK$ 80/yd		7 7/8”
		EB5	Wing Fung Industrial (Hong Kong) Ltd. HK$ 25/yd		6”
		EB6	Wing Fung Industrial (Hong Kong) Ltd. HK$ 40/yd		5 7/8”
2) Adjustable fastener	Velcro tape	VFS	Wing Fung Industrial (Hong Kong) Ltd. HK$ 80/yd		4”
3) Supportive struts	Plastic bone	PB1	Sham Shui Po Fabric Market HK$ 4/yd		1/2”
		PB2	Sham Shui Po Fabric Market HK$ 3/yd		3/16”

4.4.2 Structure and characteristics of fabrics and accessories

The characterization of the material properties has great effects on the wearing quality of a garment (Ashdown 2011). The material properties can be indicated by the density, structure, weight, composition and thickness, which influence some of the issues with comfort (Hosseini Ravandi & Valizadeh 2011), like heat transfer by conduction, itchiness (Choudhury et al. 2011), mobility, etc. In addition, characteristics including weight, density, composition and thickness may affect the physical and comfort properties. (Saville 1999). Higher weight and lower density of a material means a warmer sensation that a fabric provides to the wearer (Oğlakcioğlu & Marmarali 2007).

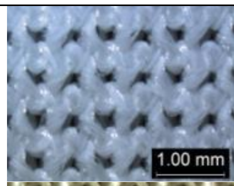
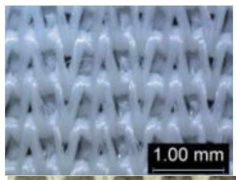
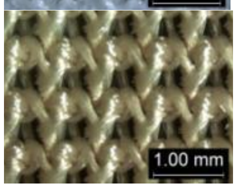
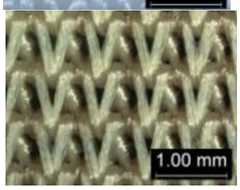
Elastic fabric may assist with ergonomics as well as psychological comfort (Bartels 2011). Tables 4.3 and 4.4 show microscopic views of the structure and characteristics of the main fabrics and elastic straps. Table 4.5 shows the characteristics of the Velcro tape and plastic bones.

Table 4.3a Structure and characteristics of fabric materials (Shell fabric)

Component	**Name & Composition ***	**Stitch density (Wale x Course)**	**Weight (g/m^2)**	**Density (g/cm^3)**	**Thickness (mm)**	**Technical Front (F) & Back (B)**
1) Shell fabric	TR1 (87% N & 13% E)	79 x 53	197	0.424	0.464	 
	TR2 (64% N & 39% E)	77 x 63	244	0.558	0.438	 
	TR3 (48% N & 52% E)	93 x 53	268	0.483	0.555	 

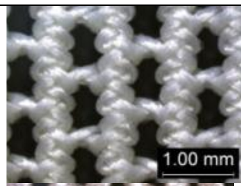
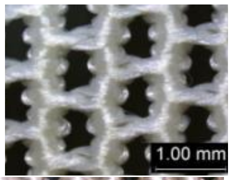
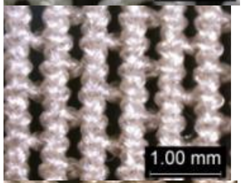
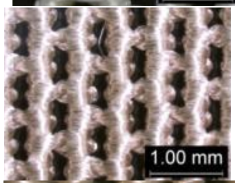
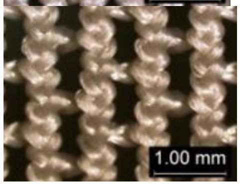
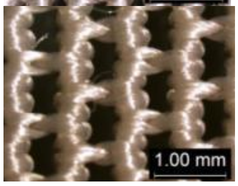
*Remarks: P = Polyester; C = Cotton; N = Nylon; N6 = Nylon6 R = Rubber; E = Elastane

Table 4.3b Structure and characteristics of fabric materials (Supportive fabric)

Component	**Name & Composition ***	**Stitch density (Wale x Course)**	**Weight (g/m^2)**	**Density (g/cm^3)**	**Thickness (mm)**	**Technical Front (F) & Back (B)**
2) Supportive fabric	SN1 (80% N6 & 20% E)	39 x 47	227	0.449	0.505	 
	SN2 (65% N, 12%P & 23% E)	29 x 37	194	0.363	0.535	 

*Remarks: P = Polyester; C = Cotton; N = Nylon; N6 = Nylon6 R = Rubber; E = Elastane

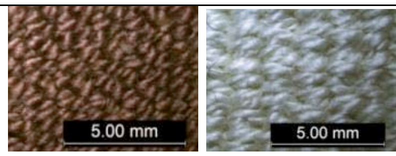
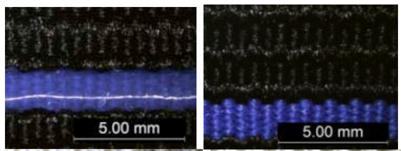
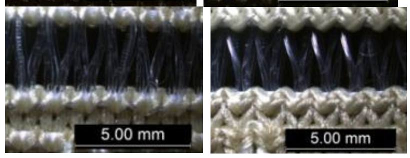
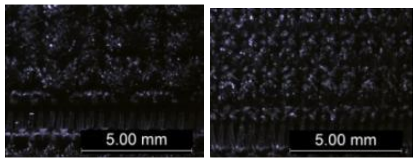
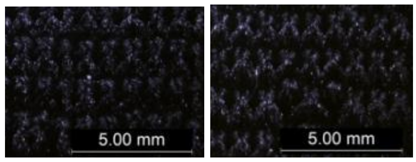
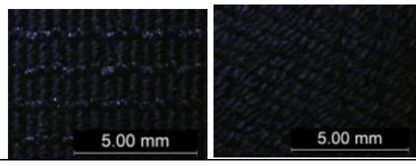
Table 4.3c Structure and characteristics of fabric materials (Pocket lining)

Components	**Name & Composition ***	**Stitch density (Wale x Course)**	**Weight (g/m^2)**	**Density (g/cm^3)**	**Thickness (mm)**	**Technical Front (F) & Back (B)**
3) Pocket lining	PN1 (65% N & 35% E)	29 x 28	166	0.390	0.426	 
	PN2 (65% N & 35% E)	43 x 36	209	0.543	0.384	 
	PN3 (76% N & 24% E)	29 x 29	205	0.449	0.456	 

*Remarks: P = Polyester; C = Cotton; N = Nylon; N6 = Nylon6 R = Rubber; E = Elastane

With reference to Tables 4.3a, b and c, TR1-3, PN1-3 and SN1-2 stand for tricot, powernet and satinette, respectively. The technical back has a better hand feel than the front, as the free-floating lapping yarns contribute to a considerably smoother surface. Therefore, the technical back (2x1 tricot stitch) is applied as the side of the garment that comes into contact with the skin. The stitch density varies largely, from 29 x 28 to 93 x 53, which indicates that tricot fabrics generally have relatively higher stitch density than powernet and satinette. Moreover, the fabric weight of each type of fabric varies, from 197 g/m^2 to 268 g/m^2 for tricot; 166 g/m^2 to 209 g/m^2 for powernet; and 194 g/m^2 to 227 g/m^2 for satinette. All of the fabrics are composed of synthetic fibers, such as nylon, polyester and spandex. The samples are blended with elastane (a fiber that can elongate for more than 200% of its own elasticity without breakage), and therefore suitable for making women's girdles as they provide a comfortable stretch (Lim et al. 2006).

Table 4.4 Structure and characteristics of elastic straps

Component	Name & Composition *	Stitch density (Wale x Course)	Weight (g/m^2)	Density (g/cm^3)	Thickness (mm)	Technical Front (F) & Back (B)
Corrective strap	EB1 (47% P, 23% C, 10% N & 20% R)	58 x 36	1308.7	0.415	3.127	
	EB2 (47% N, 30% P & 23% R)	61 x 44	734.6	0.048	1.740	
	EB3 (53% P, 20% N & 17% E)	24 x 23	635.9	0.316	2.035	
	EB4 (57% P, 10% N & 23% E)	17 x28	530.1	0.287	1.887	
	EB5 (43% P, 27% N & 30% R)	16 x 27	683.9	0.428	1.600	
	EB6 (43% C, 30% P & 27% R)	75 x 50	841.9	0.405	2.100	

*Remarks: P = Polyester; C = Cotton; N = Nylon; R = Rubber; E = Elastane

Table 4.4 lists EB1, EB2, and EB6 as woven elastic straps while EB3, EB4, EB5 are crochet (warp knitted) elastic straps. Knitted straps usually have higher elongation than woven ones because they are easier to stretch with knit loops. A weave and twill structure can be seen on the woven elastic straps (EB1, EB2 and EB6) while knit loops can be seen on the knitted straps (EB3, EB4 and EB5). It can be observed that the woven elastic straps have a higher stitch density than the knitted ones. EB6 has the highest stitch density amongst all of the woven straps while EB3 has the highest stitch density amongst all knitted straps. The weight of the elastic straps varies largely from 530.1 to 1308.7 g/m^2. EB1 is the heaviest elastic strap while EB3 is the lightest. A significant discrepancy in the thickness of the elastic straps can also be found, from 1.6 mm (EB1) to 3.127 mm (EB5). Previous research has indicated that a textile made with a cotton and polyester blend would have a certain degree of comfort and better resistance against wrinkling problems (see Hosseini Ravandi & Valizadeh 2011).

Table 4.5 Characteristics of Velcro tape and plastic bones

Component	Name & Composition*	Weight (g/m^2)	Density (g/cm^3)	Thickness (mm)
1) Adjustable fastener (Velcro tape)	VFS (80% P & 20% N)	234.3 (loop) 300.7 (hook)	0.162 (loop) 0.047 (hook)	1.45 (loop) 0.64 (hook)
2) Supportive strut (plastic bone)	PB1 (100% Pl)	651.2	0.343	1.90
	PB2 (100% Pl)	4261.7	2.131	2.00

*Remarks: P = Polyester; N = Nylon; Pl = Plastic

According to Table 4.5, the hook part of the Velcro fastening strap is slightly heavier than the loop part. For plastic bones, PB1 and PB2 have visibly the same structure, but PB2 is evidently heavier than PB1. The density of the plastic bones is correlated to their weight in which a higher density leads to more weight. In addition, the thickness of the Velcro fastening strap is different for the loop and hook sections while the thickness of the plastic bones (PB1 and PB2) are nearly the same. Moreover, the Velcro strap is made of nylon and polyester, which contribute to its high strength. It is strong enough to withstand high tension and secure the corrective bands. The compositions of PB1 and PB2 are the same, both are 100% plastic, which contribute to their high strength and good durability.

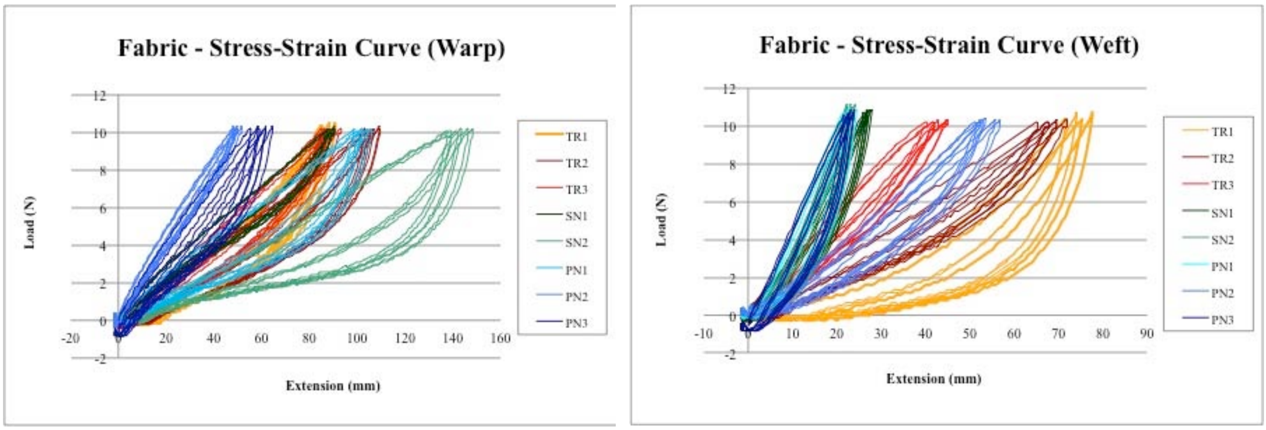
4.4.3 Results of material testing

The mechanical properties, including strength, stretch and recovery; comfort properties, including air and moisture permeabilities, and dimensional stability, were investigated. The results of these objective measurements were used as the parameters for material selection to fabricate the posture correction girdle.

4.4.3.1 Strength test

4.4.3.1.1 Fabric strength

Fabric used for girdle fabrication should have high strength in order to withstand intensive forces under an environment that undergoes stress and withstands stretching, and this would facilitate the exertion of corrective forces onto the body of the wearer to correct improper posture. Fabric strength testing was carried out to differentiate the stress-strain behavior of the fabric materials. In this test, the results of the force, extension, tensile strain and modulus at a specific load were obtained. The maximum load applied to the fabric materials was 10 N by following the international standard BS4952 (Methods of test for elastic fabrics). Each fabric was stretched 3 times for a better result.



(a) warp direction (b) weft direction

Figure 4.5 Stress-strain curves of different fabrics

The stress-strain curve of the different fabrics in the wrap and weft directions are shown in Figure 4.5 (Appendix A). According to Figure 4.5, all of the fabrics can undergo large strains under specific loads without material breakage. They have higher extension under the same load in their second and third stretching, which means a reduction in the ability to withstand stretching of each type of material after 2 times. Moreover, the results show that the stretching of the fabrics in the weft direction is more difficult as opposed to the warp direction. In other words, the fabrics are more stretchable in the warp direction than in the weft direction because of the warp knitting structure. A comparison of the extension and tensile strain between all of the fabric materials at a load of 10 N is shown in Figure 4.6 (Appendix A).

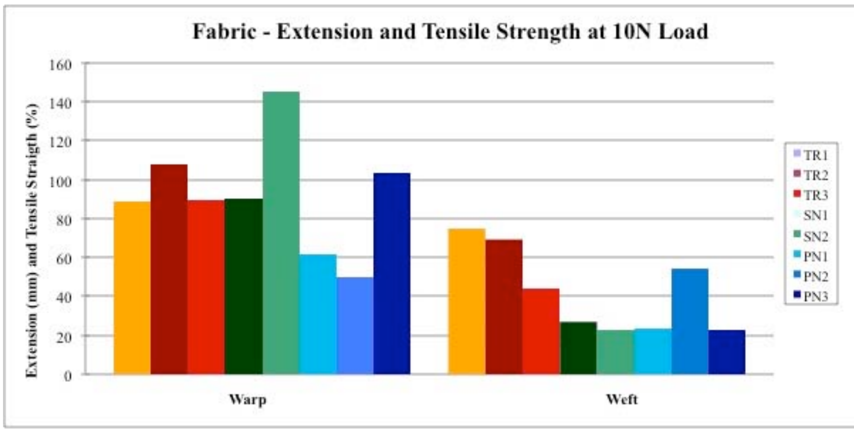


Figure 4.6 Comparison of extension and tensile strain between fabrics at load of 10 N

According to Fig. 4.6, PN2 has the lowest extensibility while SN2 has the greatest extensibility within all of the fabrics in the warp direction. TR3 is harder to deform than TR1 and TR2 amongst all three shell fabrics. In addition, PN2 is remarkably the least stretchable since the stress-strain curve of PN2 is the flattest while PN3 is the highest among the three powernet fabrics which are tested for use as the pocket lining. Moreover, SN1 has lower extensibility between the two other satinette fabrics used for supportive purposes. On the other hand, the stress-strain behavior is entirely different in the weft direction. All of the fabrics are more rigid as opposed to the warp direction. TR3, PN3, and SN2 have lower extensibility while TR1, SN2 and SN1 have relatively higher extensibility in comparison with all of the fabric materials. The modulus of the fabric materials was also calculated. Modulus is the slope of the stress-strain curve and characterizes the ability of a fabric material to resist against deformation, which is known as stiffness. A stiffer material has a higher modulus.

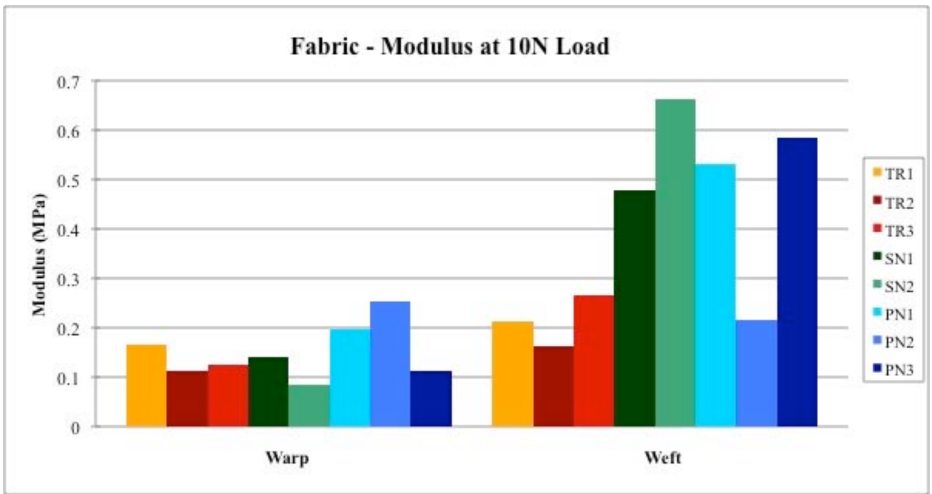


Figure 4.7 Comparison of modulus between fabrics at load of 10 N

The results shown in Figure 4.7 are correlated with the results shown in Figure 4.6. According to Figure 4.8 (Appendix A), TR3, PN3, and SN2 have a higher modulus (stiffness) due to their low extensibility, while TR1, SN2 and SN1 have a lower modulus due to their high extensibility. A negative relationship can be found between the thickness and extensibility of the fabrics, while a positive relationship can be found between the thickness and modulus of the fabrics. In other words, a thicker fabric may have lower extensibility and a higher modulus.

4.4.3.1.2 Elastic strap strength

Previous researchers stated that corrective straps are a key component on a scoliosis orthotic brace (see Mac-Thiong et al. 2004). Unlike the strength test for the fabric materials, a larger maximum force (40 N) was applied onto the elastic straps, as 40 N is the desirable strap tension for scoliosis spinal curvature (Mac-Thiong et al. 2004). Each elastic strap was stretched 3 times for better results.

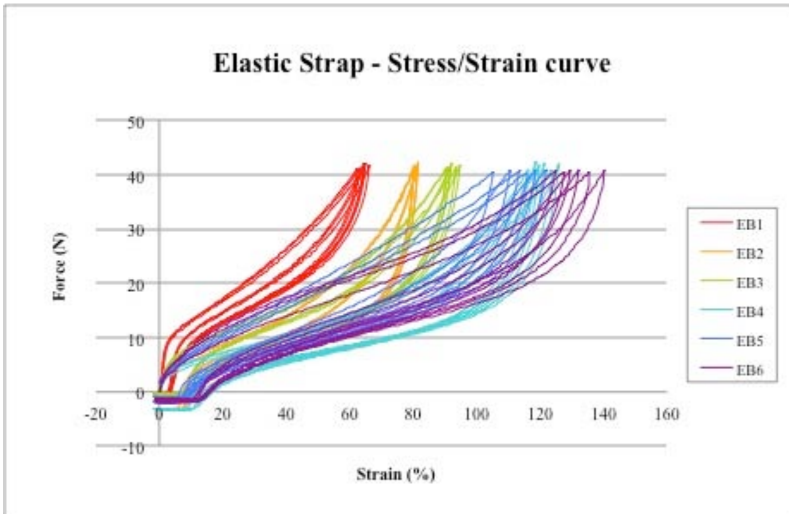


Figure 4.8 Stress-strain curve of elastic straps

The stress-strain curves of the elastic straps are shown in Figure 4.8 (Appendix A). According to the results, all of the elastic straps are capable of undergoing large strains under a specific load without material breakage. At the end of 3 stretches, negative tensile strain and extension values appeared for all of the elastic straps, which mean that there is an opposing force and there is recovery of the straps from stretching. Stokes et al. (1996) believed that the exertion of such a force to the trunk would delay the progression of spinal curves, according to the Hueter-Volkmann Law. A comparison of the extension and tensile strain between all of the elastic straps at a load of 40 N is shown in Figure 4.9 (Appendix A).

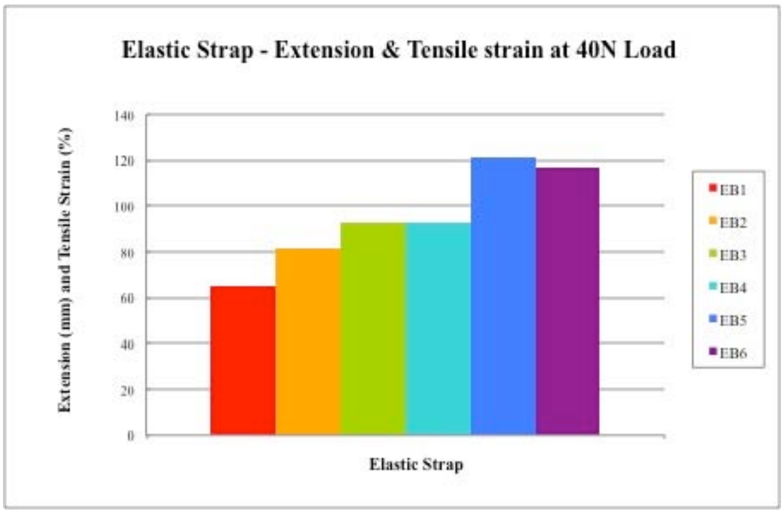


Figure 4.9 Comparison of extension and tensile strain between elastic straps at load of 40 N

According to the results that are shown in Figure 4.9, the extensibility of the elastic straps varies from 60 to 140 mm. EB1 has the lowest extensibility while EB6 the greatest extensibility amongst all of the elastic straps. The reason is possibly related to their thickness, weight and density. Generally, high thickness, weight and density lead to more resistance to stretching and pulling forces.

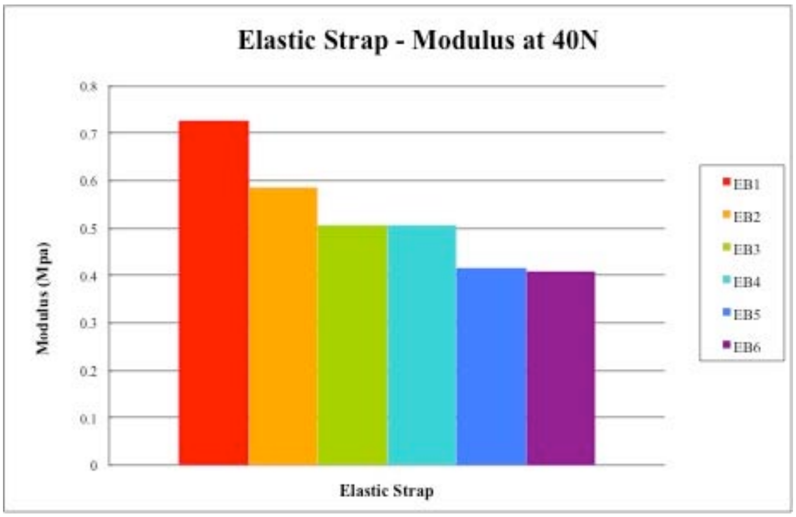


Figure 4.10 Comparison of modulus between elastic straps at load of 40 N

The results shown in Figure 4.10 are correlated to those shown in Figure 4.10 except for EB5 and EB6. According to Figure 4.10 (Appendix A), EB1 has the highest modulus while EB5 the lowest modulus; in other words, EB1 is the stiffest while EB5 is the least stiff. Although the density of EB5 is the highest amongst all of the elastic straps, it has low modulus and high extensibility. This indicates that the high rubber fiber content of EB5 is probably the reason for the high extensibility as fiber content plays a critical role in affecting the tensile properties (Gericke et al. 2007).

4.4.3.1.3 Velcro strap strength

Velcro tape was applied as an adjustable fastener on the corrective elastic straps of the posture correction girdle. Only one type of Velcro tape was tested, in order to investigate its ability to resist when fastened and during don and doff of the garment. The test results of the Velcro strap strength are shown in Table 4.6.

Table 4.6 Velcro strap strength

Velcro Strap Sample	1	2	3	4	5	Mean (N)
ASTM D5179 (T Method for Peeling Strength)	3.326	3.590	5.230	3.028	2.518	3.538
ASTM D5169-98 (Shear Strength)	224.1	222.4	222.7	238.3	229.6	277.4

According to the test results, the strength needed to separate the Velcro strap is 3.5 N, while the force to shear the fastened Velcro strap is 227.4 N. In an investigation carried out by Bader and Pearcy (1982) of the properties of the Velcro strap, the peeling strength varies from 2 N to 5 N and the shearing strength ranges from 36 N to more than 335 N. Compared with the study by Bader and Pearcy (1982), the performance of the investigated Velcro strap in this study is within the average. According to Table 4.6, the Velcro strap can withstand more than 200 N of shearing strength without any visible breakages and separation when fastened. As the force exerted from the corrective strap is around 20-60 N, this Velcro strap is suitable for use as the fastener. The peeling strength represents the ease of pulling and separating the fastener. The peeling strength of the tested strap is 3.5 N in this study. As the peeling strength is more than the minimum value of 2 N per the study by Bader and Pearcy (1982), the performance of this Velcro strap is considered to be acceptable.

4.4.3.1.4 Plastic bone strength

Plastic bone was applied as a supportive strut on the posture correction girdle. Two types of plastic bones, i.e., PB1 and PB2, were tested, in order to investigate their bending rigidity, which means the ease that the bone can be bent. Table 4.7 shows the bending rigidity of the plastic bones.

Table 4.7 Bending rigidity of plastic bones

Plastic Bone Sample	Thickness (mm)	Width (mm)	Force Applied (N)	N/mm^2 (lengthwise)
PB1	1.9	12.9	207.76	8.47654
PB2	2	4.7	114.66	12.19787

A higher value of force applied indicates a higher amount of force that the bone can withstand during bending. According to the test results, PB2, which is a narrower bone, is stronger than PB1 lengthwise. With the same material composition, PB1 has a higher weight and density. A positive correlation can be found among weight, density and the bending strength of the plastic bones. The width of PB1 is higher, so the bending rigidity widthwise is greater. PB1 was therefore used for the back of the girdle while PB2 on the side for supportive purposes to improve lateral spine curvature.

4.4.3.2 Stretch and recovery test

A posture correction girdle should be stretchable in order to accommodate different body shapes. This closely fitting garment is expected to stretch no more than 3% of its original dimensions (Saville 1999). Stretching and recovery tests were carried out to investigate the ease that the textiles could be stretched and how well they could recover after stretching.

4.4.3.2.1 Stretching and recovery of fabrics

The test results of the fabric materials are shown in Figure 4.11 (Appendix A).

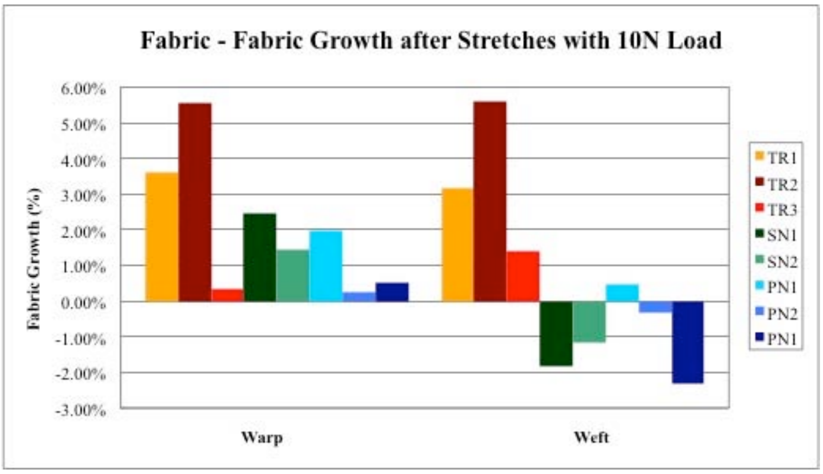


Figure 4.11 Fabric growth after stretching

According to the test results, TR1 and TR2 failed this test in both the warp and weft directions. The powernets and satinettes have an excellent performance, especially in the weft direction. Negative values even appear in the weft direction of PN2, PN3, SN1, and SN2. With regard to the percentage, the best-performing materials are TR3, SN2 and PN2. The reason behind their recovery rate is their elastane content. TR3, PN2 and SN2 have the highest elastane content among the same type of fabric. Elastane fiber has outstanding high elasticity and can be extended to 500% of its original elasticity with a recovery rate of 95% (Abdessalem et al. 2009). Thus, higher elastane content means that a fabric is able to recover more back to its original shape.

In addition, a positive correlation was found between stitch density, fabric weight and recovery rate for the tricot fabric. However, no correlation was found between the fabric characteristics and recovery for the powernet fabric. Besides that, there was no direct connection found between stress-strain behavior and stretch and recovery after a comparison was made with the extension and tensile strain performances at a load of 10 N.

4.4.3.2.2 Stretching and recovery of elastic straps

The test results of stretching and recovery of the elastic straps are shown in Figure 4.12 (Appendix A).

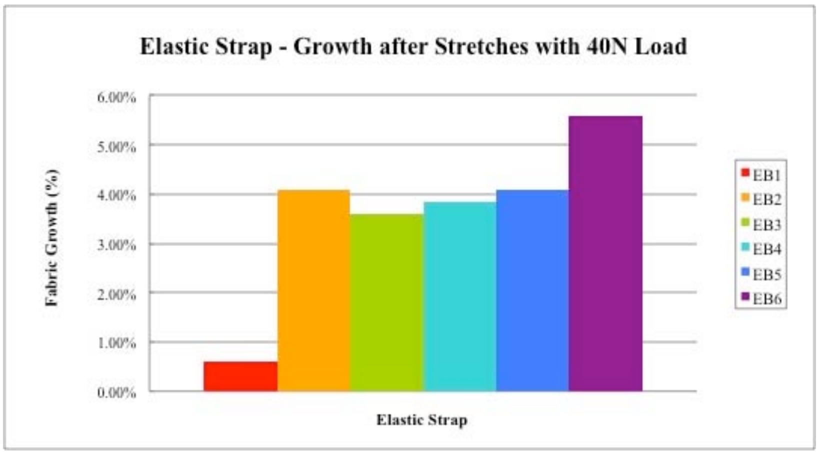


Figure 4.12 Growth of elastic straps after stretching

According to the test results, the growth of the elastic straps greatly varies from 0.06% (EB1) to 5.57% (EB6). After stretching with a force of 40 N, only EB1 and EB2 do not exceed a 3% dimensional change. A positive correlation was found between stretch recovery and modulus, which means that the recovery rate is related to the extensibility and stiffness of the strap. The thickness and weight of EB1 is the highest. This type of strap with a greater thickness tends to have a better recovery rate. A direct relationship was found between the thickness and recovery of the straps. However, there were no direct connection found between the recovery rate and other material characteristics for the other elastic straps.

4.4.3.3 Air permeability test

Air permeability testing was carried out to measure the resistance of flowing air from one side to the other side on the textile materials. A high value indicates high resistance to permeating air; in other words, low air permeability.

4.4.3.3.1 Air permeability of fabrics

The air permeability test results of the fabrics are shown in Figure 4.13 (Appendix A).

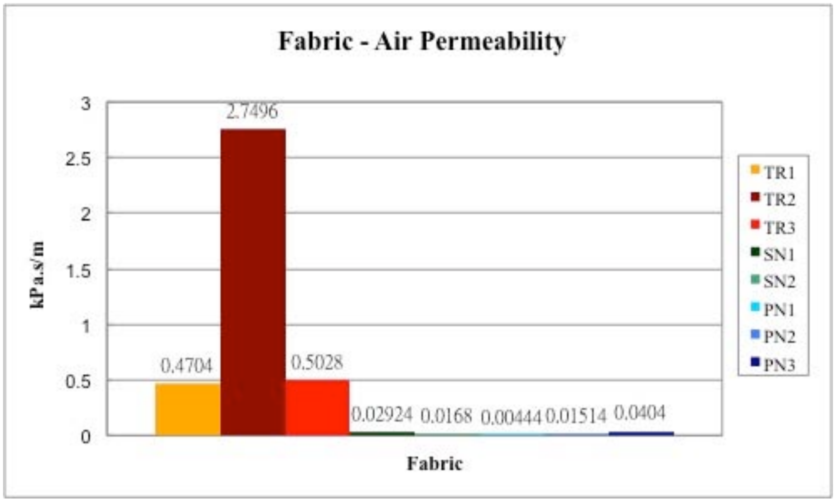


Figure 4.13 Air permeability of fabrics

According to the test results, the air permeability of the tricot fabrics is generally greater than the powernet and satinette fabrics. Kane et al. (2007) stated that air permeability is highly influenced by fabric type and fabric. Since powernet and satinette contain a net structure, the pores enable air to flow through and result in better air permeability. A lower stitch density also lead to better air permeability.

TR1 (0.47) is the most air permeable while TR2 (2.75) is the least. A significant difference was found between TR1 and TR2. For powernet and satinette, there was little variation among them and they generally had extremely high air permeability. SN2 has the lowest air permeability, which is 0.0168 kPa.s/m among all of the satinette fabrics. PN1 is the most air permeable fabric at 0.0044 kPa.s/m among all of the powernet fabrics.

Fabric characteristics are one of the factors that affect air permeability. With regard to Table 4.3, it can be seen that the density of fabrics is negatively correlated to their air permeability. A denser fabric has lower air permeability, as a dense structure would block the passage of air. In addition, Kane et al. (2007) also indicated that fabric thickness is one of the influential factors that affects air permeability. However, no significant relationship was observed in this study.

4.4.3.3.2 Air permeability of elastic straps

The test results of the air permeability of the elastic straps are shown in Figure 4.14 (Appendix A).

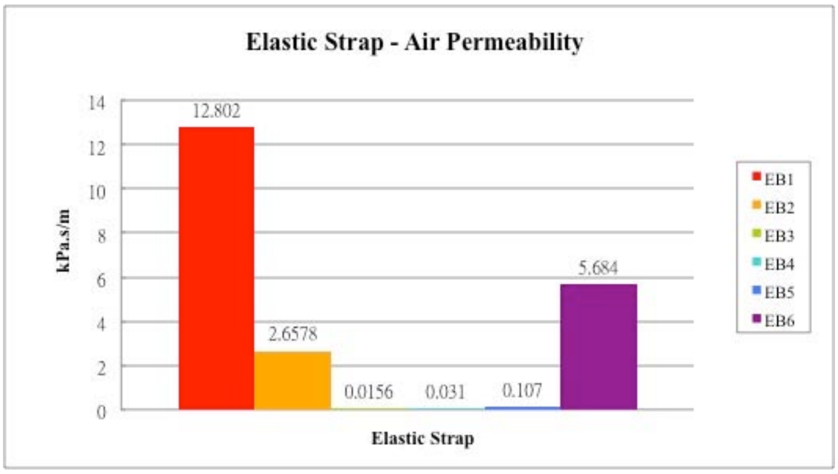


Figure 4.14 Air permeability of elastic straps

According to the test results, the air permeability of the discrepancy between the different elastic straps is extremely large, as the measurements vary from 0.0156 to 12.8 kPa.s/m. A high value indicates low air permeability as it is difficult for air to pass through the textiles. It was found that EB1 has the worst air permeability while EB3 has the best. EB3, EB4 and EB5 are obviously more air permeable than the other elastic straps, as their value ranges between 0.0156 to 0.107kPa.s/m.

Fabric type and construction, thickness and density are the key parameters that affect air permeability (Kane et al. 2007). The reason that EB1 has such a noticeably high airflow resistance (low air permeability) is related to its thickness and density. The high bulkiness of the elastic straps restricts air passage throughout the weaving structure and leads to low air permeability. Nevertheless, the thickness and density of some of the elastic straps did not produce the desired air permeability ability, i.e. EB3, EB4 and EB5 do not have low thickness and density. It is possible that type and construction are some of the influential criteria. With regard to Table 4.4, EB3, EB4 and EB5 are knitted elastic straps with lower stitch density. The space between the knitting loop enhances air permeability. The knitting structure of EB3 and EB4 was striped with different knitting densities. An eyelet structure formed on the surface of EB6. All of these structures allowed for extra flowable air to pass through the textile material.

4.4.3.4 Moisture permeability test

Moisture permeability is the ability of a textile material to transfer moisture from one face of the fabric to another. In the present study, the water method was conducted. The weight of each test dish together with the specimen was recorded and weighed every 24 hours for 5 days. Moisture permeability is measured by water vapor transmission (WVT), which indicates the amount of water vapor that passes through a material per unit areas per unit time. High WVT is associated with high moisture permeability.

4.4.3.4.1 Moisture permeability of fabrics

The results of the moisture permeability tests of the fabrics are shown in Figure 4.15 (Appendix A).

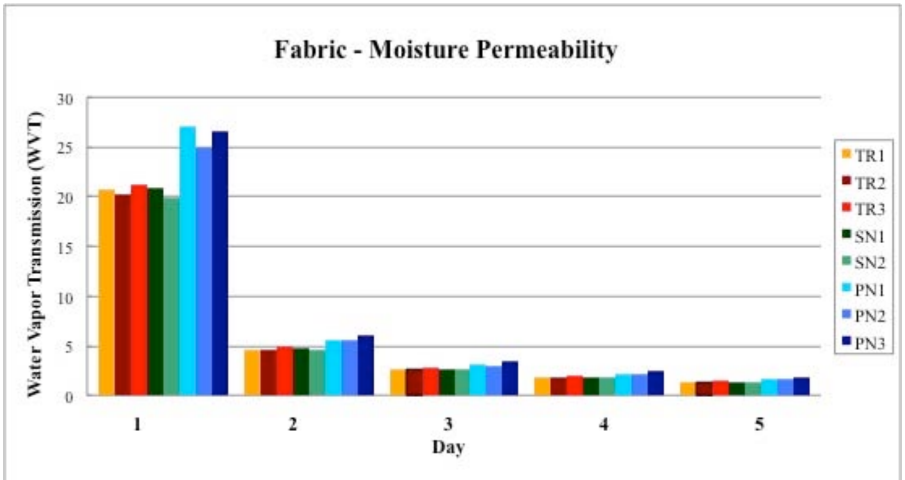


Figure 4.15 Moisture permeability of fabrics

The WVT was continuously recorded for 5 days. A noteworthy change during Days 1 to 2 was found; however, the change was not as significant during Days 3 to 5. This signifies that the fabrics actively transmitted moisture at the beginning when the fabrics were first placed into a moist condition. After a period of time, the fabrics were unlikely to permeate moisture after they reached equilibrium.

The powernet fabrics have higher moisture permeability among all of the fabrics. The most moisture permeable fabric is PN1 (26.983 WVT). The fabrics with the least moisture permeability are TR2 and SN2, which have very similar WVT values of 20.283 and 19.817. The low moisture permeability is related to their thickness and density. Normally, powernet fabrics have a lower thickness and density than tricot fabrics, and these facilitate vapor to transport from one surface to another. For satinette fabrics, they have lower moisture permeability due to their greater thickness. Fabric thickness is an important determinant in moisture permeability, as it determines the amount of moisture transported (Prahsarn et al. 2005). However, density vary depending on the fabric structure. Therefore, no correlation exists between moisture permeability and material thickness. Yet, a negative correlation can be found between moisture permeability and fabric density. Kane et al. (2007) concluded that the reason is attributed to the higher number of knit loops which may increase resistance to absorb and transmit moisture vapor.

4.4.3.4.2 Moisture permeability of elastic straps

The results of the moisture permeability tests on the elastic straps are shown in Figure 4.16 (Appendix A).

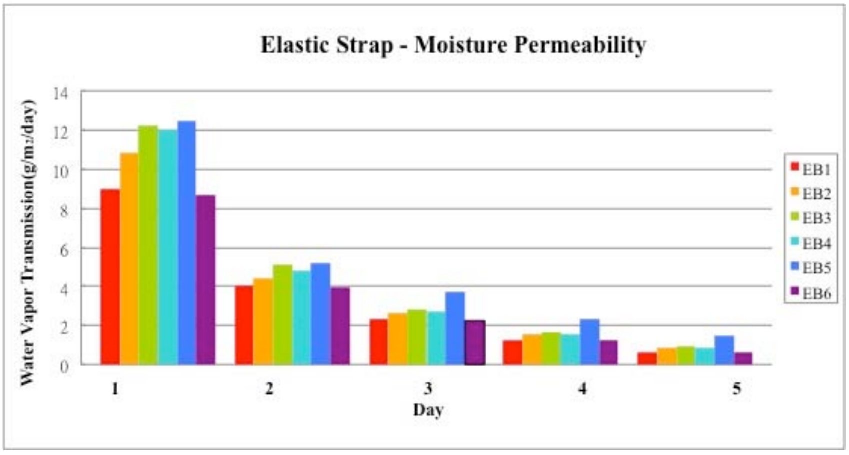


Figure 4.16 Moisture permeability of elastic straps

According to the test results, the moisture permeability varies from 0.632 g/m²/day to 1.517 WVT on Day 1. There is a notable change during Days 1 to 2 compared with Days 3 to 5. However, the tendency of the WVT rate of the elastic straps to decrease during Days 3 to 5 is more remarkable than that of the fabrics (Figure 4.16). The moisture vapor transmittance began when the conditions started to become humid and moist.

EB5 has the highest moisture permeability while EB1 and EB6 have the lowest. From Figure 4.17, it can be seen that the thickness of the elastic straps is negatively correlated to moisture permeability. EB1 and EB6 have very low moisture permeability because they are very thick. As mentioned by Kane et al. (2007), the longer the distance that moisture needs to pass through textile materials, the lower their moisture vapor permeability. In this test, it was found that the fiber composition of synthetic fiber and cotton is not able to enhance moisture permeability.

For EB3, EB4 and EB5, the results of the moisture permeability test do not correlate with their thickness. This can be explained by their different textile structure (Kane et al. 2007). EB3, EB4 and EB5 are knitted elastic straps with multi densities and an eyelet structure with low stitch density. The space created by the loose knitting and eyelets provide better conditions for moisture permeating. More space means that more moisture can pass through. As a result, the moisture permeability is relatively higher in the elastic straps with a knitted structure.

4.4.3.5 Washing test

Testing of dimensional stability was carried out to investigate the dimensional stability of the textile itself in home laundering conditions. The result was calculated as the percentage of the change from its original dimension. If the measured value was near 0, this indicated good performance in washability, as there had been little dimensional change. Normally, good dimensional stability should be between ±3%.

4.4.3.5.1 Dimensional stability of fabrics

The test results of the dimensional stability of the fabrics are shown in Figure 4.17 (Appendix A).

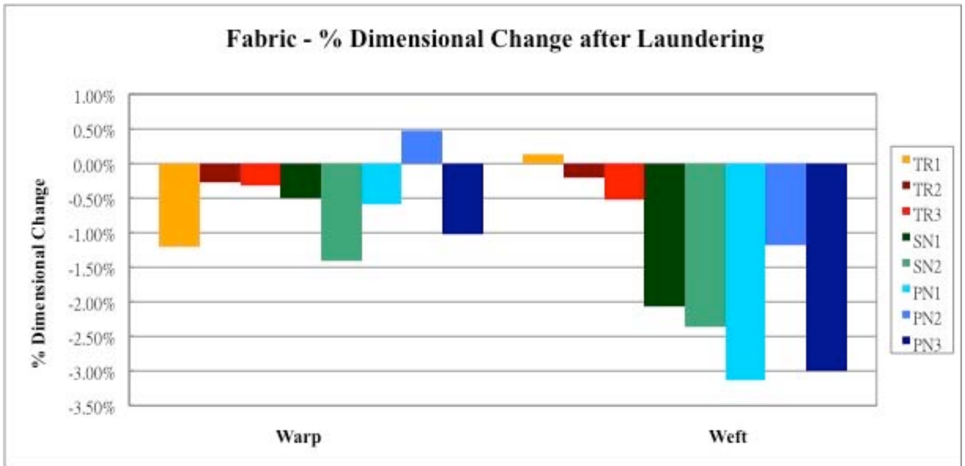


Figure 4.17 Dimensional change of fabrics after laundering

According to the test results, only PN1 failed the washing test in the weft direction. In most cases, the dimensional stability is higher in the warp direction than the weft direction. The percentage of dimensional change varies from -1.42% to 0.46% in the warp direction, and -3.13% to 0.14% in the weft direction. The knitting structure in the warp direction is more stable. Although most of the fabrics have shrinkage problems, a few fabrics were found to have fabric growth.

TR2, PN2 and SN1 have the best dimensional stability among their fabric type. The reason is related to their fabric density. A negative correlation was found between dimensional change and density in both the warp and weft directions. With reference to Table 4.3, TR2, PN2 and SN1 have the highest density among the same types of fabric. Fabrics with high density tend to have little dimensional change, as yarn shifting is reduced under their dense structure during washing.

4.4.3.5.2 Dimensional stability of elastic straps

The dimensional stability results of the elastic straps are shown in Figure 4.18 (Appendix A). The elastic straps all have different widths, so the dimensional change in the width direction of the elastic straps is not included.

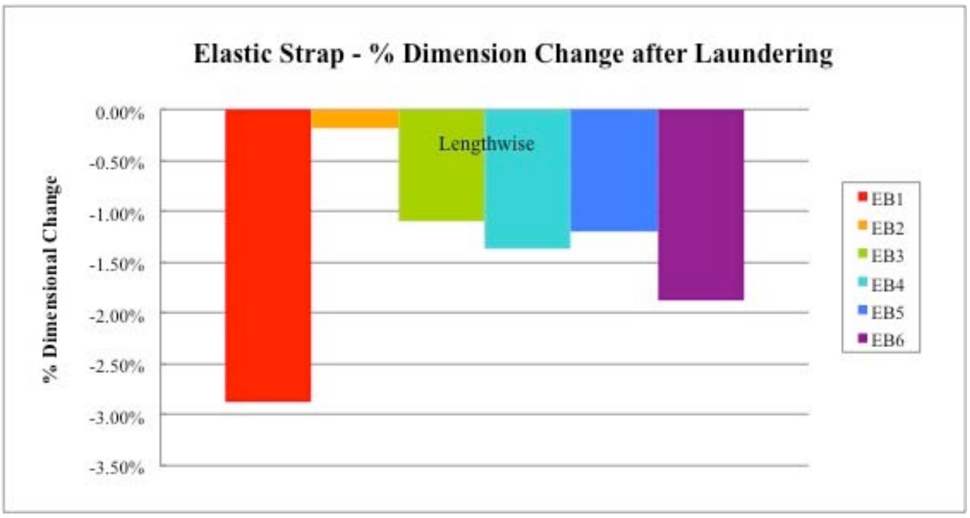


Figure 4.18 Dimensional change of elastic straps after laundering

With reference to the test results, the shrinkage of all the elastic straps is less than 3%, which means that they are all dimensionally stable. Figure 4.18 shows that EB2 is the most dimensionally stable elastic strap while the EB1 is the least. The dimensional change is apparently low for EB2. With regard to the elastic strap thickness and density, no connections were found for EB2 or even the other elastic straps due to the different strap structures. It is possible that the silicone strip greatly contributes to stabilizing the length of EB2. As the silicone strip is waterproof and does not contain yarns, dimensional changes would not take place unless it was stretched or heated. Moreover, EB1 and EB6 are the least dimensionally stable straps. This is probably due to the swelling of the cotton fiber in EB1 and EB6. Since hydrophilic fibers may absorb water and swell, the yarns will crimp to accommodate the swelling of the yarns and shorten the elastic strap length (Saville 1999).

4.4.4 Selection of fabric material and accessories for posture correction girdle

After investigating the physical properties of the potential materials, the materials for girdle fabrication were selected according to the results.

A stiffer elastic fabric material with lower extensibility and higher modulus is recommended for girdle fabrication for the purpose of posture control, as the intention of girdling treatment is to limit unnecessary motion and improve poor posture by exerting corrective and supportive forces onto the human body. The Hueter-Volkmann Law states that rigid pushing forces have a part in halting bone growth and the girdle shape and its stiffness are critical elements that push the shape of the trunk into a normal spinal curve (Aubin et al. 1999). However, Lim et al. (2006) mentioned that high extensibility fabric should be used to provide a comfortable fit. Therefore, in regards to fabric materials, TR3, SN2 and PN3 were chosen for application as the shell and supportive fabrics and pocket lining respectively, as their modulus is on average higher with low stiffness in the warp direction. Materials with a crosswise grain cut across the fabric will provide a better fit to the body and give extra dimensional stability to the girdle shape. Apart from the strength test, TR3, SN2 and PN3 also performed well in the stretching and recovery, air permeability, moisture permeability and dimensional stability tests. According to the tests results and characteristics of the fabric materials, their (TR3, SN2 and PN3) good performances of the strength test as well as the stretch and recovery were mainly related to their relatively high elastane contents among the fabric samples, i.e. at least 23%; their better performance of air permeability, moisture permeability and dimensional stability tests were mainly contributed by their moderate structure density and weight.

Extensibility and stiffness are important criteria in the selection process of elastic straps for the fabrication of the posture correction girdle, as an increase in strap tension would increase the ability to control spinal curvature (Mac-Thiong et al. 2004). Improper and inadequate corrective forces may lead to failure of the scoliosis treatment (Aubin et al. 1999). The corrective straps play an important role in exerting force onto the additional paddings that create the point-pressures, in order to compress and push the apex of scoliotic spine. The straps should be able to exert continuous pressure. Although EB1 showed low extensibility and high modulus in the strength test, it did not really perform well in the other tests in terms of its physical properties. After considering all of the test results, EB3 was finally chosen for application as a component of the corrective strap on the girdle as it has good strength, and also performed well in the stretch and recovery, air permeability, moisture permeability and dimensional stability tests, which means that it has good dimensional stability, and air and moisture permeabilities. According to the tests results and characteristics of the elastic straps, the good overall test performances of it (EB3) might be contributed by the moderate density and thickness of it. Furthermore, for the wearing comfort, weight of elastic straps might be important to consider. EB3 has relatively lower weight among the samples of elastic strap, i.e., 530.1g/m^2.

On the other hand, the Velcro tape (VSF) and plastic bone (PB1 & PB2) samples performed well in the strength test. Therefore, they were chosen as the adjustable fastener and supportive struts of the girdle respectively.

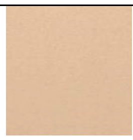
4.5 Comparison of pressure measurements results

The pressures exerted by a hard brace, and the posture correction girdle with and without padding onto a human body were measured. The pressure test results of 6 different scenarios, including: 1) wearing of a hard brace; 2) wearing of the posture correction girdle without inserted padding; 3) wearing of the posture correction girdle with padding PD1 inserted (thinner and less rigid); 4) wearing of the posture correction girdle with padding PD2 inserted (thinner and more rigid); 5) wearing of the posture correction girdle with padding PD3 inserted (thicker and less rigid); and 6) wearing of the posture correction girdle with padding PD4 inserted (thicker and more rigid) were compared.

4.5.1 Specifications and characteristics of padding material

The specifications and characteristics of the four types of padding materials (PD1 – PD4) are shown in Table 4.8. St. George et al. (2011) indicated that EVA foam has an elastomeric flexible property with the ability to withstand high-pressure environments and becomes rigid due to its closed cell structure. This means that it is flexible yet rigid, which means that the use of EVA foam can comfortably create point-pressures and improve posture through corrective forces. With reference to Table 4.8, PD4 is the heaviest because it is very dense and thick, while PD1 has the lowest weight because it is the least dense and the thinnest.

Table 4.8 Specifications and characteristics of padding materials

Component	**Name & Composition***	**Supplier & Cost**	**Weight (g/m^2)**	**Density (g/cm^3)**	**Thickness (mm)**	**Size (mm)**	**Photo**
Point-pressure creator	PD1 (100% Nora® Lunamaterial EVA)	Foot Specialist Footcare & Products Co. Ltd HK$200 /sheet	601.8	0.112	4.0	850 x 615 x 4	
	PD2 (100% Nora® Lunamaterial EVA)	Foot Specialist Footcare & Products Co. Ltd HK$200 /sheet	644.7	0.139	4.0	850 x 615 x 4	
	PD3 (100% Nora® Lunamaterial EVA)	Foot Specialist Footcare & Products Co. Ltd HK$200 /sheet	902.7	0.151	6.0	850 x 615 x 6	
	PD4 (100% Nora® Lunamaterial EVA)	Foot Specialist Footcare & Products Co. Ltd HK$200 /sheet	967.1	0.173	6.0	850 x 615 x 6	

4.5.2 Objective pressure measurements

The objective pressure measurements from the 6 different scenarios are shown in Table 4.9.

Table 4.9 Pressure measurements from 6 scenarios

Scenario		**1. Rigid Brace**	**2. Girdle without Padding**	**3. Girdle with PD1**	**4. Girdle with PD2**	**5. Girdle with PD3**	**6. Girdle with PD4**
Measured point	**Task**	**Pressure average (kPa)**					
LP1	**Standing**	3.1823	3.3498	3.6878	4.6974	5.2193	5.7346
	Sitting	3.1585	3.3143	3.6453	4.3665	4.8515	5.5784
	Walking	2.9651	3.1330	3.4463	4.2720	4.7447	5.6764
LP2	**Standing**	2.6899	2.8315	3.1146	3.3003	3.6669	5.7765
	Sitting	2.8667	2.9965	3.2965	4.0504	4.5005	5.9871
	Walking	2.5305	2.7190	2.9909	3.6667	4.0741	5.7182
LP3	**Standing**	4.9041	3.1478	3.4625	4.1191	4.5769	5.6890
	Sitting	5.0645	3.2489	3.5739	4.3245	4.8005	6.6813
	Walking	4.6973	2.8334	3.1164	4.5689	5.0761	5.9874
RP1	**Standing**	2.7424	2.8868	3.1748	4.5099	5.0110	5.6254
	Sitting	2.6725	2.7550	3.0305	4.3184	4.7983	5.4891
	Walking	2.3389	2.4621	2.7031	4.2295	4.6995	5.5663
RP2	**Standing**	2.7335	2.8771	3.1648	3.5612	3.9568	5.8761
	Sitting	3.2147	3.3839	3.7222	3.9649	4.4051	5.9782
	Walking	2.8043	2.9519	3.2470	3.7585	4.1762	5.7341
RP3	**Standing**	4.4343	3.5194	3.8713	4.1759	4.6391	5.7001
	Sitting	5.3913	3.4833	3.8316	4.1405	4.6005	6.3218
	Walking	4.4115	3.4117	3.7527	4.4778	4.9752	5.9895

According to the results, the pressure measurements of the rigid brace are generally somewhat less than those of the girdle (without padding), except for LP3 and RP3. Less pressure was found on the rigid brace in comparison with the girdle (without padding) at LP1, LP2, RP1 and RP2 which may be due to the force spreading effect (pressure=force/area), i.e. it is more difficult for a large sheet of thermal plastic that is contained by the rigid brace to intensively exert force onto a particular point as it comes into contact with a larger area of the body, while it is easier for a narrower and stiff elastic strap because it comes into contact with a smaller area of the body. In terms of the result of LP3 and RP3, the pressure measurements for the rigid brace are higher than those for the girdle (without padding), especially during sitting. This may be due to the protruding bones in the pelvic area. Higher pressure can be easier to create when force is applied onto a hard surface with hard materials.

Additionally, the pressure measurements accordingly increase in general for Scenarios 2 to 6. This may be due to the insertion of paddings with different thicknesses and hardness, i.e. no padding was inserted for Scenario 2; thinner and less rigid padding (PD1) was inserted for Scenario 3; thinner and more rigid padding (PD2) was inserted for Scenario 4; thicker and less rigid padding (PD3) was inserted for Scenario 5; and thicker and more rigid padding (PD4) was inserted for Scenario 6.

In addition, higher pressure is generally found at LP1, RP1, LP3 and RP3 as opposed to LP2 and RP2 for the 3 types of tasks. This may be due to the proportion of tissue and bone for different body parts. LP1 and RP1 are located in the rib cage area; LP2 and RP2 in the waist area; and LP3 and RP4 in the pelvic area. The bones are more visible in the rib cage and pelvic area than the waist area at the sides. Pressure can be more easily exerted onto a harder than softer surface.

Moreover, the measurements of LP2 and RP2 are greater during sitting. This may be due to the extrusion of the tissues at the waist during this action. Furthermore, the measurements recorded during walking are more fluctuated than standing and sitting due to the greater motion range.

4.5.3 Subjective opinion from subjects

Apart from the subjective pressure measurement, the opinions from the subjects on the padding materials versus level of comfort were also solicited. The ratings of the tested padding materials are shown in Table 4.10.

Table 4.10 Rating of level of comfort for padding

	PD1	**PD2**	**PD3**	**PD4**
Rating of level of comfort	4	3	2	1
* Remarks: 4 = Most comfortable, 1 = Least comfortable				

According to the feedback, the ratings accordingly decreased from PD1 to PD4 respectively, which means that PD1 has the best performance in level of comfort while the reverse is true for PD4. This may be due to the differences in thickness and hardness between the two types of paddings. PD1 is a thinner and softer pad among the samples, so it would induce less discomfort, while PD4 is a thicker and harder pad, so the result would be greater discomfort.

4.5.4 Padding selection for posture correction girdle

The padding in this study aims to create point-pressures and exert them onto protruded areas of the spine through strategic placement on the girdle in accordance with the advice provided by a prosthetist and orthotist (P & O). To correct the lateral curves of a scoliotic spine, it was advised that the paddings were to be mainly inserted on the sides. High pressure is required, in order for effective spine rectifying and posture corrective functions, to stop the scoliosis from worsening. It was concluded that a pressure of 30 mmHg (4 kPa) to 70 mmHg (9.3 kPa) is ideal for treating scoliotic curves (Périé et al. 2003). With reference to Tables 4.9 and 4.10, PD4 provides the greatest pressure (i.e. average of 5.8394 kPa for all points and all tasks) and ranks fourth in comfort. Comparatively, PD3 (i.e. average of 4.5985 kPa for all points and all tasks) is second in providing the greatest pressure and its comfort is ranked third. Although PD1 and PD2 are ranked first and second on comfort, the pressure that they induce is relatively low (i.e. average of 3.3796 and 4.1390 kPa for all points and all tasks respectively). As the pressure creates by PD1 do not reach the minimum pressure requirement, i.e. 4 kPa (Périé et al. 2003) and the pressure creates by PD2 is relatively low, they will not be chosen. PD3 and PD4 provided relatively higher pressure and reached the minimum pressure requirement, however, PD4 will not be chosen because of its worse performance in comfort. Conclusively, PD3 was chosen as the padding for the posture correction girdle due to its overall balanced ratings.

4.6 Chapter summary

A vest-like and close-fitting girdle with a shoulder to top-hip length has been designed and developed. Apart from the corrective straps and supportive struts that are found on the girdle, padding is the key to ensure that the corrective function of the girdle is a success. Paddings are inserted into different partitioned pocket linings inside the girdle in accordance with different cases, and the positions are recommended by a P&O. Conclusively, the whole corrective force mechanism consists of: 1) supportive forces provided by plastic bones and the whole girdle; 2) primary corrective force exertion by the shoulder straps and waistband; and 3) point-pressure creation and exertion by the paddings.

On the other hand, material selection is also important for girdle fabrication, as the same design would have different effects if the girdle was made of different materials. In order to select the most suitable materials for girdle fabrication, testing of the properties, including strength, stretching and recovery, air permeability, moisture permeability and dimensional stability, have been carried out on the main materials, i.e. fabrics and elastic straps. TR3, SN2, PN3 and EB3 are chosen as the components of the shell fabric, supportive fabric, pocket lining and corrective straps, respectively, as they performed well in the tests mentioned. It is recommended that the fabric materials are cut on the crosswise grain in order to obtain a better fit to the body and give extra dimensional stability to the girdle shape.

After analysis of the test results, it is found that the properties, i.e. material structure, thickness, density and fiber composition, affect the mechanical properties, comfort and dimensional stability. Weight, density, thickness and fiber content are influential on the tensile strength, especially for the elastic straps. The weight and density of the plastic bones are positively correlated to their rigidity. For stretching and recovery, the elastane content, stitch density and fabric weight are important for tricot fabrics with high recovery while thickness and modulus are key factors that affect the recovery of the elastic straps. In terms of the comfort properties, the stitch density in different fabric constructions may directly affect their air permeability, while type (knitting or weaving) and textile construction of elastic straps would affect their air permeability. According to an analysis on the relationship between moisture permeability and stitch density, the thickness and density affect the fabrics the most while thickness and textile structure affect the elastic straps the most. In terms of dimensional stability, fabric density, elastic strap construction and fiber content are factors that explain the occurrence of shrinkage in the fabrics and elastic straps.

Furthermore, pressure measurements are also carried out on different padding materials, in order to select the most suitable one for girdle fabrication so as to provide optimal corrective point-pressures with an acceptable level of comfort. Conclusively, PD3 is chosen as the padding for the posture correction girdle due to its balanced overall subjective and objective ratings. It is found that thickness, density and hardness of padding materials are the factors that affect the amount of pressure exerted and level of comfort when inserted into the girdle. Greater thickness, density and hardness mean more pressure exerted and less comfort, while less thickness, density and hardness mean less pressure exerted and greater comfort.

Chapter 5 - SUBJECT SELECTION AND GIRDLE FABRICATIOIN

5.1 Introduction

In this chapter, the results from the school screening and subject selection will be provided. The demographics and spinal curve conditions of the recruited subjects will be briefly introduced. In addition, the final pattern of the posture correction girdle is also shown with photos of the completed prototype.

5.2 Subject selection

5.2.1 Results from school-screening program

In this study, screening has been carried out at 4 primary schools and 3 secondary schools, in order to investigate the spinal conditions of the targeted group and recruit suitable human subjects for the wear trial. A total of 497 females aged 10-13 years old were screened by a P&O and well-trained research team. Table 5.1 shows the results from the school-screening program.

Table 5.1 Results from school-screening program

School Name	No. of participants	Participants with ATR 0-2	Participants with ATR ≥3
True Light Girl's College	68	57	11
St. Clare's Primary School	47	35	12
Belilios Public School	107	82	25
PLK Grandmont Primary School	126	100	26
Alliance Primary School, Whampoa	54	45	9
Hennessy Road Government Primary School	63	43	20
Lok Sin Tong Primary School	32	26	6
Total	497	388	109
Percentage		78.1%	21.9%

It was found that 109 (21.9%) females out of the 497 screened participants may have early scoliosis (with ATR ≥3°). ATR readings are obtained in the form of a non-negative integer number in this study. In the school-screening program of this study, participants who have an ATR ≥3° were treated as possible subjects with reference to the protocols of the Hong Kong school-screening program (Luk et al. 2010), in order to screen out those who have “early scoliosis”. However, in the screening program carried out by the Department of Health, sometimes the participants would only be considered to suffer from scoliosis if they had an ATR ≥4-5°**.** Moreover, it was mentioned that the increasing trend of spinal deformities might be induced and worsened by improper postures due to the changes in daily lifestyle, e.g. more and more teenagers have smartphones nowadays and use them with their head bent downward for a prolonged period of time (I-cable news 2014).

The age and BMI distributions of the screened participants are summarized in Table 5.2. The participants were assigned to the normal subject group (N group) if they have an ATR 0-2° and to the possible scoliosis group (P group) if they have an ATR ≥3°.

Table 5.2 Age and BMI distributions of screened participants

Age	Group	Underweight	Normal weight	Overweight	Total
10	**N**	15 23.4% 93.8%	36 56.3% 80%	13 20.3% 76.5%	64 100% 82%
	P	1 7.1% 6.2%	9 64.3% 20%	4 28.6% 23.5%	14 100% 18%
	Total	16 20.5% 100%	45 57.7% 100%	17 21.8% 100%	78 100% 100%
11	**N**	45 28.7% 69.2%	86 54.8% 78.2%	26 16.5% 76.5%	157 100% 75.1%
	P	20 38.5% 30.8%	24 46.1% 21.8%	8 15.4% 23.5%	52 100% 24.9%
	Total	65 31.1% 100%	110 52.6% 100%	34 16.3% 100%	209 100% 100%
12	**N**	36 24.3% 73.5%	93 62.8% 80.2%	19 12.9% 82.6%	148 100% 78.7%
	P	13 32.5% 26.5%	23 57.5% 19.8%	4 10% 17.4%	40 100% 21.3%
	Total	49 26.1% 100%	116 61.7% 100%	23 12.2% 100%	188 100% 100%
13	**N**	6 31.6% 85.7%	9 47.4% 81.8%	4 21% 100%	19 100% 86.4%
	P	1 33.3% 14.3%	2 66.7% 18.2%	0 0% 0%	3 100% 13.6%
	Total	7 31.8% 100%	11 50% 100%	4 18.2% 100%	22 100% 100%
All age	**N**	102 26.3% 74.5%	224 57.7% 79.4%	62 16% 79.5%	388 100% 78.1%
	P	35 32.1% 25.5%	58 53.2% 20.6%	16 14.7% 20.5%	109 100% 21.9%
	Total	137 27.6% 100%	282 56.7% 100%	78 15.7% 100%	497 100% 100%

*Remarks:
N = Normal group (Participants with ATR 0-2°);
P = Possible group (Participants with ATR ≥3°)

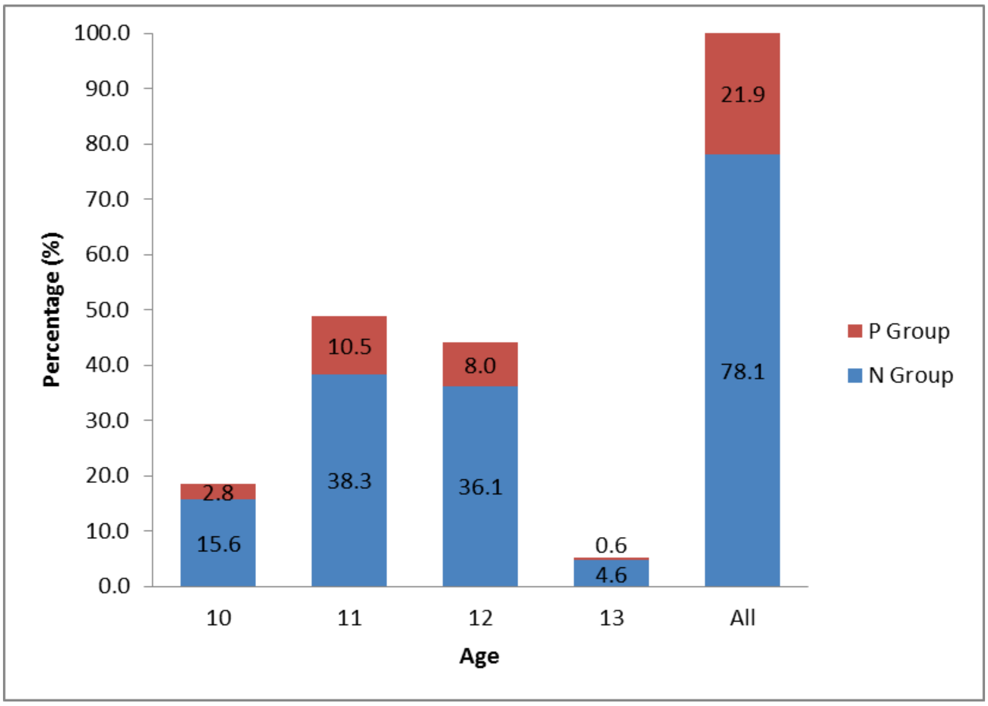


Figure 5.1 Age distributions of the screened participants in N and P groups

According to Figure 5.1 (Appendix B), the participants are mainly ages 11 (42.1%) and 12 (37.8%), while only 15.7% and 4.4% are mainly ages 10 and 13, respectively. The main reason is that the screening program is primarily for Primary 5 and 6 and Secondary 1 students, and their age distributions are between 10-12 and relatively less who are 13.

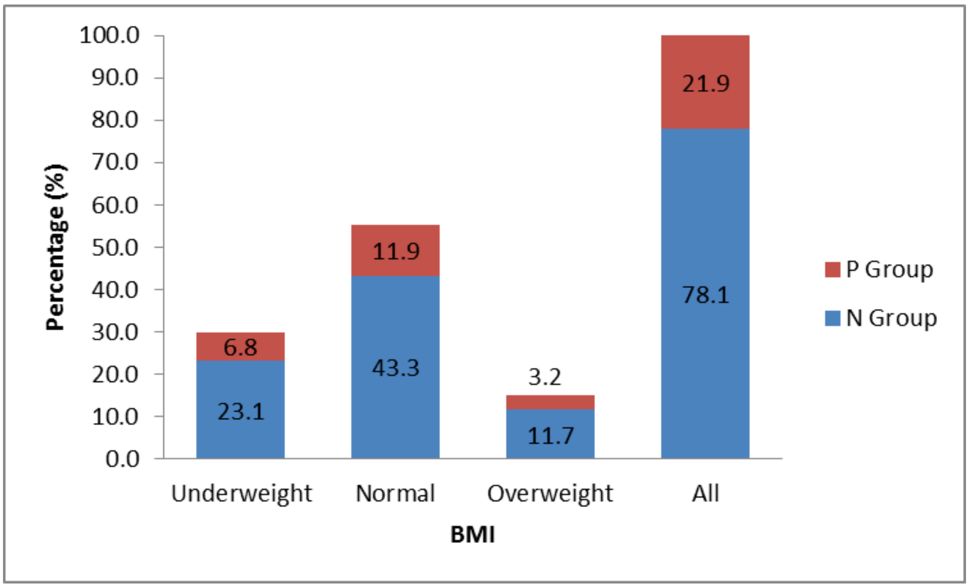


Figure 5.2 BMI distributions of the screened participants in N and P groups

As shown in Figure 5.2 (Appendix B), most of the participants (56.7%) are categorized as having a normal weight, while the rest are categorized as underweight (27.6%) or overweight (15.7%) by using the BMI (TVGH 2014).

Moreover, the results of the Chi-square tests (Table 5.3) showed there was no significant difference in the group of age among subject with and without suspected scoliosis, X^2 (3) = 2.715, *df* = 2, p = 0.438. The result of the Chi-square test showed there was no significant difference in the group of age among subjects with and without suspected scoliosis, X^2 (2) = 1.444, *df* = 2, p = 0.486.

Table 5.3 Results of Chi-square tests of age and BMl among the groups (subjects with and without suspected scoliosis)

Age x Groups (with and without suspected scoliosis)			
	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-square	2.715[a]	3	0.438
Likelihood ratio	2.821	3	0.420
N of valid cases	497		

a. 1 cell (12.5%) have expected count les than 5. The minimum expected count is 4.82.

BMI x Groups (with and without suspected scoliosis)			
	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-square	1.444[a]	2	0.486
Likelihood ratio	1.413	2	0.493
N of valid cases	496		

a. 0 cell (0%) have expected count les than 5. The minimum expected count is 17.11.

5.2.2 Demographic data of recruited human subjects

After the school-screening program was completed, possible subjects (with an ATR ≥3°) were invited to take radiographs for further evaluation of their spinal conditions, but only 12 of the possible subjects accepted the offer. Subjects who have a spinal curve (Cobb’s angle of 6-20 degrees) are defined as having early scoliosis (Dolan et al. 2007). From the result of the radiographs, 9 potential subjects with early scoliosis were found and all of them were invited to participate in the wear trial of the designed posture correction girdle after consultation with an orthopaedic surgeon. Table 5.4 shows the demographic data and basic information of the subjects.

Table 5.4 Demographic data and basic information of the subjects

Subject	Age	ATR (°)		Curve type (S/C)	Cobb's angle (°)		0 month		
		Thor	**Lum**		**Thor (Spinal level)**	**Lum (Spinal level)**	**Height (cm)**	**Weight (kg)**	**BMI**
1	12	L3	R3	S	4° **(T8-T11)**	14° **(T12-L3)**	140	33.7	17.2
2	11	R4	L3	C	/	7° **(T12-L3)**	156	44.8	18.4
3	11	R3	R3	S	6° (T7-T11)	4° **(T12-L4)**	145	30.7	14.6
4	12	R4	L3	S	19° **(T6-T12)**	15° **(T12-L4)**	157	65.1	26.4
5	13	L4	R4	S	19° **(T7-T11)**	13° **(T12-L3)**	150	37.2	16.5
6	10	R4	L3	S	17° **(T5-T11)**	13° **(T12-L4)**	146	45	21.11
7	12	R5	R4	S	8° **(T6-T9)**	15° **(T12-L4)**	159	36.8	14.56
8	10	R3	R5	S	8° **(T7-T10)**	5° **(T11-L3)**	142.5	36.5	17.97
9	11	R3	R6	S	4° **(T6-T9)**	8° **(T10-L4)**	138.5	32	16.68
				Mean	10.63	10.44	148.22	40.20	18.16
				SD	6.16	4.17	7.20	9.99	3.47

*Remarks: Thor (T) = Thoracic; Lum (L) = Lumbar

According to Table 5.3, in regards to the ages of the subjects, 2 of them are 10 years old, 3 are 11 years old, 3 are 12 years old and 1 is 13 years old. Their ATR and Cobb's angle range between 3-6° and 0-19° respectively. According to the results of Pearson correlation test (Table 5.5), there was no significant correlation of ATI and Cobb's angle in the thoracic ($r(9) = 0.356$, $p = 0.346$) and lumbar ($r(9) = -0,288$, $p = 0.453$) regions. In other words, ATR can be treated as a screening tool for scoliosis, but is not 100% correlated to the Cobb's angle that is measured by using radiographs. Moreover, C curves are found in 2 of the recruited subjects while S curves are found for the others. In terms of their BMI, 3 are underweight, 5 have a normal weight and 1 is overweight (TVGH 2014).

Table 5.5 Results of Pearson correlation test of ATI and Cobb's angle in the thoracic and lumbar region

		ATI (Thoracic)	ATI (Lumbar)	Cobb's angle (Thoracic)	Cobb's angle (Lumbar)
ATI (Thoracic)	**Pearson correlation**	1	-0.270	0.356	0.613
	Sig. (2-tailed)		0.483	0.346	0.079
	N	9	9	9	9
ATI (Lumbar)	**Pearson correlation**	-0.270	1	-0.179	-0.288
	Sig. (2-tailed)	0.483		0.645	0.453
	N	9	9	9	9
Cobb's angle (Thoracic)	**Pearson correlation**	0.356	-0.179	1	0.546
	Sig. (2-tailed)	0.346	0.645		0.128
	N	9	9	9	9
Cobb's angle (Lumbar)	**Pearson correlation**	0.613	-0.288	0.546	1
	Sig. (2-tailed)	0.079	0.453	0.128	
	N	9	9	9	9

*Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.

5.3 Prototype fabrication

5.3.1 Final pattern

Basic block alternation was applied as the method to make the pattern of the prototype. Bodice basic blocks for the subjects were developed after their body measurements were taken. Figure 5.3 shows a sample of the bodice basic block in a children's size (Rohr 1967).

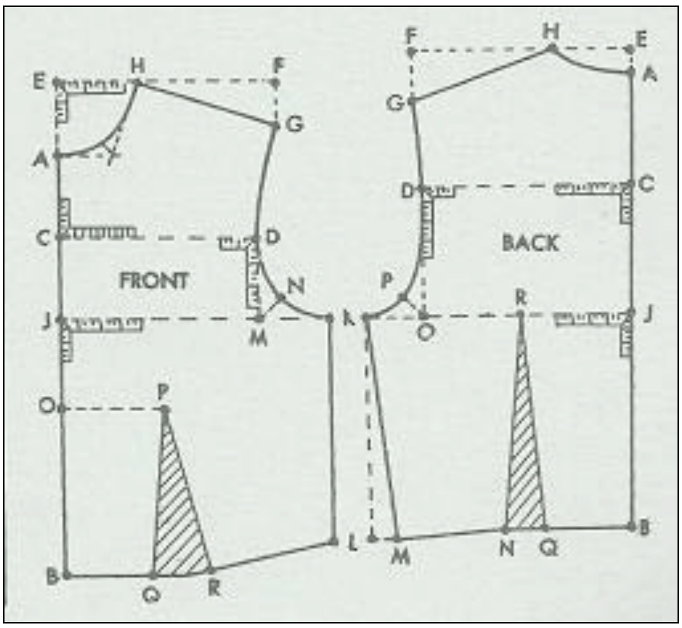


Figure 5.3 Sample of bodice basic block in a children's size (Rohr 1967)

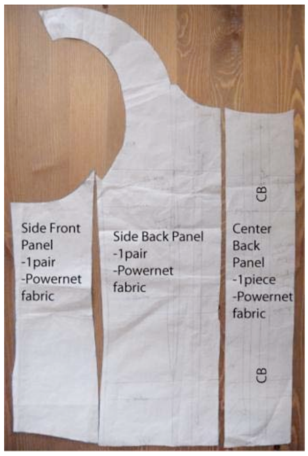
Wright (2001) believed that basic block alternation and adjustment can help to create a comfortable, attractive garment and allow a garment to better fit the body. Pattern adjustments, i.e. folding out excess fullness to make an area smaller, slashing and overlapping to reduce dimensions and redrawing darts or seam lines are carried out before cutting the fabric, in order to eliminate the problem of poor fit (Wright 2001). Additionally, some ease would need to be trimmed away for stretchable fabrics, in order to develop a pattern that would better fit the body. Usually, 10-15% of the original girth would be trimmed away, depending on the elasticity of the fabric and how tight the garment would need to be made (Keith 2008).

Once the first draft of the pattern was finished, a mock up made of the chosen fabrics was sewn for the first fitting. After eliminating the fitting problems that might affect the corrective function of the girdle, a complete set of patterns were developed. There were in total, 26 pattern pieces for the construction of the posture correction girdle excluding accessories, such as Velcro tape. Figure 5.4 shows the final pattern pieces of the posture correction girdle.

a) Shell layer

b) Support layer

c) Top pocket lining



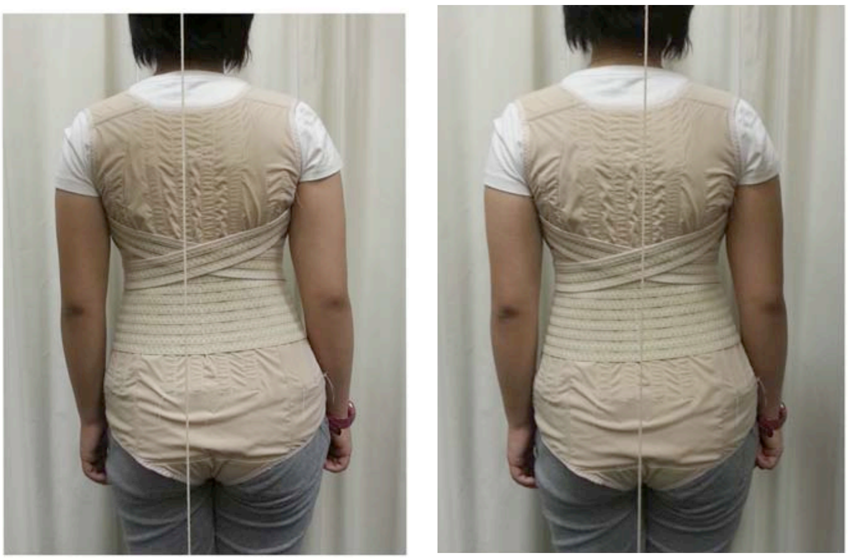
d) Under pocket lining

Figure 5.4 Final pattern pieces of the posture correction girdle

In regard to the shell layer (tricot), there were in total 11 pieces of pattern, including 1 pair of shell panels for the center front, 1 pair of shell panels for the side front, 1 pair of shell panels for the side back, 1 shell panel for the center back, 2 crotch panels, and 1 pair of front facing panels. In regard to the support layer, there were a total of 7 pieces of pattern, including 1 pair of supporting panels for the side front (satinette), 1 pair of supporting panels for the side back (satinette), 1 supporting panel for the center back (stabilizer), and 1 pair of shoulder paddings (spacer). In regard to the pocket lining layer (powernet), there were in total 8 pieces of pattern, including 1 pair of pocket lining panels for the top side front, 1 pair of pocket lining panels for the top side back, 1 lining panel for the top center back pocket, 1 pair of lining panels for the front pocket on the underside, and 1 lining panel for the back pocket on the underside.

5.3.2 Final prototype

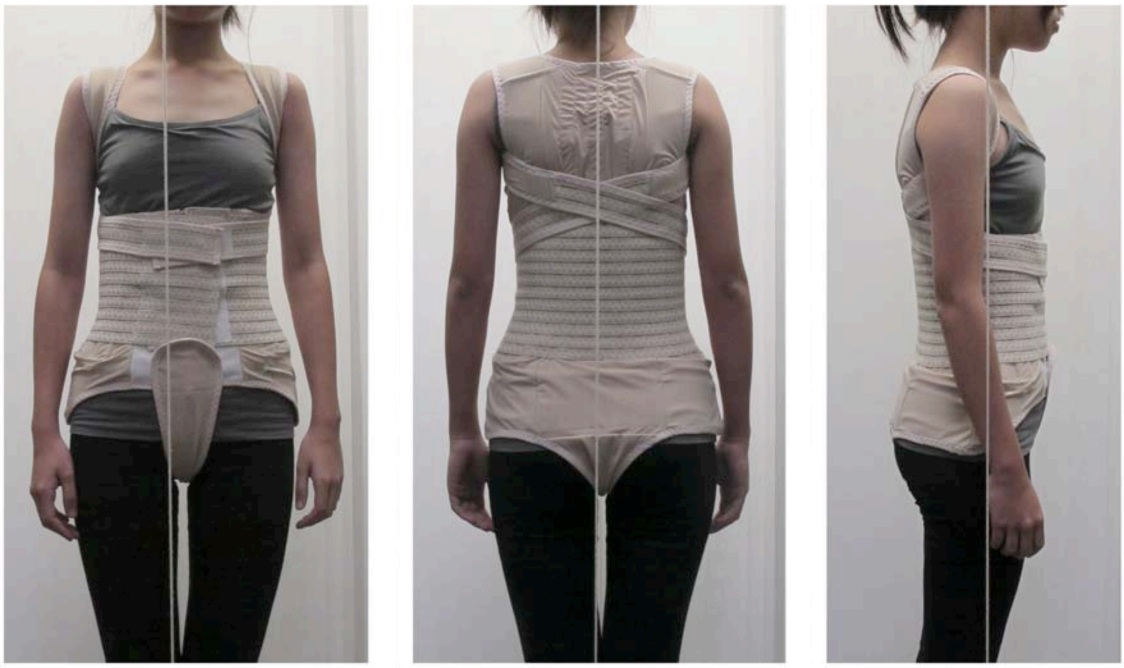
Once the set of patterns was completed, a girdle was prepared for a second fitting. During the second fitting, paddings (EVA foam) were inserted by a P&O into the pocket lining of the girdle to create point-pressures in accordance with different cases. Figure 5.5 is an example that shows the differences of the corrective effects between a girdle with paddings and without paddings on a subject. The example shows that there is only a mild corrective function provided by the girdle. The posture of the subject when she is wearing the girdle without padding is relatively imbalanced in comparison to the effect when she is wearing the girdle with padding. Her shoulders and pelvis are tilted outward to the left and right respectively from the center of body before the paddings were inserted. Then, both the shoulders and pelvis tilt back towards to the center of body and the body is more balanced after padding was inserted. The placement of the paddings for all of the subjects is shown in Appendix C.



a) Without padding b) With padding

Figure 5.5 Comparison of the corrective effect of girdle

After confirming the placement for the paddings, the prototype was completed. Figure 5.6 shows the final prototype of the posture correction girdle worn by one of the human subjects. The final prototype was then given to the subjects for the wear trial. Table 5.6 shows the levels of the padding prescribed and the level of spinal deformity of the subjects.



a) Front view b) Back view c) Side view

Figure 5.6 Final prototype of the posture correction girdle

Table 5.6 Levels of the spinal deformity and the padding prescribed of the subjects

	Levels of spinal deformity (Cobb's angle)		Levels of padding	
Subject	**Thor**	**Lum**	**Left**	**Right**
1	T8-T11 (4°)	T12-L3 (14°)	T12-L2	T9-11, L4-L5
2	/	T12-L3 (7°)	L1-L3	/
3	T7-T11 (6°)	T12-L4 (4°)	T11-L1	/
4	T6-T12 (19°)	T12-L4 (15°)	T12-L4	T7-T9
5	T7-T11 (19°)	T12-L3 (13°)	T6-T8, L1-3	T8-T11
6	T5-T11 (17°)	T12-L4 (13°)	L1-4	T7-T10
7	T6-T9 (9°)	T12-L4 (15°)	T12-L3	T7-T8, L4-L5
8	T7-T10 (8°)	T11-L3 (5°)	T8-T10, L4-L5	T12-L2
9	T6-T9 (4°)	T10-L4 (8°)	T10-L2	T6-T9, L4– L5

5.4 Chapter summary

A screening program has been carried out in various schools to investigate the prevalence of scoliosis in female students who fit the targeted criterion (ages 10-13). A total of 497 girls from 7 schools have participated in the program. The relatively high percentage might be due to the differences in the screening standards and increasing trend of scoliosis. Additionally, most of the possible subjects are 11 and 12 years old, which could be related to growth. Furthermore, there is no correlation found between the BMI and ATR, as the BMI in the P group coincides with the situations in the N group and T group.

After the school-screening program was carried out, 9 female subjects ages 10-13 were invited to participate in the wear trial. Each was provided with a tailor made posture correction girdle once the first and second fittings were finished. Padding insertion is one of the critical factors that affects the corrective function of the girdle, so a P&O was invited to give professional advice on padding placement and ensure that the corrective function of the girdles will work on the subjects before the wear trial started.

CHAPTER 6 - WEAR TRIAL AND RESULTS OF EVALUATION TESTS

6.1 Introduction

In this chapter, the compliance of the subjects during the wear trial will be discussed. The results of the tests are analyzed to investigate whether the girdling induced any problems in terms of health issues. The effectiveness on posture improvement by girdling will be evaluated by using various tests, including by 3D body scanning, examining the levelness of the shoulders by using the floor as a reference, and using a 3D motion capture system (Vicon), while the effectiveness of the control on the progression of spinal curve by girdling will be evaluated by using a radiographic method. 9 female subjects with early scoliosis were recruited, but only 7 completed the entire wear trial (6 months) and performed all of the evaluation tests. Two of the subjects (Subjects 2 and 5) withdrew from the wear trial after finished the 3-month evaluation tests due to participation in other types of therapy, i.e. subject 2 has dropped out in the 5th month and took the treatment of SpineCor (which is a type of flexible brace) and subject 5 has been dropped out in the 4th month and took the treatment of hard brace.

6.2 Wear compliance

After the adaptation period, the subjects were required to wear the posture correction girdle for 8 hours per day. A temperature logger (Thermocron) was inserted into the girdle to monitor the wear practice of the subjects. Table 6.1, Figures 6.1 and 6.2 show the wear practices of the subjects during the wear trial. If the subject wears the girdle over 8 hours per day, the compliance is regarded as 100%.

Table 6.1 Wear practices of the subjects

		Time (hours)								
Subject		**1 m**	**2 m**	**3 m**	**4 m**	**5 m**	**6 m**	**Mean**	**SD**	**Compliance (%)**
1		7.3	6.5	5.4	4.1	3.6	3.1	5	1.53	62.5
2		8.6	8.1	8.3	/	/	/	8.33	0.15	100
3		9.1	9.6	9.3	8.6	8.3	8.5	8.9	0.47	100
4		10.1	9.8	9.4	9.1	10.2	9.2	9.63	0.43	100
5		8.3	8.6	8.1	/	/	/	8.33	0.15	100
6		5.9	5.1	3.7	3.2	3.3	3.9	4.18	0.99	52.25
7		8.5	8	8.2	7.8	8.1	7.9	8.08	0.23	100
8		8.4	8.3	7.9	8.2	7.7	7.3	7.97	0.38	99.63
9		8.2	6.8	6.5	6.1	6.3	6.4	6.72	0.7	84
	Mean	8.27	7.87	7.42	6.73	6.79	6.61	7.28	0.62	93.25 (SD= 21.37)
	SD	1.09	1.42	1.77	2.14	2.36	2.14	1.72		
	Compliance (%)	100	98.38	92.75	84.13	84.88	82.63	91.33 (SD= 7.8)		

*Remarks: Subjects 2 and 5 withdrew after 3 months of participation in the wear trial

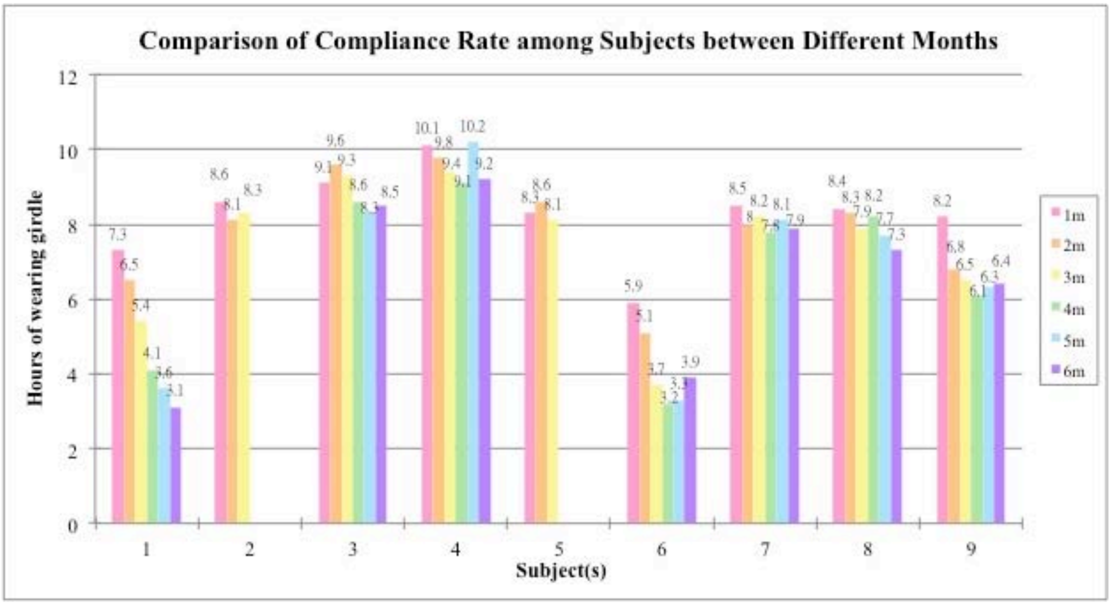


Figure 6.1 Comparison of compliance rate among subjects between different months

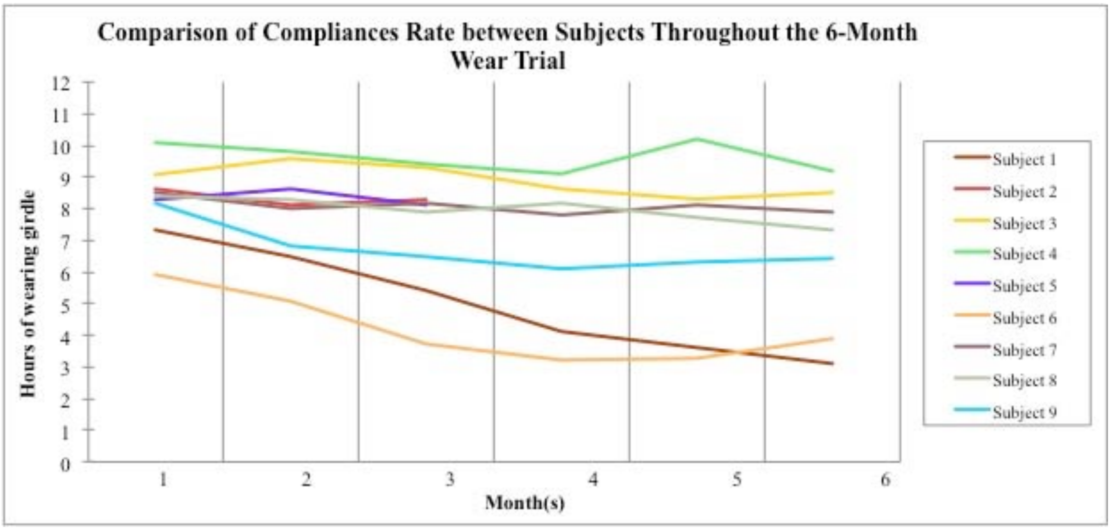


Figure 6.2 Comparison of compliance rate between subjects throughout 6-month wear trial

With regards to the results, the average rate of compliance among the 9 subjects is 93.25%, while the average rate of compliance during the 6 months is 91.33%. In other words, 93.5% presented the average wearing time among all subjects in the 6 months girdling period; while 91.33% presented the average wearing time of all subjects among the whole girdling period. The difference between the two averages is due to the withdrawal of Subjects 2 and 5 after 3 months of participation in the wear trial. As both of the calculations neglected the data that obtained in the withdrawal period (4-6m) of subject 2 and subject 6, therefore, there were only 7 subjects remained for the calculation of the wearing time of all subjects among 4-6m, which induced the difference between the two averages. For more details, the average wearing time among all subjects for the 1st month (1m) is 100%, 2nd month (2m) is 98.38%, 3rd (3m) is 92.75%, 4th (4m) is 84.13%, 5th (5m) is 84.88% and 6th (6m) is 82.63%; while the average wearing time of among the whole girdling period for subject 1 is 62.5%, subject 6 is 52.25%, subject 8 is 99.63%, subject 9 is 84%, and the rest are 100%. According to the results, higher average rates of compliance are found after the first (100%) and second months (98.38%) during the 6 months, and then reduced after the first month (100%) to the sixth month (82.63%). In this study, the wear trial (girdling period) was conducted from spring to summer (from March to August). Change of weather might be one of the factors that induced the reduction in compliance as it became increasingly warmer as the wear trial progressed. Hot weather might reduce willingness to wear the girdle as it would more or less increase skin temperature by the extra clothing which hinders heat loss (Benedict, Miles & Johnson 1919). Moreover, a higher compliance rate was found for Subjects 4 (100%) and 3 (100%), while a lower compliance rate was found for Subjects 6 (52.25%) and 1 (62.5%) throughout the 6 months of the wear trial. These results might due to the perseverance of the subjects. In other words, these subjects are more willing to wear the girdle to meet the wearing-time requirement (8 hours) since they have more perseverance as girdling would more or less bring about inconvenience to them. Perseverance might be affected by personality, psychological aesthetics and also the understanding of scoliosis (Zaina, Negrini, Fusco & Atanasio 2009; Hasler et al. 2010).

6.3 Results of health tests

In this study, health tests, including those on heart function (blood pressure and pulse measurements), pulmonary and touch, were carried out at the beginning of the wear trial (0 month) to ensure that the posture correction girdle has no health effects on the human subjects.

6.3.1 Blood pressure and pulse measurements

In regards to testing the heart function, the blood pressure and pulse change data were obtained before (without girdle) and after wearing the girdle for 3 hours (with girdle). The testing of the heart function was performed by using a digital sphygmomanometer. Tables 6.2 and 6.3 show the test results of Subjects 1 to 9.

Table 6.2 Blood pressure changes of Subjects 1 to 9

	Blood Pressure		
Subject	**Before wearing girdle**	**After wearing girdle for 3 hours**	**Change**
1	96; 67 mmHg	101; 61 mmHg	+ 5; - 6 mmHg
2	95; 61 mmHg	95; 59 mmHg	0; - 2 mmHg
3	99; 58 mmHg	97; 65 mmHg	- 2; + 7 mmHg
4	96; 55 mmHg	100; 66 mmHg	+ 4; + 11 mmHg
5	114; 68 mmHg	116; 69 mmHg	+ 2; + 1 mmHg
6	102; 56 mmHg	103; 64 mmHg	+ 1; + 8 mmHg
7	98; 60 mmHg	96; 61 mmHg	- 2; +1 mmHg
8	101; 61 mmHg	102; 65 mmHg	- 1; +4 mmHg
9	103; 58 mmHg	101; 59 mmHg	- 2; +1 mmHg
		Mean of the changes	+ 0.56; +2.78 mmHg

*Remarks: normal range is 113 ±18; 59 ±10 mmHg (National Institutes of Health 2004)

Table 6.3 Pulse changes of Subjects 1 to 9

	Pulse		
Subject	**Before wearing girdle**	**After wearing girdle for 3 hours**	**Change**
1	94 pulse/min	93 pulse/min	- 1 pulse/min
2	78 pulse/min	75.5 pulse/min	- 2.5 pulse/min
3	81 pulse/min	87 pulse/min	+ 6 pulse/min
4	94 pulse/min	100 pulse/min	+ 6 pulse/min
5	96 pulse/min	100 pulse/min	+ 4 pulse/min
6	72 pulse/min	74 pulse/min	+ 2 pulse/min
7	74 pulse/min	76 pulse/min	+ 2 pulse/min
8	80 pulse/min	83 pulse/min	+ 3 pulse/min
9	93 pulse/min	91 pulse/min	- 2 pulse/min
		Mean of the changes	+ 1.94 pulse/min
*Remarks: normal range is 60-100 pulse/min (Leena 2011)			

In regard to the results of testing the heart function of the subjects, no significant differences are found, including blood pressure and pulse rate before (without girdle) and after wearing the posture correction girdle for 3 hours (with girdle). According to the test results of repeated measures ANOVA (Appendix I), it indicates that there is no significant effect on the blood circulation including blood pressure ($F(1,8) = 3.161$, $p = 0.0113$) and pulse ($F(1,8) = 2.631$, $p = 0.143$) of the subjects, which would be induced by the wearing of posture correction girdle. The greatest change was found for Subjects 3 (+ 6 pulse/min) and 4 (+ 6 pulse/min), while the least amount of change was found for Subject 1 (-1 pulse/min). The mean of the changes of the blood pressure after wearing the flexible brace is not significant, i.e. + 0.56; +2.78 mmHg, and still within a normal range of 95-131; 49-69 mmHg (National Institutes of Health 2004). The pulse rate of the subjects after wearing the flexible brace is within a normal range and no significant changes are found, i.e. + 1.94 pulse/min (Leena 2011). The test results indicate that there is no significant effect on the blood circulation of the subjects, which would be induced by the wearing of posture correction girdle.

6.3.2 Peak expiration flow measurement

In regards to the pulmonary function tests (PFTs), changes in the peak expiration flow (PEF) values were obtained before (without girdle) and after wearing the girdle for 3 hours (with girdle). The testing was performed by using a peak flow meter. Table 6.4 shows the test results of Subjects 1 to 9.

Table 6.4 Changes in PEF values of Subjects 1 to 9

	Peak Expiratory Flow (PEF)		
Subject	**Before wearing girdle**	**After wearing girdle for 3 hours**	**Changes**
1	165 L	165 L	0 L
2	175 L	170 L	- 5 L
3	250 L	290 L	+ 40 L
4	170 L	180 L	+ 10 L
5	260 L	260 L	0 L
6	190 L	210 L	+ 20 L
7	285 L	290 L	+ 5 L
8	265 L	270 L	+ 5 L
9	200 L	195 L	- 5 L
		Mean of the changes	+ 7.78 L

*Remarks: normal range is 162-424 L (LSU Health Shreveport 2013)

In regard to the results of the PFT of the subjects, no significant differences are found in the PEF values before (without girdle) and after wearing the posture correction girdle for 3 hours (with girdle). According to the test results of repeated measures ANOVA (Appendix I), it indicates that there is no significant effect on the peak expiration flow ($F(1,8) = 2.631$, $p = 0.143$), i.e. expiration and breathing capacity of the subjects, which would be induced by the wearing of posture correction girdle. The greatest change was found for Subject 3 (+ 40 L), while the least amount of change was found for Subjects 1 (0 L) and 5 (0 L). The mean of the changes of the PEF values is not significant, i.e. 7.78 L, and within a normal range of 162-424 L (LSU Health Shreveport 2013). The test results indicate that there is no significant effect on the expiration and breathing capacity of the subjects, which are induced by the wearing of the posture correction girdle.

6.3.3 Sensory level measurement

In regards to the touch-tests, the data from the sensory level (filament size of evaluators) changes were obtained before (without girdle) and after wearing the girdle for 3 hours (with girdle). The testing was performed by using a touch-test sensory evaluator (North Coast). Table 6.5 shows the test results for Subjects 1 to 9.

Table 6.5 Sensory level (evaluator filament size) changes of Subjects 1 to 9

		Touch-test					
Subject		**Ulnar**		**Radial**		**Median**	
		Palmar	**Dorsum**	**Palmar**	**Dorsum**	**Palmar**	**Dorsum**
1	**Before**	2.83	2.83	2.83	2.83	3.61	2.83
	After	2.83	2.83	2.83	2.83	3.61	2.83
2	**Before**	2.83	2.83	2.83	3.61	2.83	3.61
	After	2.83	2.83	2.83	3.61	2.83	3.61
3	**Before**	2.83	2.83	2.83	2.83	2.83	2.83
	After	2.83	2.83	2.83	2.83	2.83	2.83
4	**Before**	2.83	2.83	2.83	2.83	3.61	2.83
	After	2.83	2.83	2.83	3.61	2.83	2.83
5	**Before**	2.83	2.83	2.83	2.83	2.83	2.83
	After	2.83	2.83	3.61	3.61	2.83	2.83
6	**Before**	2.83	2.83	2.83	2.83	2.83	2.83
	After	2.83	3.61	3.61	2.83	2.83	2.83
7	**Before**	2.83	2.83	2.83	2.83	2.83	2.83
	After	2.83	2.83	2.83	2.83	2.83	2.83
8	**Before**	2.83	2.83	2.83	2.83	2.83	2.83
	After	2.83	3.61	3.61	2.83	2.83	2.83
9	**Before**	2.83	2.83	2.83	2.83	2.83	2.83
	After	2.83	2.83	2.83	2.83	2.83	2.83

In regard to the results of the touch-test of the subjects, no significant differences are found at the sensory level (filament size of evaluators) before (without girdle) and after wearing the posture correction girdle for 3 hours (with girdle). According to the test results of repeated measures ANOVA (Appendix I), it indicates that there is no significant effect on the sensory level of the hand ($F(1,8) = 2.286$, $p = 0.169$) of the subjects, which would be induced by the wearing of posture correction girdle. The changes are only between 2.83 and 3.61. The test results indicate that there is no significant effect on the sensory level of the hand of the subjects, which is induced by the wearing of the posture correction girdle. Also, no feelings of numbness, tingling and prickliness were found.

6.4 Results of evaluation tests for posture change

The effectiveness on posture improvement by girdling was evaluated by various tests, including by 3D body scanning, examining the levelness of the shoulders by using the floor as a reference, and using a 3D motion capture system. First, the results from these evaluation tests are separately described. Then, the posture changes after the wear trial will be discussed.

6.4.1 Results of 3D body scanning

The scanning data obtained from a 3D body scanner (Anthroscan) were exported after clearing the noise and filling in the gaps. Then, the data were processed by using MatLab 2013a. The data in the "obj." file format were first converted into the "txt." file format. Secondly, the data were aligned according to the center of the body of the subjects and the placements of their foot at the x, y and z-axes (Figure 6.3). Also, their heads, hands and legs were cut to reduce the file size. Then, the cross-sections of the marking lines according to the markers that were placed onto on the subject's bodies at their shoulder and pelvis levels were exported. Finally, the angle between the shoulder and pelvis level in the horizontal plane was measured for comparison and the results were presented as an absolute angle. Figure 6.4 shows an image of a bodice with marking lines at the shoulder and pelvis levels, while Figure 6.5 shows the angle that is measured for comparison.

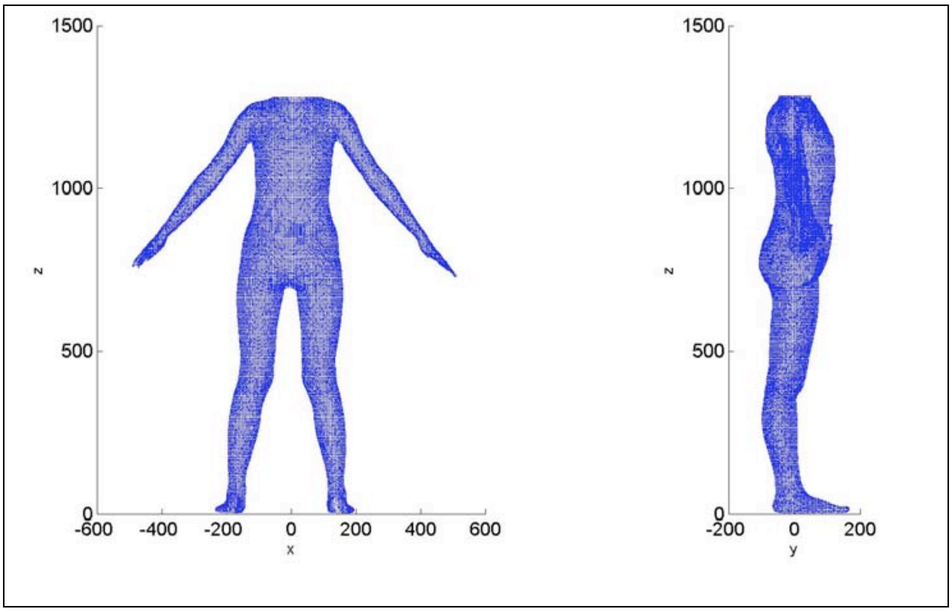


Figure 6.3 Data alignment at x, y and z-axes

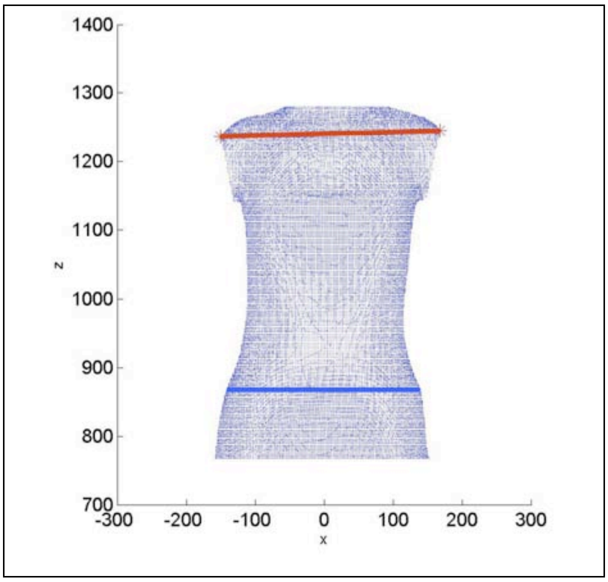


Figure 6.4 Image of bodice with marking lines

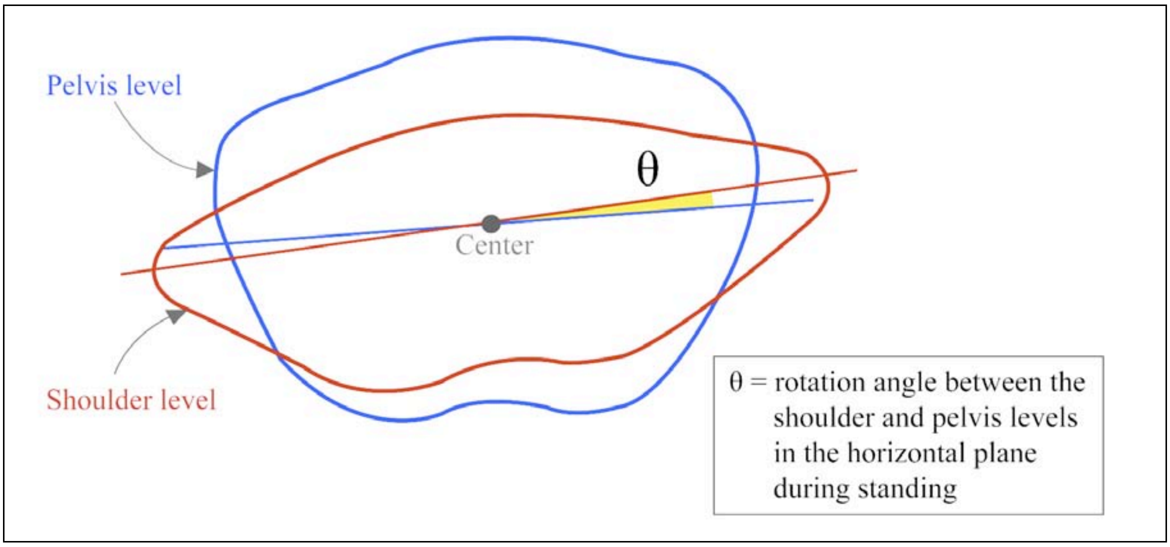


Figure 6.5 Angle between shoulder and pelvis levels in horizontal plane (cross-section)

With regards to the results, a larger angle between the shoulder and pelvis levels in the horizontal plane means greater rotation from the centerline (horizontal plane) of the body. In other words, a smaller angle means that the subject has a more balanced posture in the horizontal plane.

6.4.1.1 Results of the effects of girdling and time on postural change for 3D body scanning

By using an alpha level of 0.05, a method of 2-ways repeated measures ANOVA was conducted to evaluate the effects of girdling (with and without wearing the girdle) and time (0, 3 and 6 months) on postural change (the angle between the shoulder and pelvis levels of the subjects in the horizontal plane during standing). The reduction of rotation angle might indicate an improvement on the rotation problem between shoulder and pelvic levels in the horizontal plane during standing.

According to the results (see Table 6.6 and 6.7), for the main effect, no significant differences were found on girdling (without girdle, with girdle), $F(1,6) = 3.591$, $p = 0.107$ and time (0, 3, 6 months), $F(2,5) = 2.963$, $p = 0.142$. For the interaction effect, no interaction effect between girdling (without girdle, with girdle) and time (0, 3, 6 months) on postural change, $F(2,5) = 2.022$, $p = 0.227$. In other words, no significant improvement of rotation angle (between shoulder and pelvic levels in horizontal pane during standing) that induced by the effect of girdling and time was found. The changes of rotation angle in horizontal plane during standing from 0 month to 6 months were shown in Figure 6.6.

Table 6.6 Descriptive statistics of 2-ways repeated measures ANOVA test for 3D body scanning data

Measurement Item	Mean	Std. Deviation	N
0 month (without girdle)	2.7857	1.56162	7
0 month (with girdle)	1.5314	0.52869	7
3 month (without girdle)	2.1799	0.93299	7
3 month (with girdle)	1.4086	0.91282	7
6 month (without girdle)	1.1686	0.73647	7
6 month (with girdle)	0.9829	0.69832	7

Table 6.7 Results of 2-ways repeated measures ANOVA test for 3D body scanning data

Effect	F	Hypothesis df	Error df	Sig.
Time	2.963	2	5	0.142
Girdling	3.591	1	6	0.107
Time*Girdling	2.022	2	5	0.227

Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.

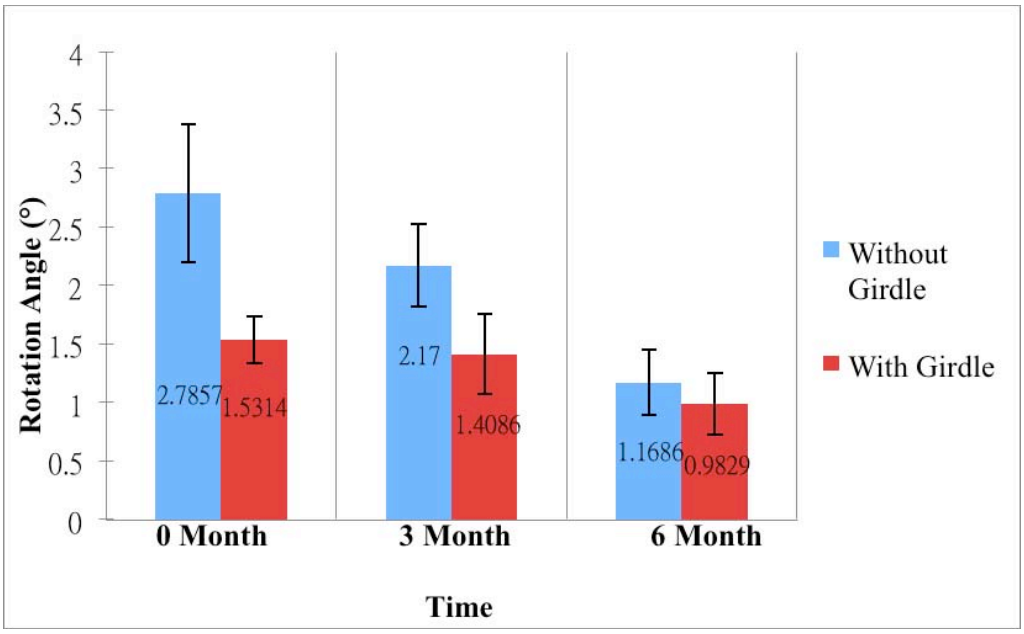


Figure 6.6 Change of rotation angle (horizontal plane) from 0 month to 6 months

6.4.2 Results of shoulder levelness measurements

Direct measurements of the shoulder levelness by using the floor as a reference were obtained at the beginning (0 month), after 3 months and at the end (6 months) of the wear trial. The measurement of shoulder levelness by using the floor as a reference of the subjects is one of the ways to determine the effect of posture correction on the shoulders after treatment. The shoulder levelness measurements were carried out by using cm as the unit of measurement. A smaller difference found on the shoulder levelness between the left and right shoulders means more balance in the shoulders in the frontal plane.

6.4.2.1 Results of the effects of girdling and time on postural change for shoulder levelness measurement

By using an alpha level of 0.05, a method of 2-ways repeated measures ANOVA was conducted to evaluate the effects of girdling (without girdle, with girdle but no padding, with girdle and padding) and time (0, 3 and 6 months) on postural change (shoulder levelness between the left and right shoulders in the frontal plane during standing). The reduction of shoulder height difference between left and right might indicate an improvement on the problem of uneven shoulder in the frontal plane during standing.

According to the results (see Table 6.8 and 6.9), in regard to the main effect, overall statistically significant difference was found in girdling (without girdle, with girdle but no padding, with girdle and padding), $F(2, 5) = 7.469$, $p = 0.031$, but no significant differences were found on time (0, 3, 6 months), $F(2,5) = 1.652$, $p = 0.281$. In regard to interaction effect, no interaction effect was found between girdling (without girdle, with girdle) and time (0, 3, 6 months) on postural change, $F(4,3) = 0.967$, $p = 0.532$.

As overall statistically significant difference was found in girdling (without girdle, with girdle but no padding, with girdle and padding), therefore, post-hoc test (Bonferroni) was conducted to examine the pairwise comparison in the variable (see Table 6.10). In regard to post-hoc comparison, in 0 month, statistically significant were found between: 1) without girdle and with girdle (no pad), $T(8) = 3.656$, $p = 0.006$, 2) with girdle (no pad) and with girdle (with pad), $T(8) = 5.415$, $p = 0.001$, and 3) without girdle and with girdle (with pad), $T(8) = 5.286$, $p = 0001$. In regard to post-hoc comparison, in 3 month, statistically significant were found between: 1. without girdle and with girdle (no pad), $T(8) = 3.492$, $p = 0.008$, 2. with girdle (no pad) and with girdle (with pad), $T(8) = 5.605$, $p = 0.001$, 33. without girdle and with girdle (with pad), $T(8) = 5.126$, $p = 0.001$. These results indicated that wear girdle with padding insertion have better effects than without wearing girdle and wear the girdle that without padding insertion in both of 0 and 3 months. However, in regard to post-hoc comparison, in 6 months, no statistically significant was found.

Table 6.8 Descriptive statistics of 2-ways repeated measures ANOVA test for shoulder levelness measurement

Measurement Item	Mean	Std. Deviation	N
0 month (without girdle)	1.5571	0.81211	7
0 month (with girdle no padding)	1.2286	0.62106	7
0 month (with girdle and padding)	0.2571	0.26367	7
3 month (without girdle)	1.3286	0.82404	7
3 month (with girdle no padding)	1.0000	0.60277	7
3 month (with girdle and padding)	0.2429	0.32071	7
6 month (without girdle)	1.1143	0.92453	7
6 month (with girdle no padding)	0.8286	0.73420	7
6 month (with girdle and padding)	0.2571	0.44293	7

Table 6.9 Results of 2-ways repeated measures ANOVA test for shoulder levelness measurement

Effect	F	Hypothesis df	Error df	Sig.
Time	1.625	2	5	0.281
Girdling	7.469	2	5	0.031
Time*Girdling	0.967	4	3	3.869

Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.

Table 6.10 Results of post-hoc test for the effect of girdling at 0 month and 3 months in shoulder levelness measurement

			0 month			
Item	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t**	**df**	**Sig. (2-tailed)**
Pair 1: without girdle vs. with girdle no padding	0.27778	0.22791	0.07597	3.656	8	0.006
Pair 2: with girdle no padding vs. with girdle and padding	0.95556	0.52941	0.17647	5.415	8	0.001
Pair 3: without girdle vs. with girdle and padding	1.23333	0.70000	0.23333	5.286	8	0.001
			3 months			
Item	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t**	**df**	**Sig. (2-tailed)**
Pair 1: without girdle vs. with girdle no padding	0.27778	0.23863	0.07954	3.492	8	0.008
Pair 2: with girdle no padding vs. with girdle and padding	0.72222	0.38658	0.12886	5.605	8	0.001
Pair 3: without girdle vs. with girdle and padding	1.00000	0.19508	0.19508	5.126	8	0.001

Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.

6.4.3 Results of motion capturing

In regard to the data obtained from the motion capture system, the results of the 16 posture parameters for different tasks including 1) standing, 2) sitting, 3) walking and 4) bending (see Table 3.7 in Chapter 3) were calculated, analyzed and presented in absolute angle (°).

With regards to the results of the absolute angle for the 16 posture parameters, a reduction of the angle means improvement in posture for 1) standing, 3) walking and 4) bending tasks, i.e. more balance in the frontal plane for standing and walking tasks, less rotation in the horizontal plane for standing and walking tasks, as well as control of extra motion for the bending task; while increases in the angle means improvement of posture for the 2) sitting task, i.e. less curviness in the sagittal plane.

6.4.3.1 Results of the effects of girdling and time on postural change for motion capturing

By using an alpha level of 0.05, a method of 2-ways repeated measures ANOVA was conducted to evaluate the effects of girdling (with and without wearing the girdle) and time (0, 3 and 6 months) on postural change (absolute angle for the 16 posture parameters). The reduction of shoulder height difference between left and right might indicate an improvement on the problem of uneven shoulder in the frontal plane during standing. The reduction of the angles might indicate improvements of posture for standing, walking and bending tasks; while increases in the angles might indicate improvements of posture for the sitting task.

According to the results (see Table 6.11 and 6.12), there were statistically significant differences of the main effect of girdling (without girdle, with girdle) on posture parameter 1 (acromion angle in frontal plane during standing) with $F(1,6) = 6.083$, $p = 0.049$, posture parameter 4 (acromion angle in horizontal plane during standing) with $F(1,6) = 13.467$, $p = 0.010$, and posture parameter 9 (thoracic angle in sagittal plane during sitting) with $F(1,6) = 24.022$, $p = 0.003$. The results indicate that girdling might possibly bring immediate improvements to the posture parameters 1, 4 and 9, i.e. more even shoulder in frontal plane and horizontal plane during standing, as well as straighter upper back in sagittal plane during sitting. In addition, there were also statistically significant differences of the main effect of time (0, 3, 6 months) on posture parameter 1 (acromion angle in frontal plane during standing) with $F(2,12) = 8.409$, $p = 0.005$, posture parameter 9 (thoracic angle in sagittal plane during sitting) with $F(2,12) = 4.270$, $p = 0.04$, and posture parameter 11 (acromion angle in frontal plane during walking) with $F(2,12) = 4.449$, $p = 0.036$. As overall statistically significant difference was found in time (0, 3 and 6 months), therefore, post-hoc test (Bonferroni) was conducted to examine the pairwise comparison in the variable (see Table 6.13). The results show that there were statistically significant differences between 0 and 6 months ($p = 0.012$) of parameter 1 acromion angle (frontal plane) during standing, 0 and 6 months ($p = 0.014$) of posture parameter 11 acromion angle (frontal plane) during walking. However, no statistically significant difference was found on posture parameter 9 thoracic angle (sagittal plane) of sitting. The results indicate that time-to-time improvements that contributed by time effect (6 months) might possibly found on posture parameters 1 and 11, i.e. more even shoulder in frontal plane during standing and walking.

Moreover, there were statistically significant differences of interaction effects of girdling (without girdle, with girdle) x time (0, 3, 6 months) on posture parameter 1 (acromion angle in frontal plane during standing) with $F(2,12) = 7.856$, $p = 0.007$, posture parameter 2 (pelvic angle in frontal plane during standing) with $F(2,12) = 4.096$, $p = 0.044$, posture parameter 10 (lumbar angle in sagittal plane during sitting) with $F(2,12) = 5.111$, $p = 0.025$, posture parameter 15 (maximum anterior bending range) with $F(2,12) = 6.021$, $p = 0.015$, and posture parameter 16 (maximum lateral bending range) with $F(2,12) = 27.411$, $p = 0.00$. Interaction effect means the independent variables, i.e. girdling and time, have a complex influence on the dependent variable, i.e. postural change. The results indicate that the possible postural changes of posture parameter 1, 2, 10, 15 and 16, i.e. more even shoulder an pelvis in frontal plane during standing, straighter lower back in sagittal plane during sitting, as well as acceptable constrained anterior and lateral bending range, might possibly contribute by both of the effects of girdling and time.

Table 6.11 Descriptive statistics of 2-ways repeated measures ANOVA test for motion capturing

		0 month		
Posture parameter	**Item**	**Mean**	**Std. Deviation**	**N**
1	**0 month (without girdle)**	3.3857	1.43994	7
	0 month (with girdle)	1.7057	0.69118	7
2	**0 month (without girdle)**	3.2529	1.12938	7
	0 month (with girdle)	2.0271	1.55864	7
3	**0 month (without girdle)**	2.3757	1.33183	7
	0 month (with girdle)	1.4771	0.46707	7
4	**0 month (without girdle)**	3.1629	3.15217	7
	0 month (with girdle)	2.8900	2.79516	7
5	**0 month (without girdle)**	4.4571	3.14226	7
	0 month (with girdle)	4.4871	3.11854	7
6	**0 month (without girdle)**	1.7857	1.62602	7
	0 month (with girdle)	1.6443	1.31997	7
7	**0 month (without girdle)**	2.5629	2.07435	7
	0 month (with girdle)	3.2086	2.49773	7
8	**0 month (without girdle)**	3.9743	2.33651	7
	0 month (with girdle)	3.9143	2.55020	7
9	**0 month (without girdle)**	151.5671	6.55324	7
	0 month (with girdle)	153.1171	6.46386	7
10	**0 month (without girdle)**	162.2257	12.28266	7
	0 month (with girdle)	172.0200	1.97966	7
11	**0 month (without girdle)**	10.3429	1.85224	7
	0 month (with girdle)	8.8629	1.84836	7
12	**0 month (without girdle)**	9.6500	1.82413	7
	0 month (with girdle)	8.4086	2.81798	7
13	**0 month (without girdle)**	22.4929	7.34049	7

	0 month (with girdle)	18.7743	4.79293	7
14	**0 month (without girdle)**	18.5100	4.32039	7
	0 month (with girdle)	17.5714	3.51198	7
15	**0 month (without girdle)**	84.7171	28.13342	7
	0 month (with girdle)	75.0571	18.86007	7
16	**0 month (without girdle)**	41.9514	6.48683	7
	0 month (with girdle)	29.7157	6.06289	7

3 months

Posture parameter	Item	Mean	Std. Deviation	N
1	**3 month (without girdle)**	2.1171	1.00651	7
	3 month (with girdle)	1.3729	0.86174	7
2	**3 month (without girdle)**	2.6286	1.43287	7
	3 month (with girdle)	2.2057	1.39636	7
3	**3 month (without girdle)**	2.0914	0.60057	7
	3 month (with girdle)	1.9986	0.75034	7
4	**3 month (without girdle)**	2.3829	2.08414	7
	3 month (with girdle)	2.2329	2.34218	7
5	**3 month (without girdle)**	4.0914	2.43342	7
	3 month (with girdle)	4.1214	3.58415	7
6	**3 month (without girdle)**	1.8243	1.64125	7
	3 month (with girdle)	1.7314	0.97552	7
7	**3 month (without girdle)**	2.5143	1.70368	7
	3 month (with girdle)	2.5443	1.91441	7
8	**3 month (without girdle)**	3.6943	1.83034	7
	3 month (with girdle)	2.6729	1.64851	7
9	**3 month (without girdle)**	153.734	5.98615	7
	3 month (with girdle)	154.2229	5.26618	7
10	**3 month (without girdle)**	167.0157	7.37461	7
	3 month (with girdle)	171.9500	3.32441	7
11	**3 month (without girdle)**	9.7757	2.50378	7
	3 month (with girdle)	9.6529	3.25326	7
12	**3 month (without girdle)**	9.0500	1.83441	7
	3 month (with girdle)	7.8386	1.33760	7
13	**3 month (without girdle)**	19.1557	4.58904	7
	3 month (with girdle)	17.3386	5.27910	7
14	**3 month (without girdle)**	17.0357	3.16968	7
	3 month (with girdle)	17.7457	4.29050	7
15	**3 month (without girdle)**	80.5471	24.84551	7
	3 month (with girdle)	73.5243	21.13012	7
16	**3 month (without girdle)**	42.3929	7.21021	7
	3 month (with girdle)	30.5043	4.84437	7

6 months

Posture parameter	Item	Mean	Std. Deviation	N
1	**6 month (without girdle)**	1.5643	0.80527	7
	6 month (with girdle)	1.2929	0.87202	7
2	**6 month (without girdle)**	2.5029	0.91535	7
	6 month (with girdle)	2.1057	1.06611	7
3	**6 month (without girdle)**	1.9771	0.57511	7
	6 month (with girdle)	1.8329	0.58108	7
4	**6 month (without girdle)**	2.2071	2.33454	7
	6 month (with girdle)	2.1071	2.32756	7
5	**6 month (without girdle)**	3.6171	3.35595	7
	6 month (with girdle)	3.4900	3.71034	7
6	**6 month (without girdle)**	1.5829	1.13975	7
	6 month (with girdle)	1.4500	1.00587	7
7	**6 month (without girdle)**	2.5357	1.62788	7
	6 month (with girdle)	2.4371	1.81716	7
8	**6 month (without girdle)**	3.0514	2.05390	7

	6 month (with girdle)	2.5071	1.74414	7
9	**6 month (without girdle)**	155.8186	5.26228	7
	6 month (with girdle)	156.8986	5.67077	7
10	**6 month (without girdle)**	168.1357	4.53602	7
	6 month (with girdle)	172.0857	3.83174	7
11	**6 month (without girdle)**	8.7457	2.04439	7
	6 month (with girdle)	7.8900	2.56388	7
12	**6 month (without girdle)**	8.3471	1.97781	7
	6 month (with girdle)	7.1471	1.10492	7
13	**6 month (without girdle)**	18.3814	4.69858	7
	6 month (with girdle)	17.2457	4.10257	7
14	**6 month (without girdle)**	16.1614	3.69630	7
	6 month (with girdle)	16.1271	4.53455	7
15	**6 month (without girdle)**	80.5886	25.20828	7
	6 month (with girdle)	74.8657	23.42956	7
16	**6 month (without girdle)**	43.4029	7.91318	7
	6 month (with girdle)	32.5657	5.58802	7

Table 6.12 Results of 2-ways repeated measures ANOVA test for motion capturing

Posture parameter	**Effect**	**F**	**Hypothesis df**	**Error df**	**Sig.**
1	**Time**	8.409	2	12	0.005
	Girdling	6.083	1	6	0.049
	Time*Girdling	7.856	2	12	0.007
2	**Time**	3.032	2	12	0.086
	Girdling	4.504	1	6	0.078
	Time*Girdling	4.096	2	12	0.044
3	**Time**	1.715	2	12	0.221
	Girdling	0.022	1	6	0.887
	Time*Girdling	2.421	2	12	0.131
4	**Time**	1.636	2	12	0.235
	Girdling	13.467	1	6	0.010
	Time*Girdling	0.220	2	12	0.805
5	**Time**	2.012	2	12	0.176
	Girdling	2.511	1	6	0.164
	Time*Girdling	0.204	2	12	0.818
6	**Time**	0.395	2	12	0.682
	Girdling	0.330	1	6	0.587
	Time*Girdling	0.406	2	12	0.675
7	**Time**	1.297	2	12	0.309
	Girdling	1.027	1	6	0.350
	Time*Girdling	0.406	2	12	0.523
8	**Time**	1.956	2	12	0.184
	Girdling	4.209	1	6	0.086
	Time*Girdling	0.522	2	12	0.606
9	**Time**	4.270	2	12	0.040
	Girdling	24.022	1	6	0.003
	Time*Girdling	0.021	2	12	0.979
10	**Time**	1.856	2	12	0.198
	Girdling	4.186	1	6	0.087
	Time*Girdling	5.111	2	12	0.025
11	**Time**	4.449	2	12	0.036
	Girdling	0.999	1	6	0.356
	Time*Girdling	1.450	2	12	0.273
12	**Time**	0.809	2	12	0.468
	Girdling	3.449	1	6	0.113
	Time*Girdling	2.409	2	12	0.132

13	**Time**	1.282	2	12	0.313
	Girdling	5.124	1	6	0.064
	Time*Girdling	3.068	2	12	0.084
14	**Time**	1.704	2	12	0.223
	Girdling	0.778	1	6	0.412
	Time*Girdling	0.061	2	12	0.941
15	**Time**	0.445	2	12	0.651
	Girdling	2.264	1	6	0.183
	Time*Girdling	6.021	2	12	0.015
16	**Time**	0.456	2	12	0.645
	Girdling	2.228	1	6	0.186
	Time*Girdling	27.411	2	12	0.000

Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.

Table 6.13 Results of post-hoc test for the effect of time in motion capturing

Posture parameter	Item	Mean Difference	Std. Error	Sig. (2-tailed)
1	**Pair 1: 0 month vs. 3 months**	0.744	0.252	0.076
	Pair 2: 3 month vs. 6 months	-0.070	0.187	1.000
	Pair 3: 0 month vs. 6 months	0.674	0.149	0.012
9	**Pair 1: 0 month vs. 3 months**	-1.573	0.970	0.468
	Pair 2: 3 month vs. 6 months	0.847	0.655	0.731
	Pair 3: 0 month vs. 6 months	-2.420	0.865	0.094
11	**Pair 1: 0 month vs. 3 months**	1.194	0.511	0.175
	Pair 2: 3 month vs. 6 months	-0.029	0.542	1.000
	Pair 3: 0 month vs. 6 months	1.165	0.266	0.014

Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.

6.4.4 Reliabilities of measurements that quantified postural changes on the subjects

Reliability tests were conducted to evaluate the reliabilities of the measurements that used to quantify postural changes on subjects. The measurements included the rotation angle between the shoulder and pelvis levels in horizontal plane from the method of 3D body scanning, shoulder levelness from the method of direct measurement and absolute angles for the 16 posture parameters from the method of motion capturing. Table 6.14 shows the results of the test-retest reliability tests for the measurements that mentioned above.

Table 6.14 Results of reliability test for the measurements that quantified postural changes on the subjects

	With girdle		Without girdle	
	r	r^2	r	r^2
3D Body scanning (rotation angle)	0.999	0.998	1.000	0.999
Direct measurement (shoulder levelness)	0.992	0.985	0.997	0.994
Motion capturing - posture parameter 1	0.987	0.974	0.974	0.948
Motion capturing - posture parameter 2	0.958	0.919	0.971	0.942
Motion capturing - posture parameter 3	0.151	0.023	0.824	0.679
Motion capturing - posture parameter 4	0.919	0.845	0.772	0.596
Motion capturing - posture parameter 5	0.971	0.942	0.930	0.865
Motion capturing - posture parameter 6	-0.152	0.023	0.864	0.746
Motion capturing - posture parameter 7	0.510	0.260	0.195	0.038
Motion capturing - posture parameter 8	0.715	0.511	0.440	0.193
Motion capturing - posture parameter 9	0.871	0.759	0.883	0.780
Motion capturing - posture parameter 10	-0.160	0.026	0.943	0.890
Motion capturing - posture parameter 11	0.775	0.600	0.806	0.649
Motion capturing - posture parameter 12	0.896	0.803	0.892	0.795
Motion capturing - posture parameter 13	0.986	0.972	0.990	0.981
Motion capturing - posture parameter 14	0.955	0.912	0.981	0.963
Motion capturing - posture parameter 15	0.996	0.992	0.994	0.988
Motion capturing - posture parameter 16	0.963	0.928	0.906	0.820

The acceptable reliability level in the present study was set as r>0.7. According to the results, for the tests during “with girdle”, most of the measurements are highly reliable including the rotation angle of 3D body scanning (r = 1), shoulder levelness of direct measurement (r = 0.99), and posture parameter 1 (r = 0.99), 2 (r = 0.96), 4 (r = 0.92), 5 (r = 0.97), 9 (r = 0.87), 12-16 (r = 0.9, 0.99, 0.96, 1, 0.96) of motion capturing; while posture parameter 11 (r = 0.78) of motion capturing has good reliability. For the tests during “without girdle”, most of the measurements are highly reliable including the rotation angle of 3D body scanning (r = 1), shoulder levelness of direct measurement (r = 1), and posture parameter 1-3 (r = 0.97, 0.97, 0.82), 5 (r = 0.93), 10 (r = 0.89), 13-16 (r = 0.98, 0.96, 0.99, 0.82) of motion capturing; while some of the measurements have good reliabilities including posture parameter 6 (r = 0.75), 9 (r = 0.78), 12 (r = 0.8) of motion capturing.

6.5 Changes in Cobb’s angle and spinal curvature of subjects from radiographic analysis

The effectiveness on the control of spinal curve progression by girdling was evaluated by using a radiographic method, which means that the Cobb’s angle was measured by using X-ray (Greiner 2002). The subjects were requested to take an X-ray before (0 month) and after the wear trial (6 months) without the girdle, in order to obtain the Cobb's angle pre and post wear trial (Appendix G). Two of the subjects (Subjects 2 and 5) did not take the X-ray after 6 months of the wear trial due as they left. Table 6.15 shows the changes in Cobb's angle of the subjects from 0 to 6 months.

Table 6.15 Changes in Cobb's angle of subjects from 0 to 6 months (without girdle)

Subject	0 month		6 months		Difference(s)	
	Thor (spinal level)	**Lum** (spinal level)	**Thor** (spinal level)	**Lum** (spinal level)	**Thor**	**Lum**
1	4° (T8-T11)	14° (T12-L3)	14° (T5-T12)	19° (T12-L4)	+ 10°	+ 5°
2	/	7° (T12-L3)	(Dropped out)		/	/
3	6° (T7-T11)	4° (T12-L4)	6° (T7-T11)	4° (T12-L4)	0°	0°
4	19° (T6-T12)	15° (T12-L4)	14° (T6-T12)	12° (T12-L4)	- 5°	- 3°
5	19° (T7-T11)	13° (T12-L3)	(Dropped out)		/	/
6	17° (T5-T11)	13° (T12-L4)	27° (T4-T12)	18° (T12-L4)	+ 10°	+ 5°
7	9° (T6-T9)	15° (T12-L4)	14° (T9-T12)	14° (L1-L4)	+ 5°	-1°
8	8° (T7-T10)	5° (T11-L3)	10° (T7-T11)	9° (T12-L3)	+ 2°	+ 4°
9	4° (T6-T9)	8° (T10-L4)	4° (T5-T9)	13° (T11-L4)	0°	+ 5°

Remarks: Thor (T) = Thoracic; Lum (L) = Lumbar

For the pre (0 month) and post (6 months) wear trial comparison of the 7 subjects (Subjects 2 and 5 were excluded), more than a 5° increase in the Cobb's angle is defined as the occurrence of curve progression, 5° or less increase and no change in the Cobb's angle are defined as progression within control, a reduction in the Cobb's angle is defined as improvement of the spinal curve in this study. (Wong et al., 2008; Wong & Tan 2010; Brooks et al. 1975; Soucacos et al. 1998; Rogala Drummond & Gurr 1978)

According to Table 6.15, an obvious improvement in the spinal curve is found for Subject 4 with a reduction of 5° for the thoracic part and 3° for the lumbar part. There were 26.32% and 20% reductions in her thoracic and lumbar curves respectively. Moreover, the angles for both of the thoracic and lumbar parts are not changed for Subject 3, which is considered to be progression within control. In addition, the spinal curve of Subjects 7, 8 and 9 are also determined as progression within control with a 5°

increase in the thoracic part and 1° decrease in the lumbar part, 2° increase in the thoracic part and 4° increase in the lumbar part, unchanged in the thoracic part and 5° increase in the the lumbar part respectively. On the other hand, the spinal curves of Subjects 1 and 6 are considered to be curve progression as both have a 10° increase in the thoracic part and 5° increase in the lumbar part. Figure 6.7 shows the pre and post wear trial X-rays of a successful case of spinal control in this project (Subject 4).

Pre (Thoracic 19°, Lumbar 15°) Post (Thoracic 14°, Lumbar 12°)

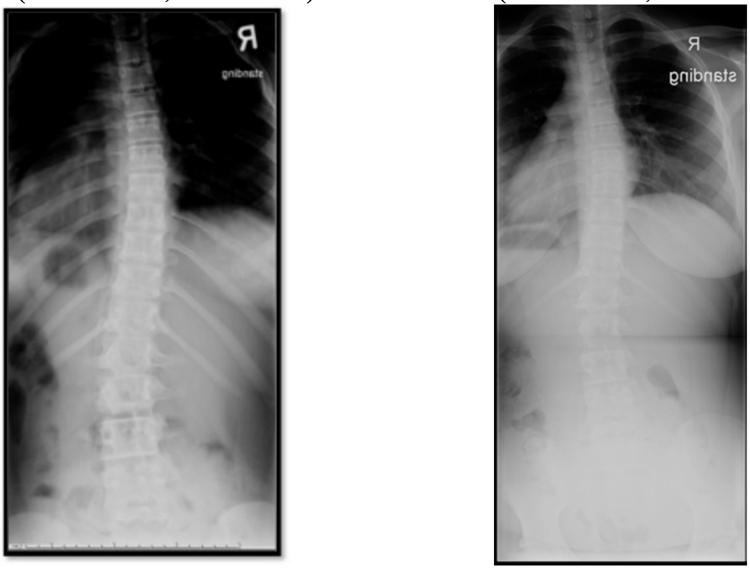


Figure 6.7 Comparison of pre (0 month) and post (6 months) wear trial X-rays of Subject 4

More importantly, although there was still curve progression in some of the cases after 6 month of girdling when comparing the pre and post X rays to the scenario when a girdle was not worn, an immediate reduction in the Cobb's angle was found on most of the subjects with and without a girdle at the same time point (Table 6.16, Appendix H). A significant difference in the Cobb's angle was found on Subject 3 who had a thoracic angle of 6° and lumbar angle of 4°, and after 6 months, a thoracic angle of 1° and lumbar angle of 1° with girdle on x-ray (see Figure 6.8). The reductions of her thoracic and lumbar curve were 5° and 3°, which means there were 83.33% and 75% reductions respectively.

Table 6.16 Comparison of Cobb's angle of subjects at 6 months with and without girdle

Subject	Without Girdle (6 m)		With Girdle (6m)		Difference	
	Thor (spinal level)	Lum (spinal level)	Thor (spinal level)	Lum (spinal level)	Thor	Lum
3	6° (T7-T11)	4° (T12-L4)	1° (T7-T11)	1° (T12-L4)	- 5°	- 3°
4	14° (T6-T12)	12° (T12-L4)	14° (T6-T12)	12° (T12-L4)	0°	0°
7	14° (T9-T12)	14° (L1-L4)	13° (T9-T12)	13° (L1-L4)	- 1°	- 1°
8	10° (T7-T11)	9° (T12-L3)	9° (T7-T11)	8° (T12-L3)	- 1°	-1 °
9	4° (T5-T9)	13° (T11-L4)	4° (T5-T9)	12° (T11-L4)	0°	- 1°

Remarks: 6 m = 6 months; Thor (T) = Thoracic; Lum (L) = Lumbar

With Girdle (Thoracic 6°, Lumbar 4°)

Without Girdle (Thoracic 1°, Lumbar 1°)

Figure 6.8 Comparison of X-rays of Subject 3 with and without girdle at 6 months

Repeated measures ANOVA test was conducted to evaluate the effect of time (0, 6 months) on the deformity change. According to Table 6.17 and 6.18, The results show that there was no statistically significant difference on the deformity (both of thoracic and lumbar regions) among time (0, 6 months) with $F(1, 6) = 3.144$, $p = 0.127$. That means there was no remarkable trend of increasing in deformity after 6 months girdling. Also, according to Figure 6.9, the increase of deformity in the thoracic (form M= 9.4286, SD = 6.1062 in 0 month to M = 127143, SD = 7.49921 in 6 months) was more than the lumbar (from M = 10.5714, SD = 4.79086 in 0 month to M = 12.7143, SD =

5.15475). It might indicate that the design of posture correction girdling was more likely to control the curve in lumbar.

Table 6.17 Descriptive statistics of repeated measures ANOVA test for radiographic analysis (Cobb's angle)

Measurement Item	Mean	Std. Deviation	N
0 month (Thoracic curve)	9.4286	6.10620	7
0 month (Lumbar curve)	10.5714	4.79086	7
6 month (Thoracic curve)	12.7143	7.49921	7
6 month (Lumbar curve)	12.7143	5.15475	7

Table 6.18 Results of repeated measures ANOVA test for radiographic analysis (Cobb's angle)

Effect	F	Hypothesis df	Error df	Sig.
Time	3.144	1.000	6.000	0.127
Spinal region	0.082	1.000	6.000	0.785
Time*Spinal region	0.447	1.000	6.000	0.529
Limitation: The data is continuous data, but due to small sample size, it may not be representative enough and cannot be normal distributed.				

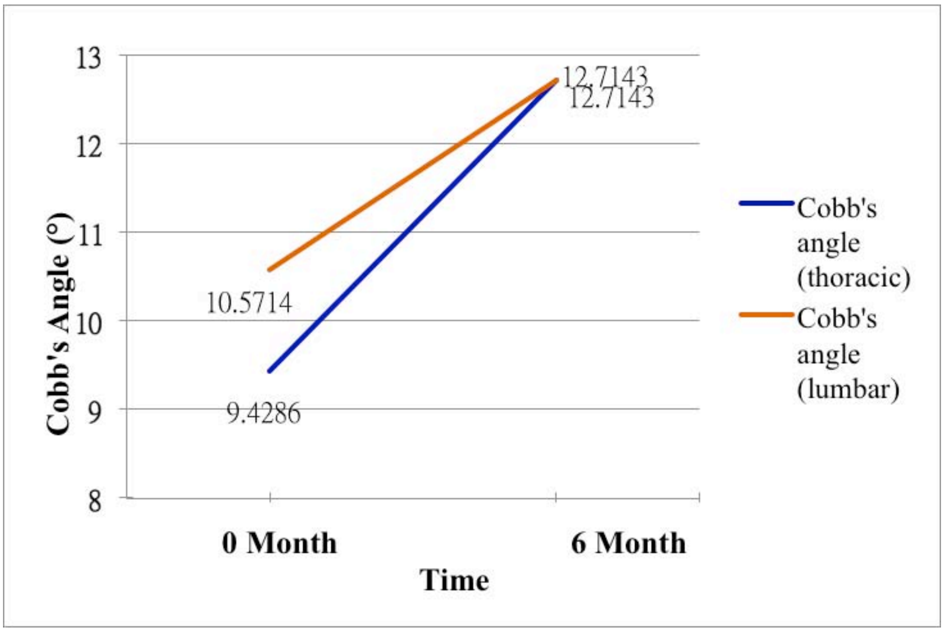


Figure 6.9 Change of Cobb's angle from 0 month to 6 months

6.5.1 Reliabilities of measurements that quantified changes of spinal curves on the subjects

Reliability tests were conducted to evaluate the reliabilities of the measurements that used to quantify the changes of spinal curves on subjects, i.e. Cobb's angle of the thoracic curve as well as lumbar curve. Table 6.19 shows the results of the test-retest reliability tests for the measurements that mentioned above.

Table 6.19 Results of reliability test for the measurements that quantified changes of spinal curves on the subjects

	r	**r^2**
Thoracic curve	0.998	0.996
Lumbar curve	0.974	0.949

The acceptable reliability level in the present study was set as r>0.7. According to the results, all of the measurements have high reliabilities, i.e. r = 0.99 for the thoracic curve and r = 0.97 for the lumbar curve.

6.6 Discussion of the results of changes on postures and spinal curves

Static posture is the state of muscular and skeletal balance within the body and this promotes stability by the orientation of the constituent parts of the body, while dynamic posture is the state that the segments of the body adopt when undertaking movement (Eston & Reilly 1999). It has been mentioned that the ideal alignment in the vertical posture is related to the gravity line, which is a vertical line that passes through the center of gravity of the body (Zatsiorsky & Duarte 1999; Penha, Baldini & João 2009). It has also been stated that good posture is a state of muscular and skeletal balance, which protects the body structure against injury or progressive deformity independent of whether the structure is working or resting (Penha et al. 2005).

After several posture evaluation tests were carried out, including by 3D body scanning, measurement of shoulder differences by using the floor as a reference, and 3D motion capturing. Some of the measurements or posture parameters have statistically significant changes. The results implied that those postural improvements might possibly bring by the effects of girdling (with girdle and with girdle) and time (0, 3 and 6 months). In regard to the results of 3D body scanning, the postural changes were obvious by observation from Figure 6.6, however, the results were not statistically significant. In this case, the effect of girdling and time on the change of postures might be affected by the large standard deviation and small sample size. Large standard deviation indicated that the subjects were not homogeneous and they have large individual difference. As the standard deviation of the measurements was large, a preliminary small statistical test was carried out to see if more homogenous subjects were recruited, whether the trend of postural change would be more obvious. In the preliminary small test, 3 subjects with Cobb's angles (both of thoracic and lumbar curves) that below 10° at the beginning were assigned to group 1, while 2 subjects with Cobb's angle angles (both of thoracic and lumbar curves) that more than 10° at the beginning were assigned to group 2. According to the results, the girdle was more likely to give better effect on postural control in group 1 (Cobb's angle below 10°), significant across time effect was found $p = 0.008$. In group 1, the homogeneity became small, and the mean of measurements was decrease from 2.6733 (in 0 month) to 2.27 (in 3 months) and to 0.7867 (in 6 months) across time in the condition of without girdle. The standard deviation of the measurements became smaller as homogeneity increased. Therefore, by using the result of this small preliminary test as subject recruit indicator, subjects with smaller Cobb's angle, i.e. 5-10°, should be recruited for the wear trial in future study.

In addition, the posture improvements might be resultant of the supportive and corrective forces exerted by the posture correction girdle. The EVA foam pads that were inserted into different partitions of the girdle in accordance with different cases and needs helped to create corrective point-pressures. These mainly helped to improve the posture problems of imbalance in the frontal plane with the aid of wrapped elastic straps. The resin bones that were inserted at the back and front helped to create supportive forces. These mainly helped to improve imbalance in posture in the sagittal plane with the aid of the wrapped elastic straps. The tight-fitting girdle base worked together with the shoulder straps, waistband, additional EVA foam pads and resin bones, and complemented each other to bring out the optimum function of the girdle. Insertion of EVA foam padding for point pressure creation is very important for the correction mechanism of the girdle design in the present study. According to the results of shoulder levelness measurement, it showed that the effect of the girdle with padding insertion was better than the girdle without padding insertion.

According to the results of motion capturing, lots of the posture parameters have the improving trend but only some of them have statistically significant improvements.

Time limit for wear trial and small sample size might be the possible factors that affect the significance of the effect. Therefore, longer wear trial period and larger sample size is suggested for the future study. Moreover, significant improvements were mainly found on the acromion part especially in the frontal planes during standing. The design of posture correction girdle in the present study and the bony structure of human might be related to this result, i.e. the corrective forces from the adjustable shoulder straps can be exerted to the bony points of the shoulders directly with little barrier of soft tissues.

These postural improvements might also be attributed to posture training with the girdle, as it is believed that the back muscles of the subjects themselves could be trained to keep the spine within a natural curvature; thus, the corresponding imbalance in posture might be prevented with awareness of posture as the subjects might learn good postural habits that could carry over into their daily life (Wong & Wong 2008; Dworkin et al. 1985; Birbaumer 1994). It has been considered that children's bodies are "moldable", which means their body postures could be improved and trained by using different methods, i.e. exercises, physiotherapy, and rehabilitation programs (Weiss & Goodall 2008). It is also believed that "reminders" of good posture may be an acceptable prophylaxis (Wong & Wong 2008), which can be provided by parents or training devices. In this study, tailor-made posture correction girdles have been provided to subjects for a 6-month wear trial. The girdles act as a training device, which reminds the subjects to maintain a better and more balanced posture during the girdling period.

In connection with the results of radiographic analysis on the change of spinal curve, it was found that Subject 4 has significant improvement and the angle of the spinal curve of Subject 3 remain unchanged, while Subjects 1 and 6 experience curve progression in their spine. Growth might be one of the factors that affects the curve progression rate as curve progression is mostly found during the period of rapid growth (Dobbs & Weinstein 1999; Mackenzie 1922; Lonstein & Carlson 1984; Rigo, Villagrasa & Gallo 2010). Table 6.20 shows the changes in the weight and height of the subjects. It can be seen that Subjects 1 and 6 have a greater increase in weight and height (+ 7 kg + 10.9 cm;+ 6.3 kg, + 6 cm) as opposed to Subjects 4 and 3 (+ 3 kg, +3 cm; + 3.5 kg, + 5 cm). In other words, higher growth rates that might induce rapid curve progression can be seen for Subjects 1 and 6 in comparison to Subjects 4 and 3. Moreover, the curve type and condition of the spine might affect the effectiveness of the girdle on the curve progression of the subjects.

Table 6.20 Changes in weight and height of subjects

Subject	0 month		6 months		Difference	
	Weight (kg)	Height (cm)	Weight (kg)	Height (cm)	Weight (kg)	Height (cm)
1	33.7	140	40.7	150.9	+ 7	+ 10.9
2	44.8	156	(Dropped out)		/	/
3	30.7	146	34.2	151	+ 3.5	+ 5
4	65.1	157	68.1	160	+ 3	+3
5	37.2	150	(Dropped out)		/	/
6	45	145	51.3	151	+ 6.3	+6
7	36.3	152	38.4	155	+ 2.1	+ 3
8	38.1	142	40.7	144	+ 2.6	+2
9	35.2	138	37	140.5	+ 1.8	+2.5

Finally, the compliance of the subjects and their personality might affect the success of girdling for improvement on postures and spinal curves, as patient involvement is one of the key factors that affects the success of treatment (Wong et al. 2001, Zaina, Negrini, Fusco & Atanasio 2009). Perseverance might be affected by personality, psychological aesthetics and also understanding of scoliosis (Zaina, Negrini, Fusco & Atanasio 2009; Hasler et al. 2010). With regards to the compliance with girdling in this study, Subjects 4 (100%) and 3 (100%) have the highest compliance, while Subjects 1 (62.5%) and 6 (52.25%) show the least compliance. These show that Subjects 4 and 3 wore the girdle nearly double the time of Subjects 1 and 6. With reference to Appendices D, E, and F, which present the data from the posture evaluation tests for each of the subjects, it is shown that the subjects who have improved posture have relatively higher compliance to the wear trial in this study.

6.7 Chapter summary

Nine subjects have been recruited to participate in a wear trial and undergo evaluation tests in order to determine the effectiveness of a posture correction girdle on posture improvement and progression control of the spinal curve. Two of the subjects withdrew after 3 months of the wear trial. Therefore, only 7 sets of data are obtained from the evaluation tests after 6 months of the wear trial.

Compliance and involvement with treatment might be two of the key factors that lead to the success of girdling (Wong et al. 2001). Thus, a temperature logger is inserted into the girdle to monitor the wear practice of the subjects. Although an acceptable mean of compliance among all of the subjects is found (93.25%), 2 of the subjects have relatively low compliance, i.e. 52.25% and 62.25%, which might be due to lack of perseverance and ignorance of the seriousness of scoliosis (Hasler et al. 2010; Zaina, Negrini, Fusco & Atanasio 2009). A reduction in compliance (from 100% at 0 month to 82.63% at 6 months) is also found, which might be due to the change in the weather, i.e. discomfort and rapid increase in skin temperature induced by hot weather.

As the posture correction girdle is a compression garment, health tests that ensured no health effects would result have been carried out at the beginning of the wear trial (0 month). The health tests include: heart and pulmonary function and sensory tests. It is found that there are no significant changes in the measurement readings of blood pressure, pulse, PEF and sensory levels.

Three dimensional body scanning, direct measuring of the levelness of the shoulders by using the floor as a reference, and motion capturing were used as the evaluation tests to assess the possible effect of girdling and time on postural. Radiographic analysis (Cobb's angle) was used as the evaluation tests to assess the possible effect of girdling and time on the change of spinal deformity. According to the results of test-retest reliability test, most of the measurements for assessments were reliable.

In regard to the results of 3D body scanning, no statistically significant was found on the measurements. In connection with the result of shoulder levelness measurement, overall statistically significant difference was found in effect of girdling (without girdle, with girdle but no padding, with girdle and padding). The results of post-hoc test indicated that wear girdle with padding insertion have better effects than without wearing girdle and wear the girdle that without padding insertion in both of 0 and 3 months, however, no statistically significant was found in 6 months. Concerning the results of motion capturing, there were statistically significant differences of the main effect of girdling (without girdle, with girdle) on posture parameter 1, 4 and 9, which indicated that girdling might possibly bring immediate improvements to the posture parameters including more even shoulder in frontal plane and horizontal plane during standing, as well as straighter upper back in sagittal plane during sitting. In addition, there were also statistically significant differences of the main effect of time (0, 3, 6 months) on posture parameter 1, 9 and 11, which indicated that time-to-time improvements that contributed by time effect (6 months) might possibly exist on posture parameters including more even shoulder in frontal plane during standing and walking. Moreover, there were statistically significant differences of interaction effects of girdling (without girdle, with girdle) x time (0, 3, 6 months) on posture parameter 1, 2, 10, 15 and 16, which indicated the improvements that might contribute by the interaction effect including more even shoulder an pelvis in frontal plane during standing, straighter lower back in sagittal plane during sitting, as well as acceptable constrained anterior and lateral bending range.

Regarding the results of radiographic analysis (Cobb's angle), 1 subject has improvement, 4 subjects were within control and 2 subjects have further progression. For time-to-time improvements, subject 4 have obvious change in the spinal curve with a reduction of 5° for the thoracic part and 3° for the lumbar part, which means 26.32% and 20% reductions in her thoracic and lumbar curves respectively. For immediate improvement, subject 3 have 5° reductions of her thoracic curve and 3° reductions of her lumbar curve, which means 83.33% and 75% reductions respectively. There was no significant difference found on the deformity change among the effect of time, and the design of posture correction girdling was found to have better control on the lumbar curve.

On the other hand, the posture improvements might be resultant of the supportive and corrective forces exerted by the posture correction girdle. Insertion of EVA foam padding for point pressure creation is very important for the correction mechanism of the girdle design in the present study. According to the results of shoulder levelness measurement, it showed that the effect of the girdle with padding insertion was better than the girdle without padding insertion. Moreover, significant improvements were mainly found on the acromion part especially in the frontal planes during standing. The design of posture correction girdle in the present study and the bony structure of human might be related to this result, i.e. the corrective forces from the adjustable shoulder straps can be exerted to the bony points of the shoulders directly with little barrier of soft tissues. Growth might be one of the factors that affect the curve progression rate as curve progression is mostly found during the period of rapid growth. The subjects who have relatively greater progressions of spinal curves were also have greater increases in weight and height, i.e. subject 1 and 6. Moreover, the curve type and condition of the spine might affect the effectiveness of the girdle on the curve progression of the subjects. Furthermore, the compliance of the subjects and their personality might affect the success of girdling for improvement on postures and spinal curves, as patient involvement is one of the key factors that affects the success of treatment. In the present study, the subjects who have improved posture have relatively higher compliance to the wear trial in this study.

Finally, there are many possible factors that affect the statistical significance of the measurements. The effect of girdling and time on the change of postures might be affected by the large standard deviation and small sample size. The standard deviation of the measurements became smaller as homogeneity increased, therefore, subjects with smaller Cobb's angle, i.e. 5-10°, should be recruited for the wear trial in future study. Also, some measurements have the improving trend but not all of them have statistically significant improvements. Time limit for wear trial and small sample size might be the possible factors that affect the significance of the effect. Therefore, longer wear trial period and larger sample size is suggested for the future study.

CHAPTER 7 - CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

7.1 Conclusions

Adolescent idiopathic scoliosis (AIS) is a multi-factorial, three-dimensional deformity of the spine that appears and sometimes progresses (girls tend to progress more than boys) during the rapid growth periods of those who are 10-15 in age. In Hong Kong, it was found that the prevalence of scoliosis has an increasing trend. Even so, only observation services were provided to adolescents with early scoliosis which is the usual practice. It is believed that earlier detection of spine deformities and treatment given in a timely manner could reduce the number of patients who need surgery throughout the years, and attention should be given to adolescents who have an ATR that is more than 3-4 degrees. It is believed that improper posturing and poor posture stability control of those with spinal disorders could further contribute to their pain and deformity, and posture control and training are thus considered to be helpful in controlling the curve progression of the spine during the rapid growth period. However, posture corrective girdles for adolescents with early scoliosis are limited in the market and there are many existing problems. As a result, a tailor-made posture correction girdle has been designed for girls in the age range of 10-13 with early scoliosis (Cobb's angle of 6-20°) in this study, with the aim to enhance postural control and reduce the possibility of spinal curve progression in scoliosis.

Once the knowledge gaps have been identified, i.e. (1) there are limited research studies that have provided details on posture control for AIS by using a soft girdle, (2a) there are limited product choices and (2b) there is unsatisfactory treatment compliance, a systematic framework with reference to a three-stage design process, as well as the functional, expressive and aesthetic (FEA) consumer needs model were made to design and develop a posture correction girdle. In terms of the problems found with existing products for scoliosis treatment, the rigid brace treatment is too demanding for adolescents with early scoliosis due to the high corrective forces which nearly constrain all of their movements, while the efficacy of treatment with a flexible brace, e.g. the SpineCor, is still controversial. Moreover, posture correction garments that are specifically designed for teenagers are limited and many can only provide partial improvement of bad posture, such as having a hunchback. The problems with these products also include discomfort, inconvenience and psychological issues, like strange appearance and bulkiness. On the other hand, compliance with treatment is sometimes affected by the needs, response and behaviors of preteen and teenage girls. Psychosocial issues, including peer pressure at school, social relations and lack of family support are common for adolescent patients, which are triggered by the lack of energy, low expectations, anxiety about failure, low self-esteem and poor body image. Therefore, both functional (i.e. corrective mechanism) and psychological (i.e. level of comfort and aestheticism) aspects have been taken into consideration during the design and development process of the posture correction girdle.

The newly developed posture correction girdle in the present study is a vest-like and close-fitting girdle with a length that extends from the shoulders to the top-hip. The paper pattern is developed by using pattern alternation from a bodice basic block. The girdle contains corrective straps (i.e. shoulder straps and waist band), supportive struts (i.e. plastic bones) and point-pressure creators (i.e. EVA foam paddings). The insertion of EVA foam paddings is one of the key factors that render the corrective function successful, as they could generate different point-pressures in accordance with the needs of different patients combined with the advice provided by a professional P&O. In order to optimize the function, level of comfort and life of the girdle, physical tests on strength, stretching and recovery, air and moisture permeabilities, as well as dimensional stability are performed to choose the most suitable primary materials for girdle fabrication. According to the results, TR3 (tricot), SN2 (satinette), PN3 (powernet) and EB3 (elastic band) are chosen for application as the components of the shell fabric, supportive fabric, pocket lining and corrective straps, respectively, as they perform well in the tests mentioned. In other words, the chosen materials have high strength, good stretch and recovery, impressive air and moisture permeabilities, as well as good dimensional stability. It is recommended that the fabric materials are cut on the crosswise grain and reduced 10% along the circumference in order to obtain a better fit to the body and give extra dimensional stability to the girdle shape. In addition, pressure measurements have also been carried out on different padding materials, in order to select the most suitable one for girdle fabrication so as to provide optimal corrective point-pressures with an acceptable level of comfort. PD3 (EVA foam padding) is chosen as the padding for the posture correction girdle due to its balanced overall subjective and objective ratings.

A school-screening program has been carried out in 7 schools and 497 girls between the ages of 10-13 took part, in order to investigate the prevalence of scoliosis and recruit suitable human subjects in accordance with the inclusion criteria for a wear trial. It is found that 21.9% are possible subjects (with an ATR ≥3°) and suspected to have early scoliosis, which is relatively high. This result might due to the differences in screening standards and increasing trend of scoliosis. Also, most of the possible subjects (with an ATR ≥3°) in this study are 11 and 12 years old, which is believed to be related to the growth factor, but no correlation is found between the BMI and ATR. Meanwhile, 9 females from the possible subject group have participated in the wear trial after the pre-wear trial radiographic analysis and doctor consultation, which identified that they are in the early stages of scoliosis (Cobb's angle of 6-20°). Each received a tailor made posture correction girdle once adjustments were made after two fittings, and padding positions were determined (by a P&O). Flexible girdles should fit the wearer's body, otherwise corrective forces would not be effectively delivered to the body and the corrective effect of the girdles would thus be affected. In this research, the circumference of the girdle fits the body with a space tolerance of 2 fingers.

The length of the wear trial is 6 months, however, only 7 subjects have completed the whole wear trial and performed all of the evaluation tests as 2 of them withdrew due to participation in other types of therapy. As compliance is one of the keys to a successful treatment, a temperature logger is inserted into the girdle for compliance monitoring. An acceptable mean of compliance (93.25%) is found among all of the subjects, but relatively low compliance rates, i.e. 52.25% and 62.25%, are found for 2 of the subjects, which might be due to their lack of perseverance and disregard of the seriousness of scoliosis. A reduction in compliance rate (from 100% at 0 month to 82.63% at 6 months) is also found, which might be due to the change in the weather, i.e. discomfort induced by sweating and rapid increase in skin temperature under hot weather. Health tests i.e. tests on heart and pulmonary functions and sensory levels have been carried out at the beginning (0 month) of the wear trial, in order to ensure that no health effects would result from wearing the girdle since it is a compressive garment. According to the results, no significant changes can be found on the tested items.

Improvements in the posture of the subjects as a result of wearing the girdle are evaluated by using 3D body scanning, direct measurements of shoulder levelness by using the floor as a reference and motion capturing. Good posture is the state of muscular and skeletal balance that protects the body structure against injury or progressive deformities independent of whether the structure is working or resting. According to the result of shoulder levelness measurement, overall statistically significant difference was found in effect of girdling. It indicated that wear girdle with padding insertion have better effects than without wearing girdle and wear the girdle that without padding insertion in both of 0 and 3 months. In regard to the results of motion capturing, there were statistically significant differences of the main effect of girdling (without girdle, with girdle) on the posture change including more even shoulder in frontal plane and horizontal plane during standing, as well as straighter upper back in sagittal plane during sitting. In addition, there were also statistically significant differences of the main effect of time (0, 3, 6 months) on posture changes after 6 months girdling, including more even shoulder in frontal plane during standing and walking. Moreover, there were statistically significant differences of interaction effects of girdling (without girdle, with girdle) x time (0, 3, 6 months) on posture changes including more even shoulder an pelvis in frontal plane during standing, straighter lower back in sagittal plane during sitting, as well as acceptable constrained anterior and lateral bending range. However, no statistically significant was found on the measurements of 3D body scanning. The posture improvements in the present study might be resultant of the supportive and corrective forces exerted by the girdle with the aid of elastic straps, plastic bones and EVA padding. Children are said to be “moldable” which means that their posture could be trained by different methods like providing them with devices as a reminder. Once they have increased their awareness of good posture and learnt good postural habits, they could carry these practices over into their daily life and reduce the possibility of spinal curve progression.

The effectiveness of the girdle on controlling spinal curve progression has been evaluated by using a radiographic method to determine the changes in the spinal curve and Cobb’s angle. Regarding the results of radiographic analysis (Cobb’s angle), 1 subject has improvement, 4 subjects were within control and 2 subjects have further progression. For time-to-time improvements, subject 4 have obvious change in the spinal curve with a reduction of 5° for the thoracic part and 3° for the lumbar part, which means 26.32%

and 20% reductions in her thoracic and lumbar curves respectively. Moreover, immediate improvements in the spinal curve are found for most of the subject when x-rays are compared between wearing a girdle and without a girdle at 6 months. For subject 3, she have 5° reductions of her thoracic curve and 3° reductions of her lumbar curve, which means 83.33% and 75% reductions respectively. It is believed that compliance, growth and curve type are factors that affect curve progression. At the same time, less compliance, greater weight and height increases and more complicated curve type, i.e. lateral curve with rotation, are found for subjects who experience greater curve progression in the present study.

To sum up, the posture correction girdle aims to provide a non-invasive method to control the body posture in order to reduce the possibility of progression of the spinal curve. Patience is needed to see improvement as training of posture needs time. The important thing is that treatment or training should be provided as soon as possible at the right time, i.e. puberty period, as it is more difficult to reverse poor posture or spinal curve deformity if it has already reached a certain level of severity. Furthermore, involvement is often one of the keys to success in treatment or training, and can be enhanced by support from family, friends as well as society. Parents should also observe changes in the body of their children as they are still young and sometimes cannot clearly explain their feelings and they will also disregard the seriousness of scoliosis. Although scoliosis is a multi-factorial deformity of the spine that sometimes results due to heredity, waiting to address the issue until it is too advanced is detrimental.

7.2 Limitations and suggestions for future research

In terms of the subject selection in this study, the school-screening program is only carried out in 7 schools and only 9 human subjects are recruited due to time limitations. It is recommended that the number of schools be increased for screening purposes and recruitment of human subjects for the wear trial to improve the accuracy of the results. In the present study, there are trends of improvement. However, a larger sample size might provide even more statistically significant improvements.

With regards to the material selection in this study, 3 types of tricot fabrics, 2 types of satinette fabrics, 3 types of powernet, 6 types of elastic bands, 2 types of plastic bones and 4 types of padding materials are preselected as samples to perform the physical tests due to time and resource limitations. It is suggested that the number of test samples be increased, in order to select materials that have better quality and physical properties to fabricate a posture correction girdle with optimum functions and level of comfort. In addition, aesthetic refinements on the fabric materials, e.g. color printing, are suggested to enhance the acceptability of the girdle appearance, in order to increase compliance by taking into consideration the psychological needs of the subjects.

With regards to the wear trial in this study, only 6-months of supervision is provided to each subject due to time and resource limitations. A longer wear trial and supervision period are suggested, in order to evaluate the possible effectiveness of girdling and time on the change of body posture spinal deformity for a lengthier amount of time. Moreover, there is still room for improvement on the compliance of the wear trial in this study. Educational sessions are suggested to provide the subjects with more information on scoliosis and inform them of the consequences of bad body posture, in order to increase their awareness on such issues and further enhance their compliance.

As for the evaluation tests in this study, only 3 tests, i.e. 3D body scanning, direct measurement of shoulder levelness by using floor as a reference, as well as motion capturing are carried out to evaluate the effectiveness of the girdle on posture correction, and 1 method, i.e. radiographic analysis, is carried out to evaluate the effectiveness of the girdle on controlling spinal deformity due to time limitations. It is recommended that the number of evaluation methods be increased so as to obtain more data for analysis in order to reduce errors and obtain more comprehensive results. An increase in the number of analysis items for the tests is also suggested, e.g. gait analysis for motion capturing, in order to gain more comprehensive results.

Last but not least, for the statistical analysis, the data obtained from different methods was continuous data, but due to small sample size, it might not be representative enough and cannot be normal distributed. Lack of control group might affect the internal validity in the present study and it could not claim that the differences or changes seen were due to the independent variable. Therefore, a control group is suggested to add in the future study.

APPENDICES

Appendix A

Result of strength test of fabric materials (warp direction)

Warp direction				
Fabric Name	**Maximum Load Applied (N)**	**Extension at Maximum Load (mm)**	**Tensile strain at Maximum Load (%)**	**Modulus (Automatic) (Mpa)**
TR1	10.28667	88.48247	88.48247	0.1644
TR2	10.15333	107.8042	107.8042	0.11157
TR3	10.15333	89.46013	89.46014	0.12501
SN1	10.2	89.9772	89.9772	0.13992
SN2	10.15333	145.384	145.384	0.08471
PN1	10.2	61.36267	61.36267	0.19654
PN2	10.2	49.74677	49.74677	0.25417
PN3	10.10667	103.2208	103.2208	0.11123

Result of strength test of fabric materials (weft direction)

Weft direction				
Fabric Name	**Maximum Load Applied (N)**	**Extension at Maximum Load (mm)**	**Tensile strain at Maximum Load (%)**	**Modulus (Automatic) (Mpa)**
TR1	10.46	74.84997	74.84997	0.21127
TR2	10.24333	69.28997	69.28997	0.16294
TR3	10.2	43.76937	43.76937	0.26608
SN1	10.68667	26.93713	26.93713	0.47934
SN2	10.73333	22.87627	22.87627	0.66292
PN1	10.64333	23.28733	23.28733	0.53123
PN2	10.28667	53.9965	53.9965	0.2151
PN3	10.68667	22.8707	22.8707	0.58336

Result of strength test of elastic straps

Elastic Strap Name	Maximum Load Applied (N)	Extension at Maximum Load (mm)	Tensile strain at Maximum Load (%)	Modulus (Automatic) (Mpa)
EB1	41.29333	64.7958	64.7958	0.72508
EB2	42.23	81.2555	81.2555	0.58533
EB3	41.24667	92.54883	92.54883	0.50449
EB4	41.47333	121.5529	121.5529	0.41649
EB5	40.71	116.8421	116.8421	0.40667
EB6	40.71333	133.7966	133.7966	0.42336

Result of stretch and recovery test of fabric materials

	Warp				Waft			
Fabric Name	**Fabric Growth (%)**			**Average**	**Fabric Growth (%)**			**Average**
TR1	5.8	2	3	3.60%	2.6	2.9	4	3.17%
TR2	5.7	6	5	5.57%	7	4.6	5.2	5.60%
TR3	1	0.5	-0.5	0.33%	1.4	1	1.8	1.40%
SN1	3	3.4	1	2.47%	-2	-2	-1.5	-1.83%
SN2	2	1.3	1	1.43%	-1	-1.5	-1	-1.17%
PN1	1.6	1.3	3	1.97%	0.9	0.5	0	0.47%
PN2	-1.3	1	1	0.23%	0.6	-1	-0.6	-0.33%
PN3	1	0	0.5	0.50%	-2	-2	-3	-2.33%

Result of stretch and recovery test of elastic straps

Name	**Growth of Elastic Straps (%)**			**Average**
EB1	1	0.8	0	0.60%
EB2	2.8	2.5	7	4.10%
EB3	3.5	4.3	3	3.60%
EB4	3	5.1	3.4	3.83%
EB5	10.41	10.34	10.35	4.10%
EB6	5.6	6.1	5	5.57%

Result of air permeability test of fabric materials

Name	**Air Permeability (kPa.s/m) of Fabric**					**Average**
TR1	0.476	0.456	0.47	0.486	0.464	0.4704
TR2	2.71	2.707	2.921	2.697	2.713	2.7496
TR3	0.454	0.651	0.359	0.574	0.476	0.5028
SN1	0.031	0.0313	0.0285	0.0271	0.0283	0.02924
SN2	0.0155	0.016	0.0172	0.0187	0.0166	0.0168
PN1	0.0063	0.0052	0.0044	0.0042	0.0021	0.00444
PN2	0.0148	0.0134	0.0171	0.0153	0.0151	0.01514
PN3	0.021	0.043	0.059	0.034	0.045	0.0404

Result of air permeability test of elastic straps

Name	**Air Permeability (kPa.s/m) of Elastic Straps**					**Average**
EB1	11.66	12.74	13.91	12.78	12.92	12.802
EB2	2.594	2.712	2.558	2.712	2.713	2.6578
EB3	0.017	0.016	0.0144	0.0165	0.0143	0.01564
EB4	0.029	0.033	0.027	0.03	0.036	0.031
EB5	0.1	0.111	0.112	0.093	0.117	0.1066
EB6	5.22	5.25	5.76	6.42	5.77	5.684

Result of moisture permeability test of fabric materials

	Water Vapor Transmission (WVT)				
Name	**Day1**	**Day2**	**Day3**	**Day4**	**Day5**
TR1	20.717	4.667	2.633	1.838	1.383
TR2	20.283	4.583	2.611	1.822	1.369
TR3	21.133	4.9	2.911	2.047	1.549
SN1	20.85	4.817	2.744	1.922	1.449
SN2	19.817	4.558	2.617	1.826	1.373
PN1	26.983	5.567	3.194	2.259	1.719
PN2	24.867	5.525	3.028	2.134	1.619
PN3	26.5	6.083	3.478	2.472	1.889

Result of moisture permeability test of elastic straps

	Water Vapor Transmission (WVT)				
Name	**Day1**	**Day2**	**Day3**	**Day4**	**Day5**
EB1	9.000	4.069	2.310	1.274	0.633
EB2	10.868	4.403	2.667	1.542	0.867
EB3	12.264	5.090	2.833	1.667	0.967
EB4	11.972	4.830	2.706	1.571	0.890
EB5	12.500	5.160	3.750	2.354	1.517
EB6	8.694	3.948	2.275	1.248	0.632

Result of washing test of fabric materials

	Warp				Weft			
Name	**% Dimensional Change**			**Average**	**% Dimensional Change**			**Average**
TR1	-1.43	-1.14	-1.07	-1.21%	0.36	0.43	-0.36	0.14%
TR2	0.18	-0.61	-0.39	-0.27%	0.04	-0.39	-0.25	-0.20%
TR3	0.4	-0.4	-1	-0.33%	-0.56	-0.8	-0.24	-0.53%
SN1	0.25	-0.86	-0.89	-0.50%	-2	-1.82	-2.39	-2.07%
SN2	-1.96	-1.43	-0.86	-1.42%	-2.32	-2.64	-2.14	-2.37%
PN1	-0.21	-1.39	-0.18	-0.60%	-3.11	-3.64	-2.64%	-3.13%
PN2	0.36	0.82	0.21	0.46%	-0.71	-1.57	-1.25	-1.18%
PN3	-0.79	-1.04	-1.25	-1.02%	-2.32	-3.43	-3.21	-2.99%

Result of washing test of elastic straps

	Lengthwise			
Name	**% Dimensional Change**			**Average**
EB1	-2.40%	-3.00%	-3.20%	-2.87%
EB2	-0.50%	0.00%	0.00%	-0.17%
EB3	-1.00%	-0.80%	-1.50%	-1.10%
EB4	-1.00%	-1.30%	-1.80%	-1.37%
EB5	-0.40%	-1.70%	-1.50%	-1.20%
EB6	-2.10%	-1.50%	-2.00%	-1.87%

Appendix B

Table of age distributions of the screened participants in N and P groups

Group(s)	Age(s) 10		11		12		13		Total	
N	64	16.5%	157	40.5%	148	38.1%	19	4.9%	388	100%
	82.1%		75.1%		78.7%		86.4%		78.1%	
P	14	12.8%	52	47.7%	40	36.7%	3	2.8%	109	100%
	17.9%		24.9%		21.3%		13.6%		21.9%	
T	78	15.7%	209	42.1%	188	37.8%	22	4.4%	497	100%
(Total)	100%		100%		100%		100%		100%	

* Remarks: N = Normal group (Participants with ATR 0-2°);

P = Possible group (Participants with ATR ≥3°)

Table of BMI distributions of the screened participants in N and P groups

Group(s)	BMI Under weight		Normal weight		Overweight		Total	
N	102	26.3%	224	57.7%	62	16%	388	100%
	74.5%		79.4%		78.4%		78.1%	
P	35	32.1%	58	53.2%	16	14.7%	109	100%
	25.5%		20.6%		20.5%		21.9%	
T	137	27.6%	282	56.7%	78	15.7%	497	100%
(Total)	100%		100%		100%		100%	

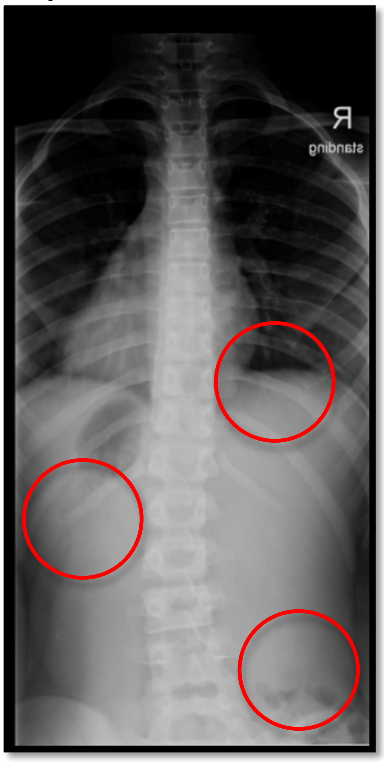
* Remarks: N = Normal group (Participants with ATR 0-2°);

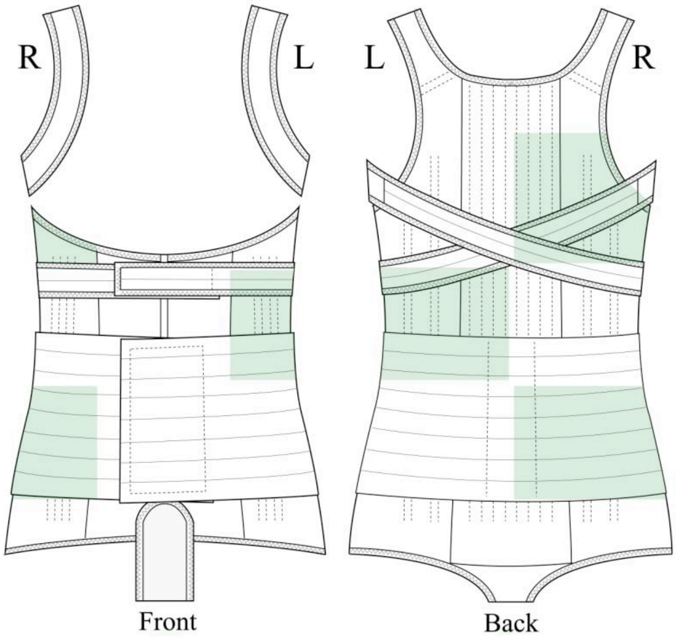
P = Possible group (Participants with ATR ≥3°)

Appendix C

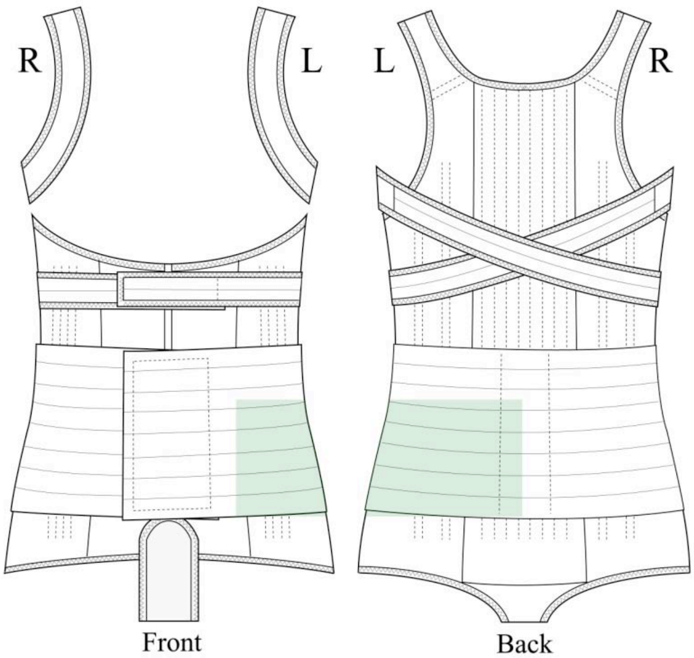
Placements of padding insertions for all of the subjects
(Green areas showed the padding placements in the girdle)

<u>Subject 1</u>





<u>Subject 2</u>



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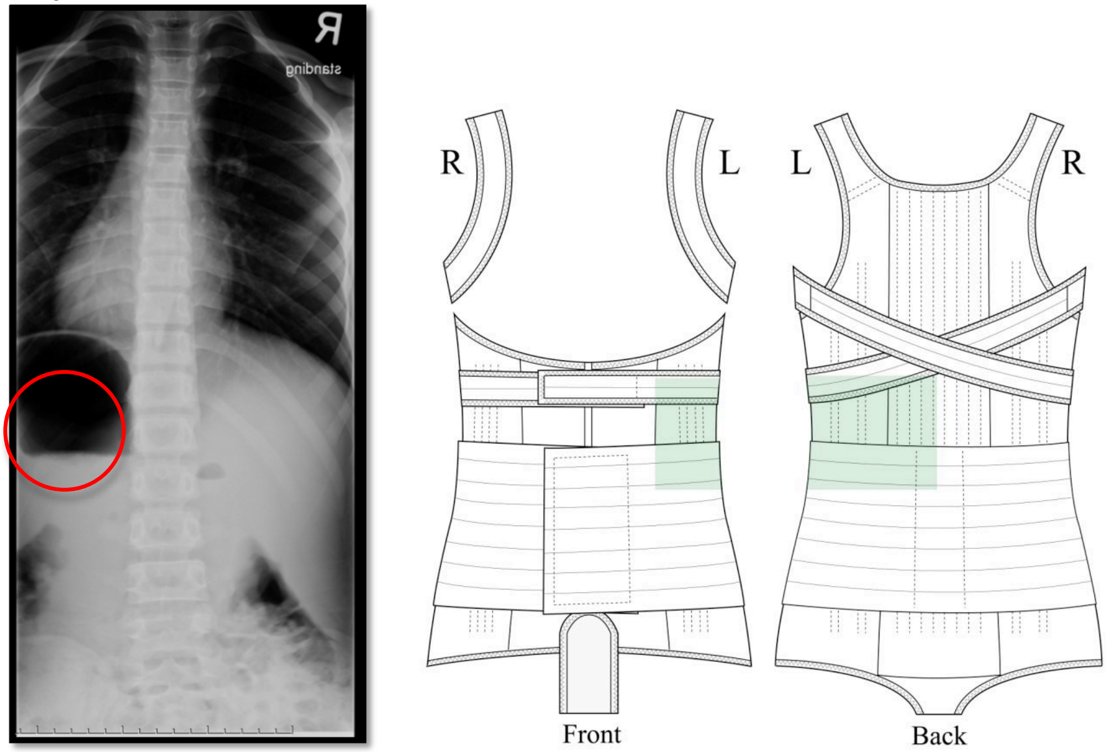

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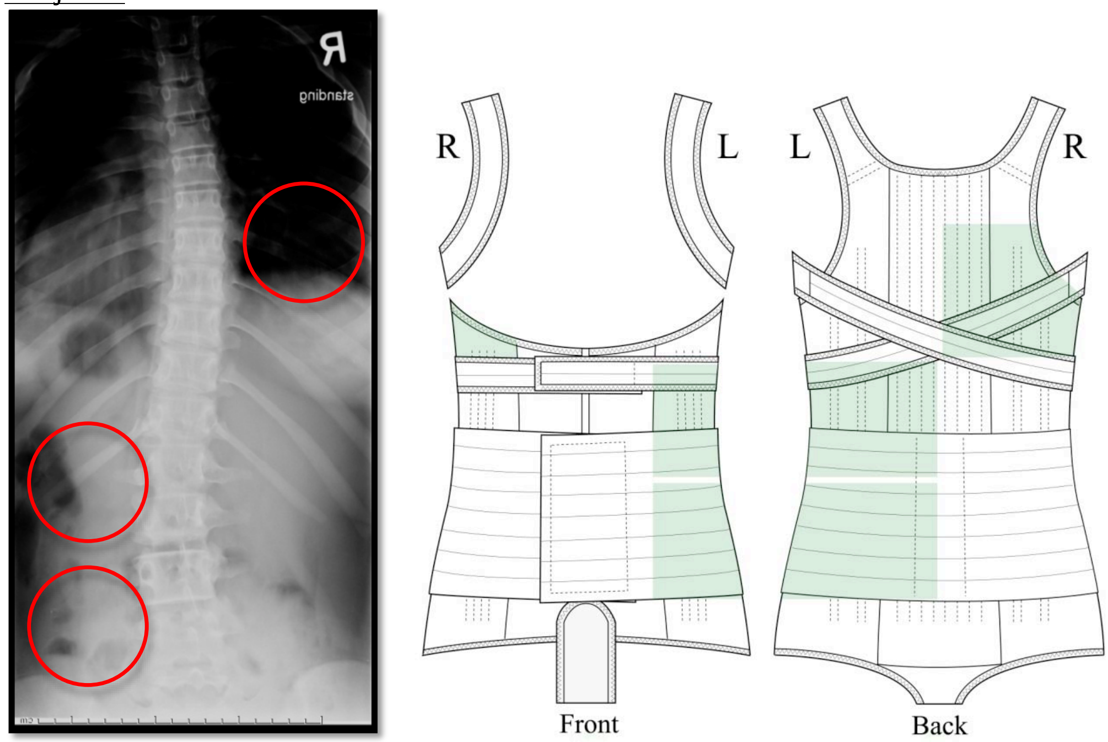

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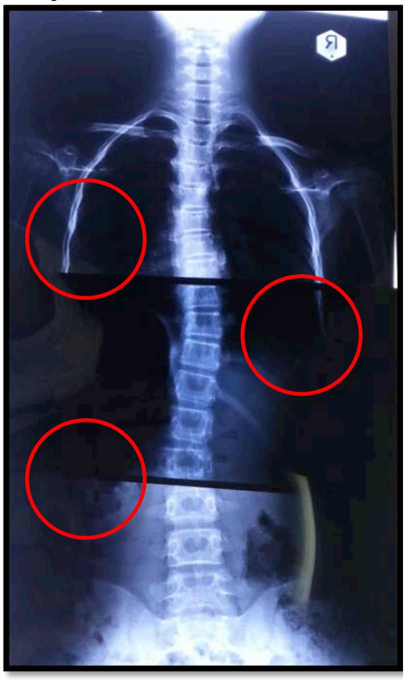
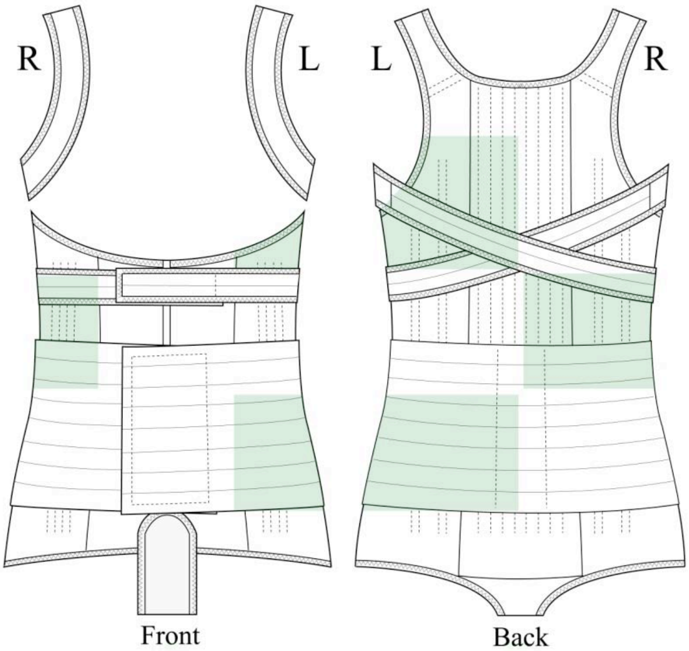
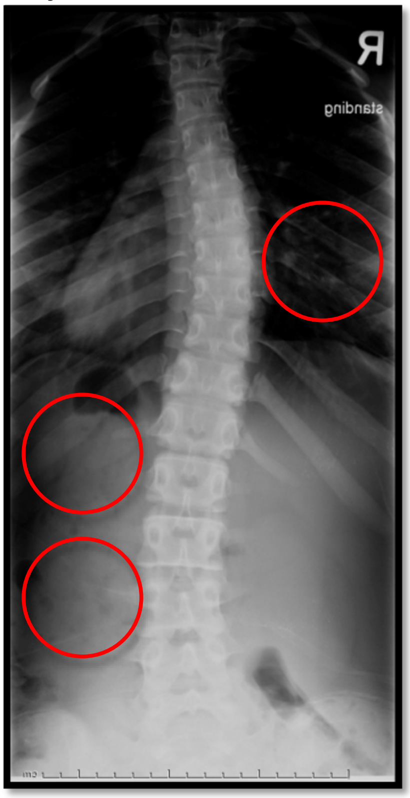
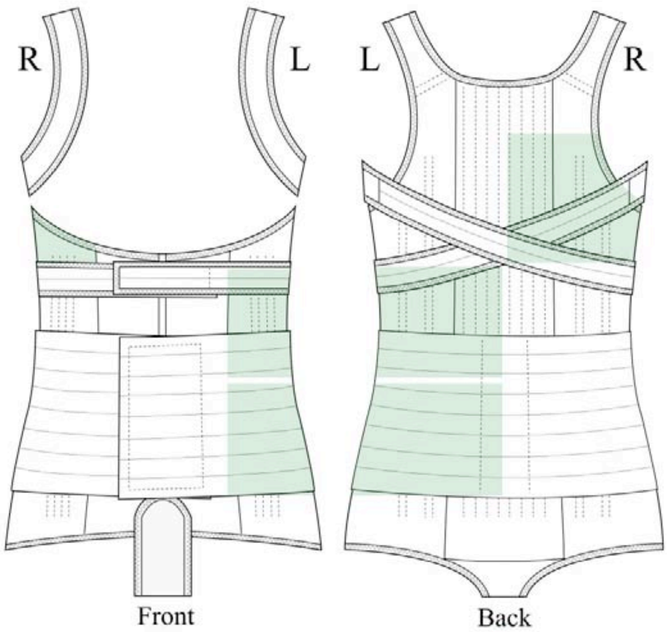




Subject 6





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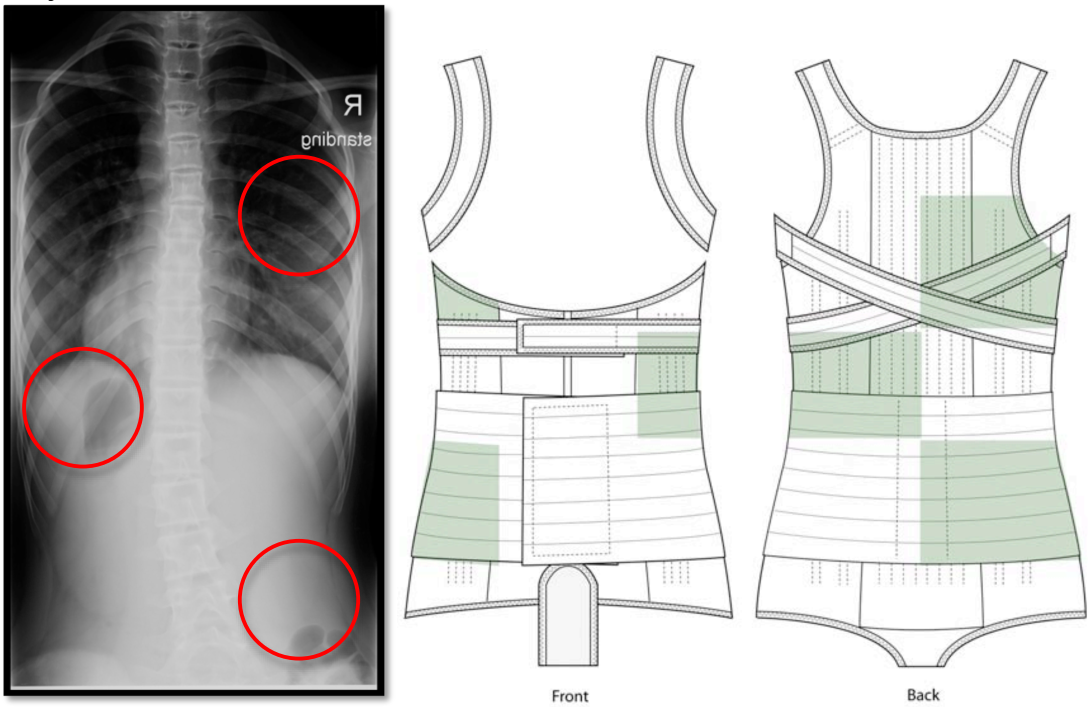

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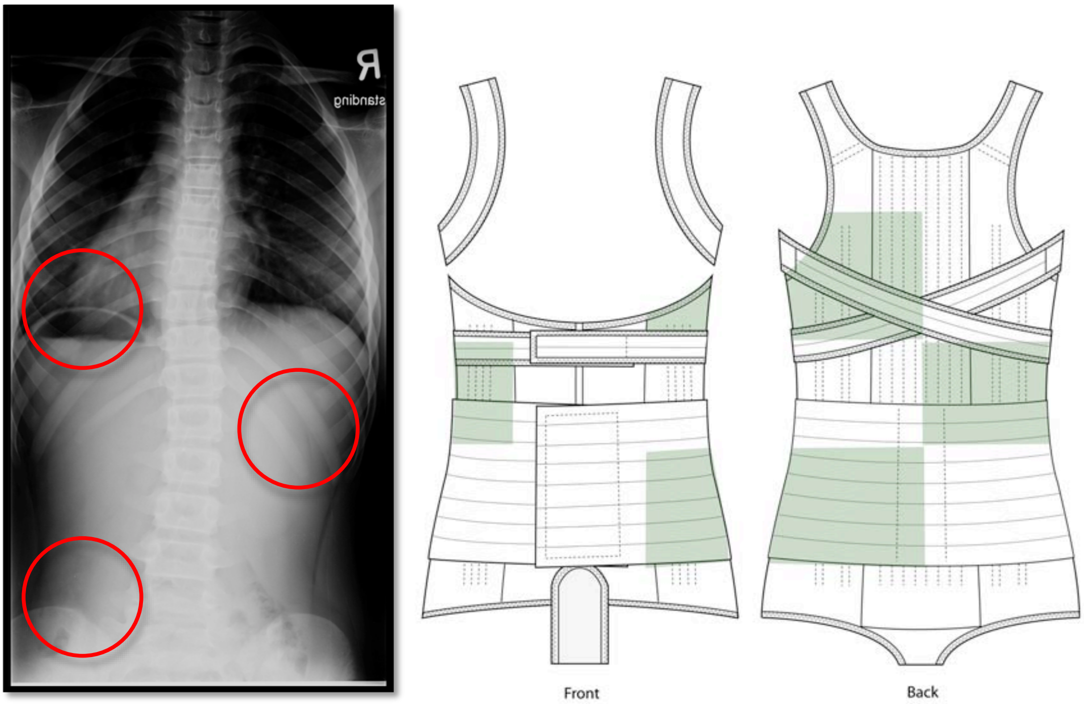

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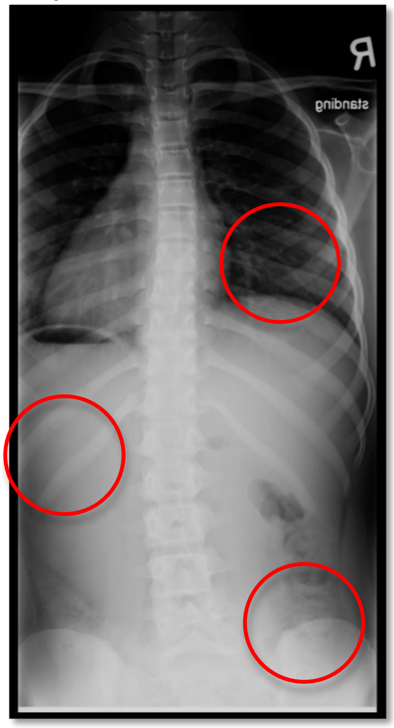
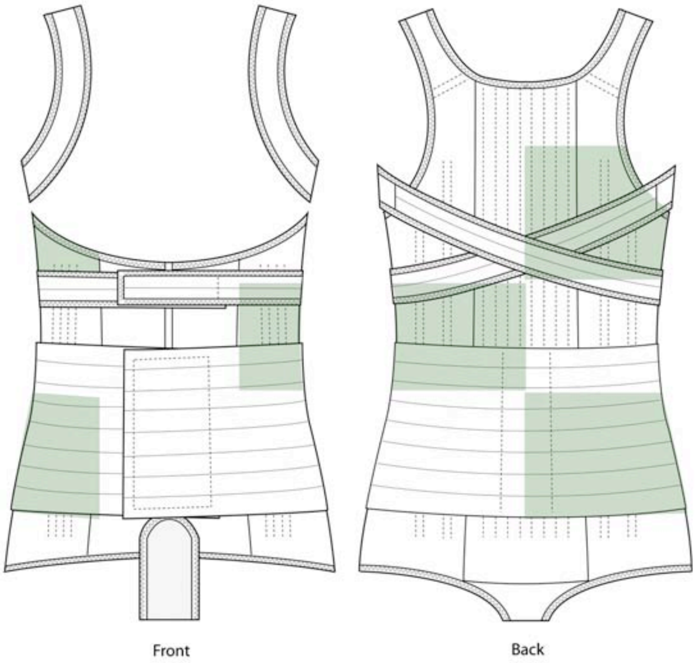




Appendix D

Rotation angle between shoulder and pelvis levels of the subjects in horizontal plane of standing postures at 0, 3, 6 months

	0 month (°)			3 month (°)			6 month (°)		
Subject	**Without Girdle**	**With Girdle**	**Difference (s)**	**Without Girdle**	**With Girdle**	**Difference (s)**	**Without Girdle**	**With Girdle**	**Difference (s)**
1	2.49	1.33	- 1.17	1.51	1.30	- 0.21	0.70	1.20	+0.50
2	2.90	0.17	- 2.72	1.65	1.66	+0.01		(Dropped out)	
3	2.94	1.09	-1 .85	3.24	2.16	- 1.08	1.01	0.68	- 0.33
4	4.40	1.85	- 2.55	2.35	0.47	- 1.88	1.37	0.41	- 0.95
5	2.88	2.66	- 0.21	2.06	0.87	- 1.19		(Dropped out)	
6	0.72	1.97	+1.25	1.38	2.99	+1.61	2.55	2.41	- 0.14
7	4.77	1.76	- 3.00	3.14	1.53	- 1.61	1.20	0.45	- 0.75
8	3.60	0.64	- 2.96	0.85	0.57	- 0.27	1.21	0.63	- 0.58
9	1.48	2.08	0.60	2.72	0.84	- 1.88	0.14	1.10	+0.96
Mean	2.91	1.51	-1.40	2.10	1.38	-0.72	1.17	0.98	-0.18
SD	1.28	0.78	1.61	0.83	0.82	1.13	0.73	0.70	0.69

*Remarks: the results were presented in absolute angles

Appendix E

Differences of shoulder levelness measurement between without girdle, with girdle but no padding and with girdle that inserted padding at 0 to 3 months, 3 to 6 months and 0 to 6 months

A. Changes from i) Without girdle to ii) With girdle (no padding inserted)			
	0 to 3 months (cm)	3 to 6 months (cm)	0 to 6 months (cm)
Subject	$D0_1$-D0	$D3_1$-D3	$D6_1$-D6
1	-0.2	-0.1	-0.1
2	-0.2	-0.2	-0.1
3	-0.2	-0.2	-0.1
4	-0.3	-0.2	-0.1
5	0	0	-0.1
6	-0.6	-0.6	-0.1
7	-0.1	-0.1	-0.1
8	-0.7	-0.7	-0.1
9	-0.2	-0.4	-0.1
Mean	-0.28	-0.28	-0.1
SD	0.21	0.22	0
B. Changes from ii) With girdle (no padding inserted) to iii) With girdle (padding inserted)			
	0 to 3 months (cm)	3 to 6 months (cm)	0 to 6 months (cm)
Subject	$D0_2$-$D0_1$	$D3_2$-$D3_1$	$D6_2$-$D6_1$
1	-0.2	-0.4	-0.2
2	-1.2	-0.7	/
3	-1	-0.6	-0.4
4	-1.7	-1.1	-0.5
5	-0.6	-0.5	/
6	-1.2	-1.1	-0.9
7	-0.3	-0.3	-0.1
8	-1.6	-1.4	-1.6
9	-0.8	-0.4	-0.3
Mean	-0.96	-0.72	-0.57
SD	0.5	0.36	0.5
C. Changes from i) Without girdle to iii) With girdle (padding inserted)			
	0 to 3 months (cm)	3 to 6 months (cm)	0 to 6 months (cm)
Subject	$D0_2$-D0	$D3_2$-D3	$D6_2$-D6
1	-0.4	-0.5	-0.4
2	-1.4	-0.9	/
3	-1.2	-0.8	-0.5
4	-2	-1.3	-0.6
5	-0.6	-0.5	/
6	-1.8	-1.7	-1.4
7	-0.4	-0.4	-0.4
8	-2.3	-2.1	-2.3
9	-1	-0.8	-0.4
Mean	-1.23	-1	-0.86
SD	0.66	0.55	0.72

*Remarks: D= Differences between left and right shoulder height
Subject 2 and 5 have dropped out after 3months of the wear trial

Changes of shoulder levelness measurements of the 9 subjects among time

i) Without posture correction girdle

	0 month (cm)	3 month (cm)	6 month (cm)	
Subject	**D0**	**D3**	**D6**	**Changes after 6 months (D6-D0)**
1	0.5	0.6	0.6	+ 0.1
2	1.4	1.2	/	- 0.2
3	1.2	0.8	0.5	- 0.7
4	2	1.3	0.6	- 1.4
5	0.7	0.5	/	- 0.2
6	2.5	2.6	2.6	+ 0.1
7	0.7	0.5	0.4	- 0.3
8	2.5	2.3	2.3	- 0.2
9	1.5	1.2	0.8	- 0.7
Mean	1.44	1.22	1.11	- 0.39
SD	0.72	0.72	0.86	0.45

ii) With posture correction girdle (no padding inserted)

	0 month (cm)	3 month (cm)	6 month (cm)	
Subject	**$D0_1$**	**$D3_1$**	**$D6_1$**	**Changes after 6 months ($D6_1$-$D0_1$)**
1	0.3	0.5	0.4	+ 0.1
2	1.2	1	/	- 0.2
3	1	0.6	0.4	- 0.6
4	1.7	1.1	0.5	- 1.2
5	0.7	0.5	/	- 0.2
6	1.9	2	2.1	+ 0.2
7	0.6	0.4	0.1	- 0.5
8	1.8	1.6	1.6	- 0.2
9	1.3	0.8	0.7	- 0.6
Mean	1.17	0.94	0.83	- 0.36
SD	0.53	0.52	0.68	0.4

iii) With posture correction girdle (padding inserted)

	0 month (cm)	3 month (cm)	6 month (cm)	
Subject	**$D0_2$**	**$D3_2$**	**$D6_2$**	**Changes after 6 months ($D6_2$-$D0_2$)**
1	0.1	0.1	0.2	+ 0.1
2	0	0.3	/	+ 0.3
3	0	0	0	0
4	0	0	0	0
5	0.1	0	/	- 0.1
6	0.7	0.9	1.2	+ 0.5
7	0.3	0.1	0	- 0.3
8	0.2	0.2	0	- 0.2
9	0.5	0.4	0.4	- 0.1
Mean	0.21	0.22	0.26	0.02
SD	0.23	0.27	0.41	0.23

*Remarks: D= Differences between left and right shoulder height
Subject 2 and 5 have dropped out after 3months of the wear trial

Appendix F

Motion capturing results for subject 1 (at 0, 3 6 months)

Posture	0 month WTG	0 month WG	0 month Diff.	3 months WTG	3 months WG	3 months Diff.	6 months WTG	6 months WG	6 months Diff.
Standing									
Frontal									
1.Acromion (°)	2.41	1.26	-1.15	1.93	2.13	0.20	2.13	1.93	-0.20
2.Pelvis (°)	2.24	0.78	-1.46	1.89	1.35	-0.54	1.99	1.55	-0.44
3.Acromion/Pelvis (°)	1.94	1.36	-0.58	2.04	2.02	-0.02	1.94	1.90	-0.04
Horizontal									
4.Acromion (°)	1.61	0.29	-1.32	0.21	0.15	-0.06	0.19	0.15	-0.04
5.Pelvis (°)	2.13	3.15	1.02	2.23	2.06	-0.18	2.43	2.36	-0.08
6.Scapula (°)	0.30	0.23	-0.07	0.32	0.24	-0.08	0.39	0.22	-0.17
7.Scapula/Acromion (°)	0.29	0.15	-0.14	0.18	0.15	-0.03	0.38	0.25	-0.13
8.Acromion/Pelvis (°)	2.15	2.01	-0.13	2.41	2.24	-0.17	2.41	2.34	-0.07
Sitting									
Sagittal									
9.Thoracic Angle (°)	153.89	151.52	-2.37	159.60	154.58	-5.02	161.50	158.68	-2.82
10.Lumbar Angle (°)	169.25	172.54	3.29	173.77	174.24	0.47	172.47	175.44	2.97
Walking									
Front									
11.Acromion (°)	10.13	10.34	0.20	12.35	11.74	-0.62	11.43	10.15	-1.28
12.Pelvis (°)	8.10	8.71	0.61	8.18	8.08	-0.10	8.35	8.02	-0.33
Horizontal									
13.Acromion (°)	14.83	16.59	1.77	15.09	15.69	0.60	15.09	15.69	0.60
14.Pelvis (°)	14.93	15.10	0.17	19.99	20.19	0.20	19.99	20.19	0.20
Bending									
Frontal									
15.Max. Anterior Bending (°)	72.85	69.12	-3.73	73.46	70.13	-3.33	75.58	68.84	-6.74
Horizontal									
16.Max. Lateral Bending (°)	29.25	28.14	-1.11	30.15	28.15	-2.00	29.15	28.17	-0.98

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 2 (at 0, 3 6 months)

Posture	0 month WTG	0 month WG	0 month Diff.	3 months WTG	3 months WG	3 months Diff.	6 months WTG	6 months WG	6 months Diff.
Standing									
Frontal									
1.Acromion (°)	2.76	1.11	-1.65	1.65	1.67	0.02			
2.Pelvis (°)	1.76	1.80	0.04	1.64	0.73	-0.91			
3.Acromion/Pelvis (°)	2.43	1.36	-1.07	2.05	2.18	0.13			
Horizontal									
4.Acromion (°)	1.96	1.11	-0.84	2.16	1.81	-0.36			
5.Pelvis (°)	1.29	1.80	0.52	2.11	0.78	-1.33			
6.Scapula (°)	4.87	4.20	-0.67	4.52	3.79	-0.73			
7.Scapula/Acromion (°)	2.94	4.74	1.80	2.55	3.16	0.61			
8.Acromion/Pelvis (°)	1.28	0.71	-0.56	1.79	1.74	-0.06			
Sitting									
Sagittal								(Dropped out)	
9.Thoracic Angle (°)	163.63	163.00	-0.63	160.18	159.13	-1.05			
10.Lumbar Angle (°)	178.23	172.11	-6.12	171.84	175.40	3.56			
Walking									
Front									
11.Acromion (°)	6.96	7.27	0.31	3.57	2.93	-0.64			
12.Pelvis (°)	4.91	4.62	-0.29	5.18	3.30	-1.88			
Horizontal									
13.Acromion (°)	8.77	9.96	1.19	14.91	11.06	-3.85			
14.Pelvis (°)	10.05	10.31	0.26	12.29	12.93	0.63			
Bending									
Frontal									
15.Max. Anterior Bending (°)	77.56	74.68	-2.88	82.13	76.91	-5.22			
Horizontal									
16.Max. Lateral Bending (°)	33.96	27.20	-6.75	32.99	22.72	-10.27			

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 3 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	WG	Diff.	WTG	WG	Diff.	WTG	WG	Diff.
Standing									
Frontal									
1.Acromion (°)	5.71	1.43	-4.28	3.97	0.87	-3.10	1.17	0.57	-0.60
2.Pelvis (°)	5.38	4.22	-1.16	4.79	4.26	-0.53	3.60	3.19	-0.41
3.Acromion/Pelvis (°)	5.08	1.33	-3.75	3.20	3.06	-0.14	2.39	2.16	-0.23
Horizontal									
4.Acromion (°)	0.79	1.22	0.43	1.11	1.46	0.35	0.99	0.92	-0.07
5.Pelvis (°)	3.48	3.15	-0.33	3.06	2.52	-0.53	1.06	0.84	-0.22
6.Scapula (°)	2.16	2.11	-0.06	1.71	2.17	0.46	1.21	1.27	0.06
7.Scapula/Acromion (°)	2.82	0.29	-2.53	2.31	1.61	-0.70	1.74	1.23	-0.52
8.Acromion/Pelvis (°)	2.67	2.62	-0.05	2.26	2.05	-0.21	1.66	1.65	-0.01
Sitting									
Sagittal									
9.Thoracic Angle (°)	158.10	158.83	0.73	160.54	162.90	2.36	161.94	164.80	2.86
10.Lumbar Angle (°)	167.03	168.74	1.71	170.19	178.00	7.81	171.45	177.90	6.45
Walking									
Front									
11.Acromion (°)	10.78	10.46	-0.32	10.58	7.24	-3.34	6.79	3.94	-2.85
12.Pelvis (°)	10.70	10.18	-0.52	9.96	8.62	-1.34	6.14	5.90	-0.25
Horizontal									
13.Acromion (°)	13.46	12.49	-0.97	14.73	10.56	-4.17	13.00	11.06	-1.93
14.Pelvis (°)	13.97	13.94	-0.03	13.69	10.96	-2.73	9.09	7.16	-1.93
Bending									
Frontal									
15.Max. Anterior Bending (°)	93.10	84.03	-9.06	70.77	61.72	-9.06	71.73	63.16	-8.58
Horizontal									
16.Max. Lateral Bending (°)	45.56	21.68	-23.88	43.99	31.59	-12.41	44.70	30.69	-14.01

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 4 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	WG	Diff.	WTG	WG	Diff.	WTG	WG	Diff.
Standing									
Frontal									
1.Acromion (°)	3.96	2.50	-1.45	1.85	0.88	-0.97	0.85	0.62	-0.23
2.Pelvis (°)	3.12	0.89	-2.23	2.64	0.79	-1.85	2.31	0.90	-1.41
3.Acromion/Pelvis (°)	2.50	2.25	-0.25	1.78	0.81	-0.97	0.95	0.76	-0.19
Horizontal									
4.Acromion (°)	3.34	2.48	-0.85	2.51	2.00	-0.50	2.50	2.00	-0.49
5.Pelvis (°)	4.18	1.86	-2.32	2.16	1.23	-0.93	1.68	1.18	-0.51
6.Scapula (°)	2.75	1.75	-1.00	2.36	2.15	-0.21	1.69	1.40	-0.29
7.Scapula/Acromion (°)	5.10	6.24	1.13	5.02	4.65	-0.37	4.58	4.48	-0.11
8.Acromion/Pelvis (°)	8.51	8.63	0.11	7.24	4.50	-2.73	6.56	4.20	-2.35
Sitting									
Sagittal									
9.Thoracic Angle (°)	140.56	149.60	9.04	148.77	148.29	-0.48	150.56	151.92	1.36
10.Lumbar Angle (°)	136.24	173.06	36.81	154.52	169.30	14.78	161.23	171.67	10.44
Walking									
Front									
11.Acromion (°)	13.11	11.02	-2.09	11.64	11.01	-0.62	10.59	10.23	-0.36
12.Pelvis (°)	12.77	12.45	-0.32	11.08	6.50	-4.58	11.08	6.50	-4.58
Horizontal									
13.Acromion (°)	20.46	13.49	-6.97	15.20	14.54	-0.66	15.20	14.54	-0.66
14.Pelvis (°)	21.40	16.41	-4.99	20.23	14.19	-6.04	18.67	14.57	-4.10
Bending									
Frontal									
15.Max. Anterior Bending (°)	73.96	69.61	-4.35	72.37	68.98	-3.39	70.75	68.23	-2.52
Horizontal									
16.Max. Lateral Bending (°)	41.46	40.98	-0.48	40.26	21.61	-18.65	40.36	23.74	-16.62

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 5 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	**WG**	**Diff.**	**WTG**	**WG**	**Diff.**	**WTG**	**WG**	**Diff.**
Standing									
Frontal									
1.Acromion (°)	1.63	0.95	-0.68	1.26	0.85	-0.41			
2.Pelvis (°)	1.34	1.55	0.21	1.98	1.39	-0.59			
3.Acromion/Pelvis (°)	0.98	1.13	0.16	2.64	0.81	-1.83			
Horizontal									
4.Acromion (°)	1.37	1.56	0.19	1.51	0.92	-0.58			
5.Pelvis (°)	2.18	1.31	-0.87	2.03	1.40	-0.63			
6.Scapula (°)	1.52	2.11	0.59	0.98	1.26	0.28			
7.Scapula/Acromion (°)	2.64	1.20	-1.44	2.21	1.47	-0.74			
8.Acromion/Pelvis (°)	3.47	4.16	0.69	2.61	1.27	-1.34			
Sitting									
Sagittal								(Dropped out)	
9.Thoracic Angle (°)	161.26	155.13	-6.13	167.87	167.42	-0.45			
10.Lumbar Angle (°)	176.87	179.06	2.19	170.62	176.10	5.48			
Walking									
Front									
11.Acromion (°)	6.33	6.80	0.47	3.80	3.96	0.16			
12.Pelvis (°)	4.03	4.05	0.03	3.27	2.66	-0.60			
Horizontal									
13.Acromion (°)	7.38	12.72	5.34	8.57	8.15	-0.42			
14.Pelvis (°)	9.42	10.31	0.89	10.19	8.16	-2.03			
Bending									
Frontal									
15.Max. Anterior Bending (°)	78.98	73.13	-5.86	75.61	71.71	-3.91			
Horizontal									
16.Max. Lateral Bending (°)	36.74	23.93	-12.81	38.45	23.83	-14.62			

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 6 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	**WG**	**Diff.**	**WTG**	**WG**	**Diff.**	**WTG**	**WG**	**Diff.**
Standing									
Frontal									
1.Acromion (°)	4.64	2.36	-2.27	2.50	2.48	-0.02	2.81	2.62	-0.18
2.Pelvis (°)	3.84	0.23	-3.61	0.61	1.12	0.51	1.41	1.24	-0.17
3.Acromion/Pelvis (°)	2.84	1.32	-1.52	1.80	1.66	-0.14	2.65	1.57	-1.08
Horizontal									
4.Acromion (°)	9.13	4.33	-4.79	4.69	4.52	-0.17	6.18	6.15	-0.02
5.Pelvis (°)	10.43	9.15	-1.29	8.99	10.66	1.67	10.80	10.96	0.17
6.Scapula (°)	1.34	1.25	-0.09	1.53	0.50	-1.03	2.17	1.29	-0.87
7.Scapula/Acromion (°)	2.35	2.39	0.05	1.96	2.16	0.20	2.46	2.40	-0.06
8.Acromion/Pelvis (°)	4.21	5.32	1.11	4.17	5.26	1.09	4.72	5.41	0.68
Sitting									
Sagittal									
9.Thoracic Angle (°)	159.75	156.54	-3.21	158.40	155.68	-2.72	159.64	161.43	1.79
10.Lumbar Angle (°)	157.24	175.26	18.02	159.84	168.50	8.66	162.84	165.76	2.92
Walking									
Front									
11.Acromion (°)	9.10	6.29	-2.81	11.58	15.58	4.00	10.27	10.74	0.46
12.Pelvis (°)	9.96	7.61	-2.36	11.16	9.13	-2.03	10.65	8.08	-2.56
Horizontal									
13.Acromion (°)	20.52	19.08	-1.44	23.54	17.11	-6.44	25.42	20.54	-4.88
14.Pelvis (°)	15.93	14.27	-1.66	17.44	19.52	2.07	17.35	19.18	1.83
Bending									
Frontal									
15.Max. Anterior Bending (°)	135.22	135.22	110.96	129.82	117.72	-12.10	131.93	124.33	-7.60
Horizontal									
16.Max. Lateral Bending (°)	49.64	49.64	32.48	53.93	37.60	-16.33	55.22	40.96	-14.26

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 7 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	WG	Diff.	WTG	WG	Diff.	WTG	WG	Diff.
Standing									
Frontal									
1.Acromion (°)	2.84	0.58	-2.26	1.46	0.34	-1.12	0.90	0.53	-0.36
2.Pelvis (°)	1.95	1.53	-0.42	1.58	1.31	-0.27	1.68	1.46	-0.22
3.Acromion/Pelvis (°)	1.61	1.54	-0.07	2.59	1.54	-1.05	2.35	1.68	-0.67
Horizontal									
4.Acromion (°)	0.93	1.07	0.14	1.91	0.48	-1.42	0.42	0.38	-0.04
5.Pelvis (°)	3.35	4.75	1.41	3.42	3.85	0.43	2.20	2.21	0.01
6.Scapula (°)	4.83	4.30	-0.54	5.20	2.78	-2.42	3.63	3.51	-0.12
7.Scapula/Acromion (°)	1.54	3.36	1.82	1.13	0.70	-0.42	1.18	0.69	-0.49
8.Acromion/Pelvis (°)	4.93	3.69	-1.24	4.12	2.69	-1.43	3.71	2.42	-1.29
Sitting									
Sagittal									
9.Thoracic Angle (°)	147.20	144.40	-2.80	144.69	150.27	5.58	148.89	151.23	2.34
10.Lumbar Angle (°)	169.74	171.76	2.02	173.92	172.80	-1.12	172.23	172.03	-0.20
Walking									
Front									
11.Acromion (°)	9.72	7.25	-2.47	8.43	7.49	-0.94	7.29	6.42	-0.87
12.Pelvis (°)	8.46	3.17	-5.29	7.61	7.09	-0.52	7.11	7.07	-0.04
Horizontal									
13.Acromion (°)	33.47	25.11	-8.36	20.33	23.38	3.05	18.93	19.95	1.02
14.Pelvis (°)	26.48	22.84	-3.64	18.17	24.07	5.90	17.72	19.72	2.00
Bending									
Frontal									
15.Max. Anterior Bending (°)	89.87	68.43	-21.43	83.28	69.99	-13.29	80.21	70.77	-9.44
Horizontal									
16.Max. Lateral Bending (°)	44.85	26.21	-18.63	45.04	31.76	-13.28	47.20	34.18	-13.02

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 8 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	WG	Diff.	WTG	WG	Diff.	WTG	WG	Diff.
Standing									
Frontal									
1.Acromion (°)	2.53	2.21	-0.33	2.37	2.19	-0.17	2.22	2.03	-0.19
2.Pelvis (°)	3.06	2.85	-0.20	2.90	2.89	-0.01	2.77	2.80	0.03
3.Acromion/Pelvis (°)	1.07	0.74	-0.33	1.77	2.68	0.91	1.99	2.57	0.58
Horizontal									
4.Acromion (°)	5.51	8.50	2.98	5.68	6.37	0.70	4.56	4.50	-0.05
5.Pelvis (°)	6.56	8.28	1.72	5.53	7.35	1.81	4.64	5.84	1.20
6.Scapula (°)	0.32	0.86	0.53	0.58	2.44	1.86	0.29	0.95	0.66
7.Scapula/Acromion (°)	5.45	6.27	0.81	4.36	5.12	0.76	4.67	4.85	0.18
8.Acromion/Pelvis (°)	1.49	0.86	-0.62	1.85	0.97	-0.88	1.48	0.52	-0.95
Sitting									
Sagittal									
9.Thoracic Angle (°)	150.02	148.24	-1.78	151.58	149.57	-2.00	153.76	150.45	-3.32
10.Lumbar Angle (°)	165.97	171.54	5.57	166.06	170.26	4.20	167.63	170.77	3.14
Walking									
Front									
11.Acromion (°)	7.53	7.52	-0.02	5.26	6.96	1.70	6.26	6.20	-0.07
12.Pelvis (°)	10.14	8.39	-1.75	9.14	9.46	0.32	8.79	8.59	-0.19
Horizontal									
13.Acromion (°)	25.46	22.58	-2.89	26.50	25.50	-0.99	23.95	23.00	-0.95
14.Pelvis (°)	18.54	19.64	1.10	17.97	18.79	0.82	16.76	16.98	0.21
Bending									
Frontal									
15.Max. Anterior Bending (°)	86.23	73.77	-12.46	85.67	75.77	-9.90	84.35	78.37	-5.98
Horizontal									
16.Max. Lateral Bending (°)	38.98	27.49	-11.49	39.06	30.57	-8.49	41.66	35.66	-6.00

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Motion capturing results for subject 9 (at 0, 3 6 months)

Posture	0 month			3 months			6 months		
	WTG	**WG**	**Diff.**	**WTG**	**WG**	**Diff.**	**WTG**	**WG**	**Diff.**
Standing									
Frontal									
1.Acromion (°)	1.61	1.60	-0.01	0.74	0.72	-0.02	0.87	0.75	-0.12
2.Pelvis (°)	3.18	3.69	0.51	3.99	3.72	-0.26	3.76	3.60	-0.16
3.Acromion/Pelvis (°)	1.59	1.80	0.21	1.46	2.22	0.76	1.57	2.19	0.62
Horizontal									
4.Acromion (°)	0.83	2.34	1.51	0.57	0.65	0.08	0.61	0.64	0.03
5.Pelvis (°)	1.07	1.07	0.00	3.24	1.18	-2.05	2.51	1.04	-1.47
6.Scapula (°)	0.80	1.01	0.22	1.07	1.85	0.78	1.70	1.51	-0.20
7.Scapula/Acromion (°)	0.39	3.76	3.37	2.64	3.42	0.77	2.74	3.16	0.42
8.Acromion/Pelvis (°)	3.86	4.27	0.41	3.81	1.00	-2.81	0.83	1.01	0.18
Sitting									
Sagittal									
9.Thoracic Angle (°)	151.45	162.69	11.24	152.54	158.27	5.72	154.44	159.78	5.34
10.Lumbar Angle (°)	170.11	171.24	1.13	170.81	170.55	-0.26	169.10	171.03	1.93
Walking									
Front									
11.Acromion (°)	12.03	9.16	-2.87	8.59	7.55	-1.04	8.59	7.55	-1.04
12.Pelvis (°)	7.42	8.35	0.93	6.23	5.99	-0.24	6.32	5.87	-0.45
Horizontal									
13.Acromion (°)	29.25	22.08	-7.17	18.71	14.59	-4.11	17.08	15.94	-1.14
14.Pelvis (°)	18.32	20.80	2.48	11.76	16.50	4.74	13.55	15.09	1.54
Bending									
Frontal									
15.Max. Anterior Bending (°)	41.79	49.48	7.70	48.46	50.36	1.91	49.57	50.36	0.79
Horizontal									
16.Max. Lateral Bending (°)	43.22	31.03	-12.19	44.32	32.25	-12.08	45.53	34.56	-10.96

*Remarks: WTG = Without Girdle; WG = With Girdle; Diff. = Difference(s)

Appendix G

Pre (0 month) and post (6 months) X-rays of the subjects

Pre (Thoracic: 4°, Lumbar 14°)

Post (Thoracic: 14°, Lumbar 19°)

Pre (0 month) and post (6 months) X-ray of subject 1 (without girdle)

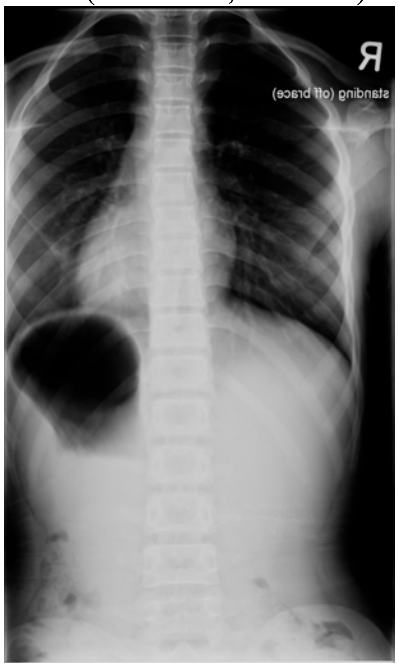
Pre (Thoracic: / , Lumbar 7°)

No post X-ray (Dropped out)

Pre (0 month) and post (6 months) X-ray of subject 2 (without girdle)

Pre (Thoracic: 6°, Lumbar 4°)

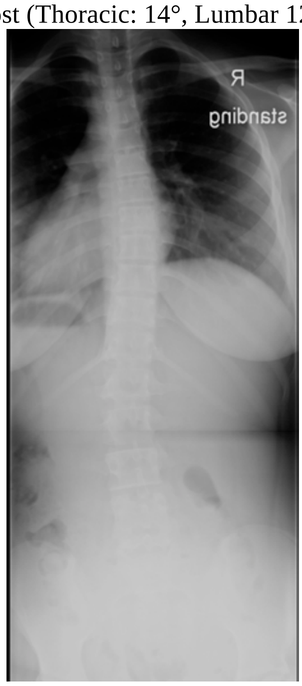
Post (Thoracic: 6°, Lumbar 4°)



Pre (0 month) and post (6 months) X-ray of subject 3 (without girdle)

Pre (Thoracic: 19°, Lumbar 15°)

Post (Thoracic: 14°, Lumbar 12°)



Pre (0 month) and post (6 months) X-ray of subject 4 (without girdle)

Pre (Thoracic: 19°, Lumbar 13°)

No post X-ray (Dropped out)

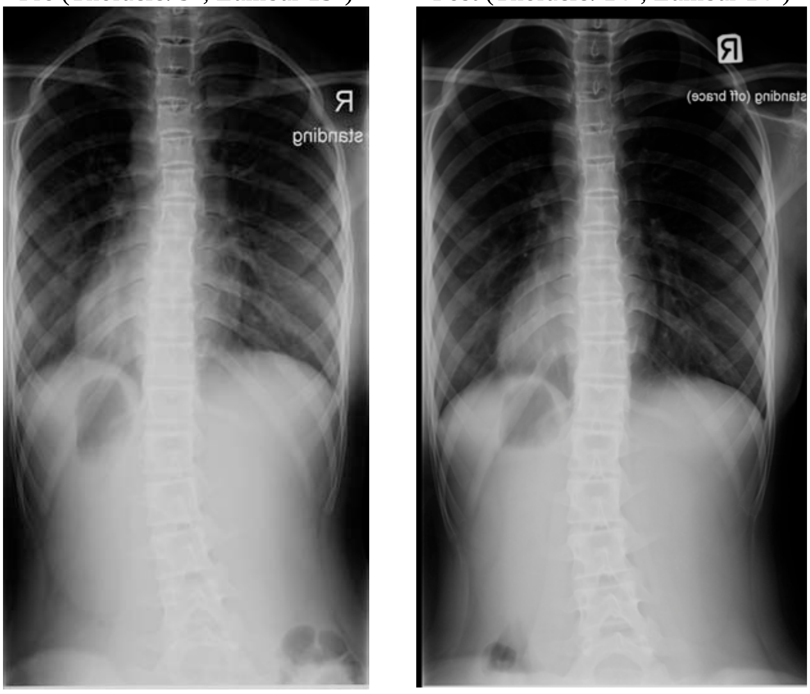
Pre (0 month) and post (6 months) X-ray of subject 5 (without girdle)

Pre (Thoracic: 17°, Lumbar 13°)

Post (Thoracic: 27°, Lumbar 18°)

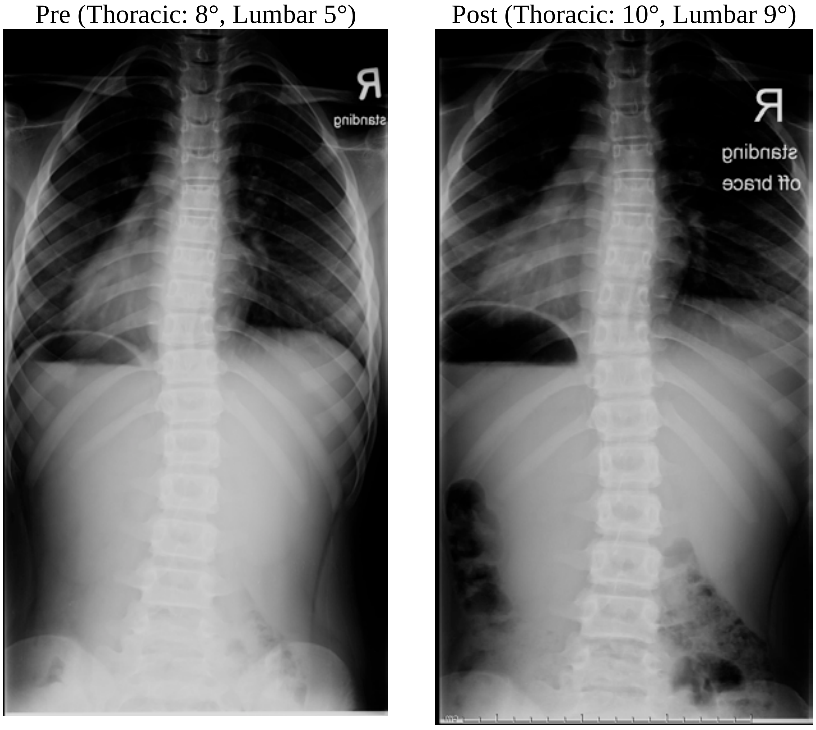
Pre (0 month) and post (6 months) X-ray of subject 6 (without girdle)

Pre (Thoracic: 9°, Lumbar 15°) Post (Thoracic: 14°, Lumbar 14°)



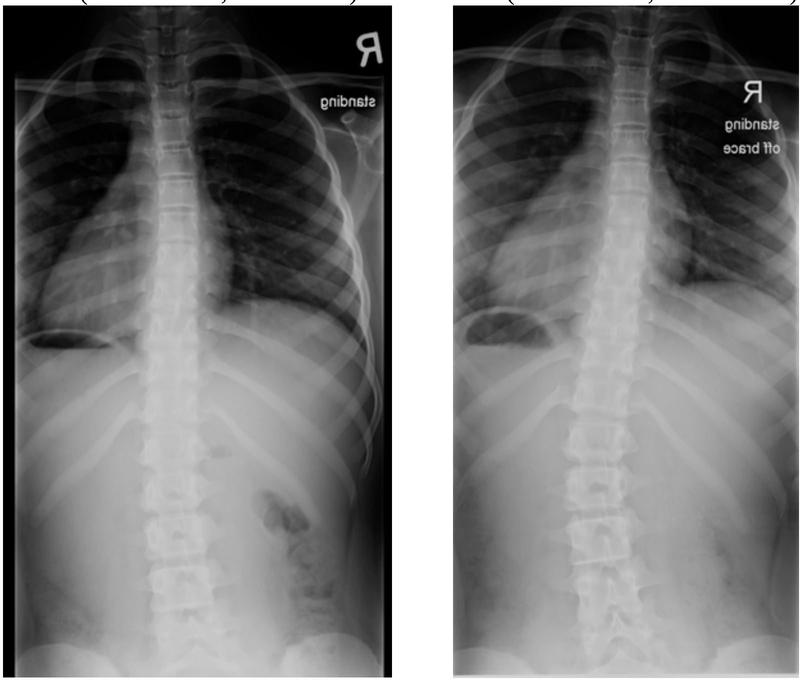
Pre (0 month) and post (6 months) X-ray of subject 7 (without girdle)

Pre (Thoracic: 8°, Lumbar 5°) Post (Thoracic: 10°, Lumbar 9°)



Pre (0 month) and post (6 months) X-ray of subject 8 (without girdle)

Pre (Thoracic: 4°, Lumbar 8°) Post (Thoracic: 4°, Lumbar 13°)

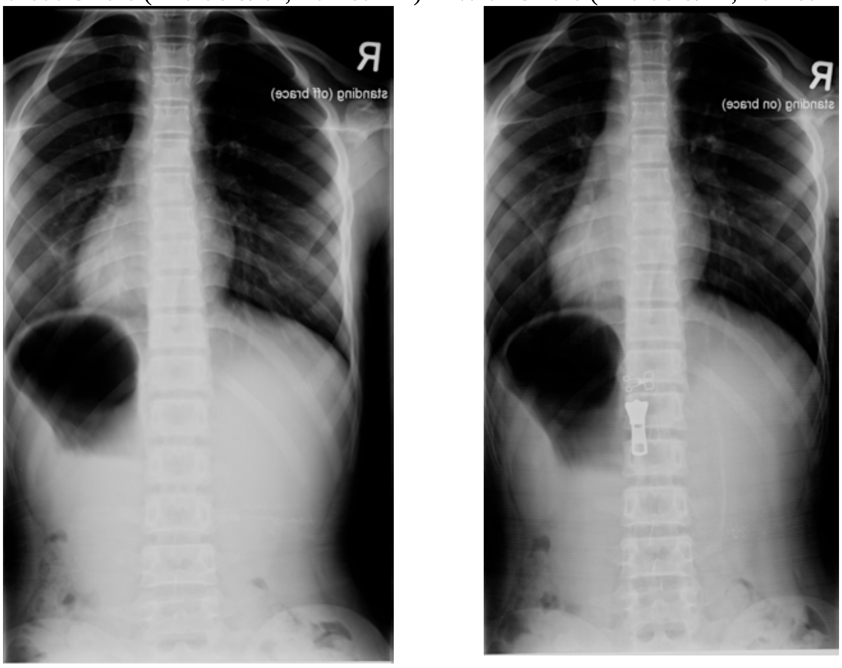


Pre (0 month) and post (6 months) X-ray of subject 9 (without girdle)

Appendix H

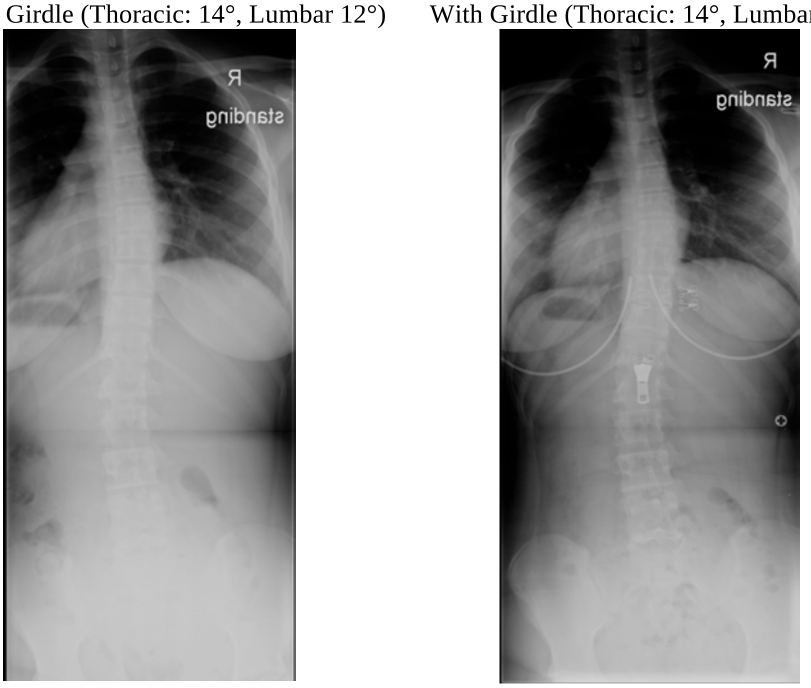
Comparison of without girdle and with girdle X-rays of the subjects (at 6 months)

Without Girdle (Thoracic: 6°, Lumbar 4°) With Girdle (Thoracic: 1°, Lumbar 1°)



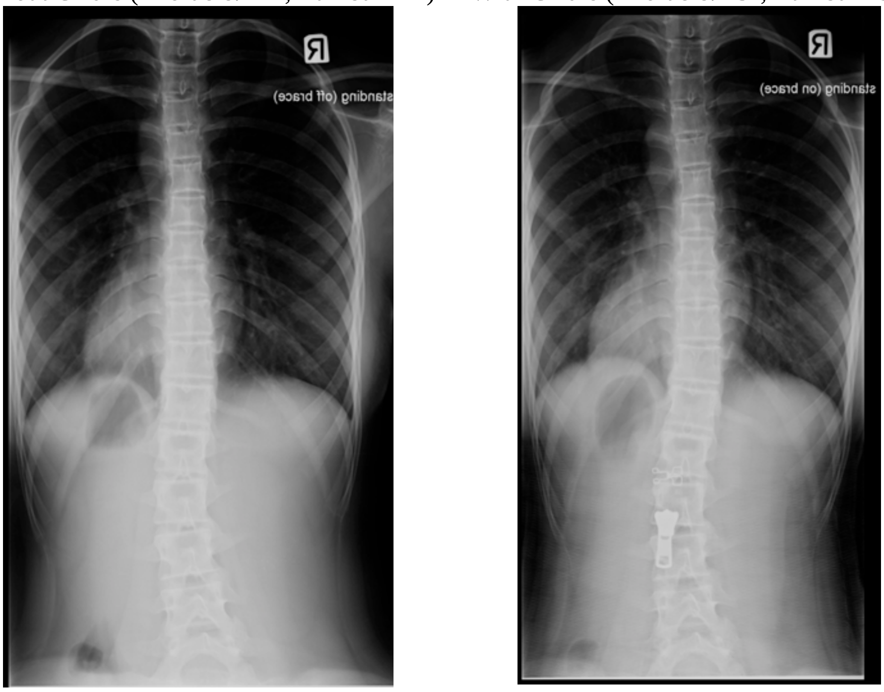
Comparison of without girdle and with girdle X-rays of subject 3 (at 6 months)

Without Girdle (Thoracic: 14°, Lumbar 12°) With Girdle (Thoracic: 14°, Lumbar 12°)



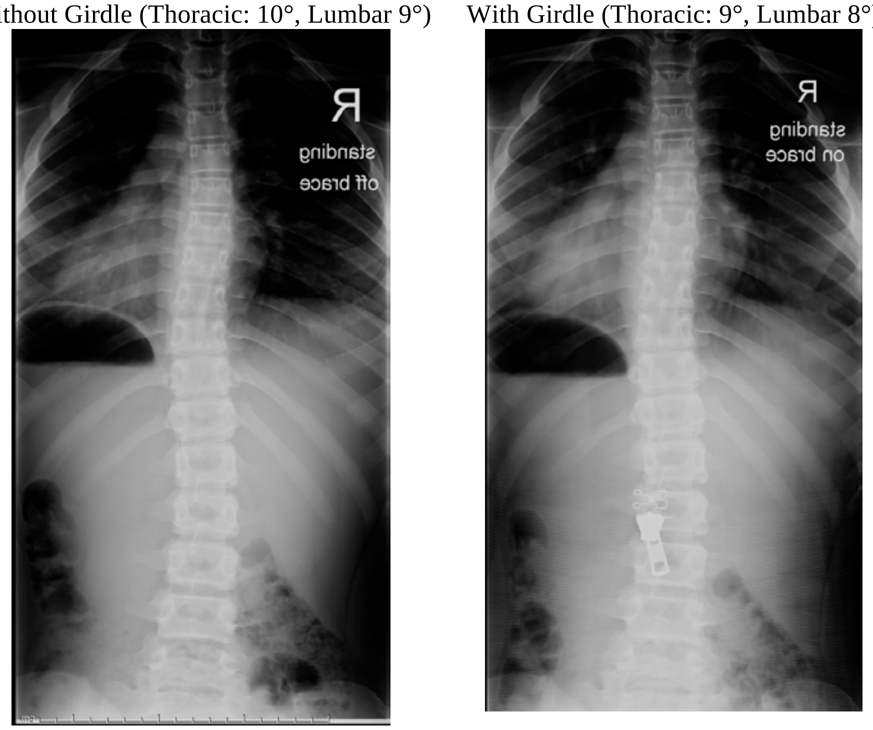
Comparison of without girdle and with girdle X-rays of subject 4 (at 6 months)

Without Girdle (Thoracic: 14°, Lumbar 14°)   With Girdle (Thoracic: 13°, Lumbar 13°)



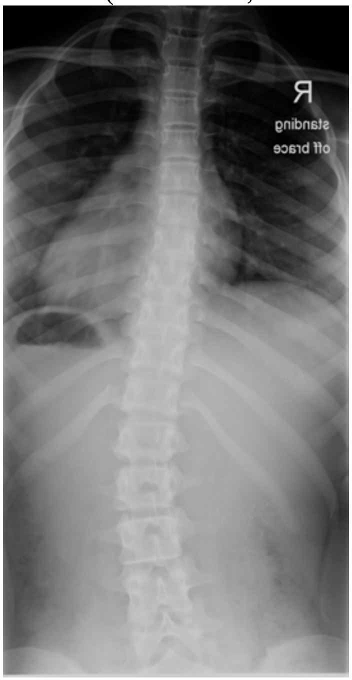
Comparison of without girdle and with girdle X-rays of subject 7 (at 6 months)

Without Girdle (Thoracic: 10°, Lumbar 9°)   With Girdle (Thoracic: 9°, Lumbar 8°)



Comparison of without girdle and with girdle X-rays of subject 8 (at 6 months)

Without Girdle (Thoracic: 4°, Lumbar 13°)   With Girdle (Thoracic: 4°, Lumbar 12°)



Comparison of without girdle and with girdle X-rays of subject 9 (at 6 months)

Appendix I

The results of repeated measures ANOVA of health test including (1) blood pressure and pulse measurements, (2) peak expiration flow measurement and (3) sensory level.

1a. Blood pressure

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
condition	Sphericity Assumed	26.694	1	26.694	3.161	.113
	Greenhouse-Geisser	26.694	1.000	26.694	3.161	.113
	Huynh-Feldt	26.694	1.000	26.694	3.161	.113
	Lower-bound	26.694	1.000	26.694	3.161	.113

1b. Pulse

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
condition	Sphericity Assumed	17.014	1	17.014	3.311	.106
	Greenhouse-Geisser	17.014	1.000	17.014	3.311	.106
	Huynh-Feldt	17.014	1.000	17.014	3.311	.106
	Lower-bound	17.014	1.000	17.014	3.311	.106

2. Peak expiration flow

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
condition	Sphericity Assumed	272.222	1	272.222	2.631	.143	2.631	.299
	Greenhouse-Geisser	272.222	1.000	272.222	2.631	.143	2.631	.299
	Huynh-Feldt	272.222	1.000	272.222	2.631	.143	2.631	.299
	Lower-bound	272.222	1.000	272.222	2.631	.143	2.631	.299

3. Sensory level

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
condition	Sphericity Assumed	.090	1	.090	2.286	.169	2.286	.266
	Greenhouse-Geisser	.090	1.000	.090	2.286	.169	2.286	.266
	Huynh-Feldt	.090	1.000	.090	2.286	.169	2.286	.266
	Lower-bound	.090	1.000	.090	2.286	.169	2.286	.266

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