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Effects of a tailor-made girdle on posture of adolescents with early scoliosis

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Abstract

Spinal curvature and postural deviation are commonly found in female patients with adolescent idiopathic scoliosis (AIS). The purpose of this study is to assess the effect of applying a tailor-made posture correction girdle on patients with early scoliosis with the aim to help them to improve their imbalanced posture and reduce the likelihood of curve progression. A total of 10 subjects who are female adolescents with symptoms of early scoliosis are recruited through a school-screening program to undertake a 3-month wear trial with the posture correction girdle. The Vicon motion capture system has also been employed to evaluate the short-term effectiveness of this therapeutic girdle on posture correction. The results show that the imbalanced posture of the subjects improves after the 3-month wear trial, and the effect is particularly significant for the acromion in the frontal plane in a standing posture. Posture could be improved with posture training. This study shows that there is an improving trend in posture and effectiveness of motion control through the use of the posture correction girdle.

Keywords: Posture correction; Adolescent idiopathic scoliosis; Motion capture; Wear trial; soft brace

Introduction

Adolescent idiopathic scoliosis (AIS) [1] is a multi-factorial, three-dimensional deformity of the spine and trunk which can appear and sometimes progress during any rapid growth period of apparently healthy children with higher prevalence in females [2]. In Hong Kong, 38,000 (16%) out of 230,000 students were found to have scoliosis per the assessment conducted by the Department of Health during the school year of 2012/13 with an increasing trend [3, 4]. Researchers generally believe that growth is the main variable that contributes to the increased progression of the spinal curve [5-6], and other factors, including developmental destabilization [7], morphology [8], and neuromuscular imbalance [9] could also lead to the onset of AIS. Serious progression of AIS will affect the cardiac and pulmonary functions of patients and may even lead to death [10]. It is therefore important to monitor and control the situation once spinal curvature is found. The multi-disciplinary rehabilitation concept for combating the postural deviation of AIS patients comprises surgical, medical and orthotic interventions, and also back muscle strengthening exercises [11].

Posture is defined as the alignment or orientation of body segments while the human subject is maintaining an upright position [12]. The resulting body alignment depends on the effect of gravity, muscle tension and integrity of the bony structures [13]. Poor posture is defined as any prolonged deviation from the "natural spine" [14-15]. Spinal deformity alters the shape of the trunk and changes the relations between body segments [16-21]. Postural alterations are commonly found in patients with AIS, including the orientation of the head, shoulders, scapula, and pelvis in all three planes, while rotations of body segments in the horizontal plane are particularly more significant [22]. So, AIS can be observed through postural "warning signs", including a curved-body, rib or flank prominence on one side, curved head-spinous process - pelvis line, tilting of one side of the pelvis, head that is not directly centered above the pelvis, prominence of shoulder blade on one side, scapular rotation, imbalances in the scapulas (i.e. abduction, adduction, elevation and depression motions), as well as raised and prominently uneven hips [23-25].

It is believed that improper posture and poor postural stability control can further contribute to the pain and deformity of patients with spinal disorders [11,26]; therefore, posture controlling and training are considered to be helpful in reducing the further progression of the spinal curve during the rapid growth period of the patients.

Improvement of posture or body alignment for those at risk can be achieved through exercises, physiotherapy, and rehabilitation programs. "Reminders" for a good posture may also be an acceptable prophylaxis, which can be provided through parents or training devices. According to the proposed therapeutic approach of posture training, the rationale is to use the back muscles of the patients to keep the spine within the natural curvature, thus, the corresponding symptoms may be prevented with awareness of their posture as adolescents may learn good postural habits that could carry over throughout their entire life [11, 14-15].

Currently, there is only a limited supply of posture training girdles for adolescents with early scoliosis in the market as most of them are not designed for AIS youths, and disappointing treatment compliance due to discomfort, unattractiveness in appearance, inconvenience in mobility and psychological effects are profound [27-31]. In addition, only observation is carried out with periodical spine re-examination for patients with early scoliosis which implies that the spinal curve is between 6 and 20 degrees [32, 33]. It is believed that the number of patients who need surgery throughout the years could be reduced by earlier detection of spinal deformity through scoliosis screening programs and thus providing patients with suitable treatment [34]. In this study, a tailor-made posture correction girdle is fabricated for each of the participating subjects [35]. The originality of this study is expected to fill the knowledge gap that exists in the design and development of a suitable product for pre-teen and teenage girls with early scoliosis, to help them to improve their posture deviation and reduce progression of their spinal curvature by means of a girdle-type of device which can exert optimal corrective force to problematic parts of the body.

Methods

Subject recruitment and selection criteria

In this study, a school-screening program was carried out in Hong Kong during 2012 to 2013 and the target population was pre-teen and teenage girls between the ages of 10 to 13. The study was approved by The Hong Kong Polytechnic University and informed consent was obtained from the volunteers and their parents. Ethic approval was obtained from the Human Ethics Committee of the University. The recruitment started with 443 volunteers from 3 secondary and 4 primary schools. The screening was undertaken by a professional prosthetist-orthotist (P&O) with the aid of a research team for data recording. All of the volunteers were invited to take part in the Adam's forward bend test [36], and an OSI scoliometer [37] was used to measure the angle of the trunk inclination (ATI) in the spine of the volunteers who were considered prone to scoliosis [38, 39]. It was found that teenagers who have ATIs of 3°, 4° or greater per the screening program had to be re-screened more frequently, which means more attention needs to be given to adolescents who have 3-4° in terms of ATI [40]. As an ATI of 3° or greater may be an early sign of scoliosis [41-42], volunteers who met this criterion were defined as possible subjects in this study, in order to recruit human subjects who are in the early instead of middle or final stage of AIS. Upon completion of the screening process, 79 possible subjects with an ATI of left 3° or right 3° or greater were identified and 12 then went through an X-ray examination for further evaluation of their spinal conditions. As the peak growth rate for girls is at 11.5 ±2 years of age [43], and a high percentage of progression risk was found in those aged 10-12 (88%) as well as with Risser sign 1-2 (52%) [44], the subject selection criteria [45] were set as females students diagnosed with progressive scoliotic deformity and a Cobb's angle (a method to measure the spinal deformity of the coronal plane on the antero-posterior plane to determine the type and extent of scoliosis on radiographs [46]) between 6° and 20°, between the ages of 10 and 13, and a Risser sign ≤2 (a measure of maturity at the iliac crest on a scale of 5 grades. Grade 2 corresponds to the stage before or during a growth spurt [47]). The subjects were to have good spinal flexibility and had not previously received any other type of spinal treatment. Furthermore, the subjects were to be pre-menarchal or post-menarchal less than one year as there is a strong correlation between the age at menarche and the age which deformity is noted, i.e. those who were 11 at menarche were noted to have occurrence of deformity at 12, those who were 12 at menarche were noted to have occurrence of deformity at 12.5, etc. [44]. In addition, the subjects were to have the ability to adhere to a girdle protocol both physically and mentally, and able to read and speak English or Chinese for effective communication purposes. As a result, 10 out of the 443 volunteers were accepted as potential subjects for this study.

Girdle design

Each of the 10 subjects received a tailor-made posture correction girdle designed to provide supportive and point-pressure corrective forces [35]. As shown in Figure 1, the girdle is similar to underwear with a vest-like design for the shoulders that is mainly made of warp knitted fabric i.e. tricot, satinette, powernet, etc. and elastic bands with high strength and good recovery. The close-fitting and shoulder-to-hip length design helps to facilitate supportive and controlling functions. The supportive force was exerted by resin bones attached to the back and two sides of the girdle, while the point-pressure corrective forces were exerted by using ethylene vinyl acetate (EVA) foam paddings inserted into different pocket linings of the girdle in accordance with the unique posture and curvature conditions of the individual subjects. 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 [48]. This means that it is flexible yet rigid, and therefore, the use of EVA foam can comfortably create point-pressures and improve posture through corrective forces. For most of the cases, 2 semi-rigid paddings were enough for the correction and they were placed opposite to one another. Some cases might have required 3 or more paddings while others only one padding for the correction. In Example 1, where the subject has right thoracic and left lumber S-type scoliosis, the paddings should be inserted into the R1, L2 and L3 pockets to exert corrective forces onto the body. In Example 2, the subject has a larger curve on the right thoracic and a mild curve on the left thoracic, and therefore, the paddings should be inserted into the R1, R2 and L1 pockets. The tightness of all the straps and placement of the paddings were determined by the P&O. The warping and extension of the elastic shoulder straps and waistband also generate corrective forces onto the torso, so as to allow better posture at the shoulders, straighten the back by reducing forward bending tendencies and reduce side-bending of the waist. These supportive and corrective forces help to reduce imbalance, extra movements or tilting of the waist and pelvis, and therefore, the spine, which will enhance the corrective effects.

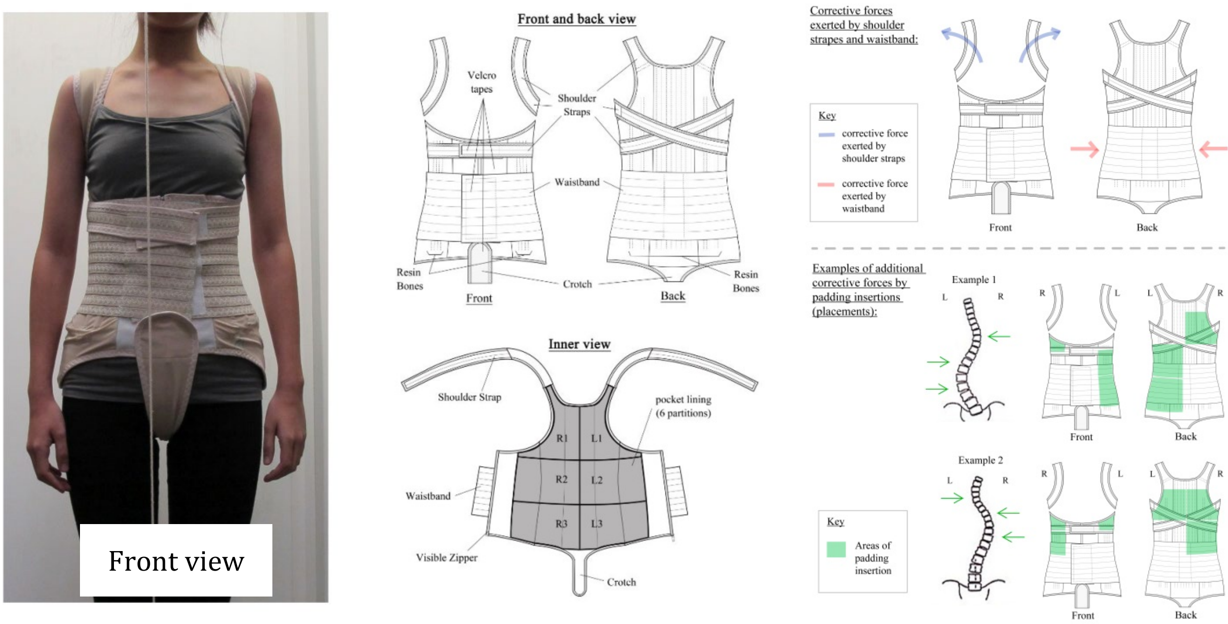


Figure 1Front view of the Posture Correction Girdle on a subject, the corrective forces exerted onto the body and examples of padding insertion for different types of scoliosis

Wear trial

Before the wear trial started, health tests, including those for blood pressure, pulse rate and peak expiratory flow, were conducted on the subjects before and after they wore the girdle for 3 hours, to ensure that their health would not suffer any negative effects due to the girdling [35]. The wear trial spanned a period of 3 months for each subject, and they were advised to wear the girdle each day for a duration of 8 hours when they were awake. The subjects were given an adaption period of 2 weeks before they undertook the 3-month wear trial in order to give them sufficient time to become accustomed to their girdle. During the adaptation period, it was recommended to the subjects that they were to wear the girdle for 2 hours each day for the first week and then 4 hours for the second week. Temperature loggers (LogTag, OnSolution Pty Ltd.) were inserted into the girdle to monitor the wear. In the end, 9 out of the 10 subjects completed the whole wear trial, as 1 withdrew due to participation in another form of therapy. Table 1 shows the demographic data and basic information of the subjects.

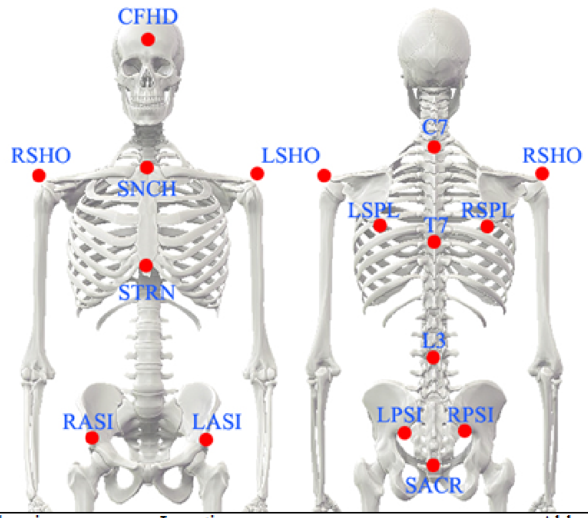
Posture analysis by 3D motion capture

To evaluate the short-term effectiveness of the posture correction girdle, the Vicon motion capture system (Vicon 612 system, Oxford Metrics Ltd., Oxford, UK) was used, as it is a non-invasive method for repeated quantitative measures of body segment posture [49]. The system contains a data-station, six wall-mounted video cameras with infrared sources, and a PC workstation. The infrared light-emitting diodes of each camera have a flash of 60 Hz and the system could obtain 3D co-ordinates from each marker through a 3-D reconstruction method. Calibrations, including static and dynamic calibrations, were implemented before the motion capturing in order to determine the desirable position and orientation of the six cameras with respect to the origin and set of axes. The subjects were required to wear thin bra tops and tight shorts during the motion capturing process, in order to more accurately obtain the results. After the calibrations and before the start of capturing, 16 reflective markers were placed on specific landmarks on the body of the subjects. The reflective marker on the left arm acted as the reference point which provided easy locating of the body direction in the motion capturing process. The locations of the other 15 reflective markers are shown in Table 2 with their abbreviations. To ensure data accuracy, identical holes with a diameter of 3 cm were cut into clothing, including the posture correction girdles worn by the subjects during the motion capturing process in accordance with the 15 body landmarks, so that the reflective markers could be directly placed onto the skin after palpation to find the bony structures and thus errors induced by shifting of the clothing could be eliminated. It was proven that there is almost no difference found on the posture correcting effectiveness of the girdle between those with holes and those without through a preliminary motion capturing test.

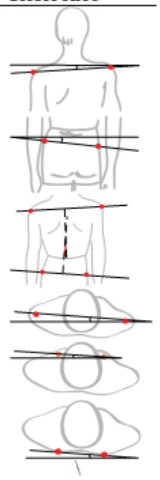
In this study, both the static and dynamic phases of posture have been assessed and evaluated [50]. A series of tasks that model daily life activities, including standing, sitting, walking, and bending, were performed by the subjects during the motion capturing process, and the tasks are shown in Figure 2 with a sequence chart. They were required to carry out each task 3 times with and without wearing the posture correction girdle. The first time was to allow the subject to adapt to the task. Subsequently, the data from the second and the third time that the task was carried out were used to conduct test-retest reliability.

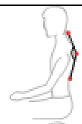
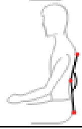
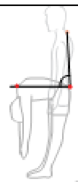
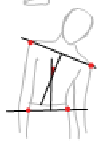
Table 2 Location of markers and Posture parameters used in the analysis

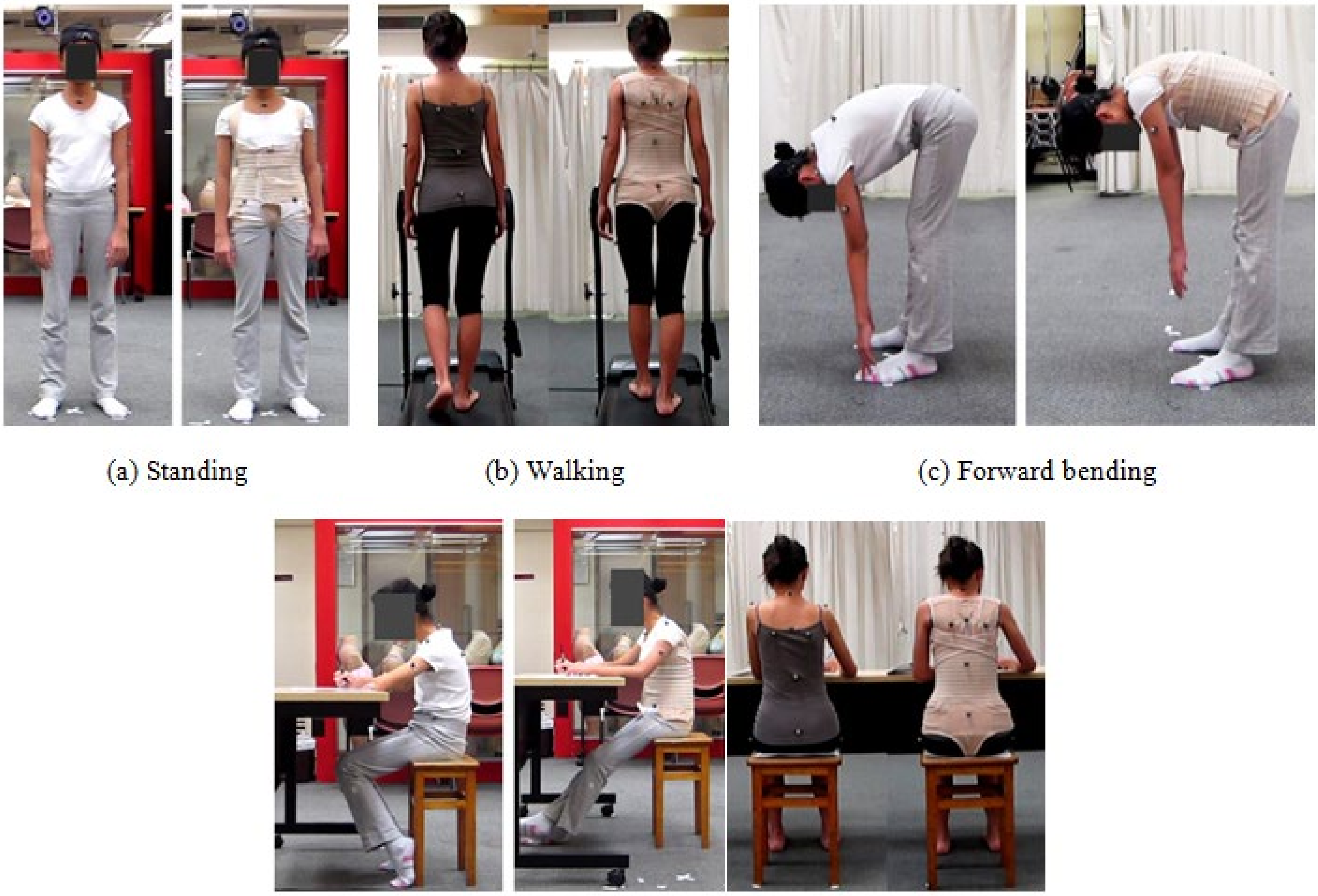
Location of markers (location of markers with respect to skeleton, but on the body surface)



Anatomical region	Location	Abbreviation
Head (1 marker)	· Centre front of the forehead	CFHD
Neck (1 marker)	· Sternal notch	SNCH
Bust (1 marker)	· Sternum	STRN
Shoulder (2 markers)	· Acromion of left upper arm bone	LSHO
	· Acromion of right upper arm bone	RSHO
Spine (4 markers)	· Spinous process of C7	C7
	· One thoracic vertebrae	T7
	· One lumbar vertebrae	L3
	· Between two posterior superior iliac spines (Sacrum)	SACR
Pelvis (2 markers)	· Left Anterior ASIS	LASI
	· Right Anterior ASIS	RASI
	· Left Posterior ASIS	LPSI
	· Right Posterior ASIS	RPSI
Scapula (2 markers)	· Left Scapula	LSPL
	· Right Scapula	RSPL

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	



(a) Standing (b) Walking (c) Forward bending

(d) Sitting

Figure 2 Posture differences of the subject with and without the Posture Correction Girdle during the tasks

For the *standing* test, the subjects were asked to stand up straight as they naturally would for 1 minute in accordance with a footprint marker placed on the floor. In terms of *sitting*, the subjects had to sit on a chair to read a book for 5 minutes with the aid of a desk. As for *walking*, the subjects were asked to walk on a treadmill in their bare feet at their normal speed for 3 minutes. Finally, for the *bending* test, the subjects had to perform maximum anterior and lateral bending. The whole process was carried out in a relaxing and comfortable environment. The room temperature was controlled at 25°C (±1°C) which was not too hot or cold for the participants. With regard to the data reduction process, only the data that were recorded halfway through the second time of each task at 1 minute were extracted for analysis, i.e. the recorded data at the start and the end of the task were not used. After collecting the data, the posture parameters shown in Table 2 were analyzed.

Statistical analysis

The data obtained from the 3D motion capturing process were analyzed by using BodyBuilder software. In the analysis, the angles between specific body segments (shoulder, scapula, pelvis and trunk) and the range of values during the *walking* test were considered to describe the posture changes. The data were analyzed by using IBM SPSS Statistic Version 20. Paired T-testing was used to compare the posture parameters in the two trials and between the two trials. The confidence interval was set at 95% ($p<0.05$). This helped to evaluate whether the posture of the subjects significantly differed when they wore and took off the girdle at 0 and 3 months, as well as when they took off the girdle between 0 and 3 months. With regards to the results of the absolute angle for the 16 posture parameters, a reduction of the angle means improvement in posture during standing as well as walking and bending, i.e. more balance in the frontal plane and less rotation in the horizontal plane during standing and walking, as well as control of extra motion during bending, while increases in the angle means improvement in posture during sitting, i.e. less curviness in the sagittal plane.

Results

A 93.25% compliance of the wear trial was found according to the data obtained from the temperature loggers which were inserted into the posture correction girdles of the 9 subjects, see Table 1. Table 3 presents the analyzed results of the posture parameters in the motion capture tests.

Table 1 Demographic data and basic information of subjects

Subject	Age	ATI		Curve type (S/C)	Cobb's angle (°)	0 month			3 months		
		Throcic	Lumber			Height (cm)	Weight (kg)	BMI	Height (cm)	Weight (kg)	BMI
1	12	L3	R3	S	12	140	33.7	17.2	144	35	16.9
2	11	R4	L3	C	7	156	44.8	18.4	161	45.1	17.4
3	11	R3	R3	C	6	145	30.7	14.6	149	32.8	14.8
4	12	R4	L3	S	19	157	65.1	26.4	158	68.1	27.3
5	13	L4	R4	S	19	150	37.2	16.5	152	37.8	16.4
6	10	R4	L1	S	17	146	45	21.11	150	50.2	22.3
7	12	R5	R4	S	15	159	36.8	14.56	160	37.5	14.6
8	10	R3	R5	S	8	142.5	36.5	17.97	144	37	17.8
9	11	R3	R6	S	8	138.5	32	16.68	140	33.5	17.1
				Mean	12.33	148.22	40.20	18.16	150.89	41.89	18.29
				SD	4.99	7.20	9.99	3.47	7.11	10.68	3.82

Comparison of results at 0 month

According to Table 3, the mean of the posture parameters of the *standing* posture in the frontal plane, *walking* posture in both the frontal and horizontal planes, and *bending* posture in both the frontal and horizontal planes is generally decreased, while the mean of the lumbar angle of the *sitting* posture in the sagittal plane is increased after the subjects wore the posture correction girdle in comparison with the results prior to wearing the girdles at 0 month. This shows that the posture corrective girdle helps to improve imbalance problems, control the motion range and straighten the lower back in the sagittal plane of the subjects at the beginning of the wear trial. Significant differences are found on the acromion in the frontal plane during *standing* with p = 0.01 (d = -1.49), anterior *bending* in the frontal plane with p = 0.03 (d = -0.44) and lateral *bending* in the horizontal plane with p = 0.00 (d = -1.57). This indicates that the subjects had more balanced shoulders during *standing* after they put on the girdle. It also indicates that both the anterior and lateral *bending* ranges were constrained when the subjects were wearing the girdle, but the levels of constraint are still acceptable.

Table 3 Comparison of results at 0 month and at 3 months (with and without girdle) by paired-t testing

	0 month test (n=9) (mean ± SD)			**3 months test (n=9) (mean ± SD)**			**0 month test (n=9) (mean ± SD)**	**3 months test (n=9) (mean ± SD)**	
Anthropometry									
Height (cm)	148.2 ± 7.20			150.9 ± 7.11					
Mass (kg)	40.2 ± 9.99			41.89 ± 10.68					
Cobb's Angle (°)	12.33 ± 4.99			18.29 ± 3.82					
Body Posture	Without Girdle	With Girdle	p value	Without Girdle	With Girdle	p value	Without Girdle (0 month)	Without Girdle (3 months)	p value
Standing									
Frontal									
1.Acromion (°)	2.91 ± 1.3	1.44 ± 0.5	0.01	2.15 ± 0.9	2.15 ± 1.2	0.87	2.91 ± 1.3	2.15 ± 0.9	0.02
2.Pelvis (°)	2.22 ± 2.0	2.04 ± 1.5	0.78	1.89 ± 1.3	2.43 ± 1.9	0.54	2.22 ± 2.0	1.89 ± 1.3	0.71
3.Acromion/pelvis (°)	1.94 ± 1.5	1.36 ± 0.7	0.37	2.04 ± 1.0	2.14 ± 0.7	0.80	1.94 ± 1.5	2.04 ± 1.0	0.87
Horizontal									
4.Acromion (°)	2.83 ± 3.0	3.77 ± 3.9	0.48	2.52 ± 1.4	2.40 ± 2.0	0.76	2.83 ± 3.0	2.52 ± 1.4	0.30
5.Pelvis (°)	3.63 ± 3.4	3.61 ± 2.9	0.97	2.96 ± 1.9	2.76 ± 2.4	0.83	3.63 ± 3.4	2.96 ± 1.9	0.60
6.Scapula (°)	1.49 ± 1.3	1.85 ± 1.1	0.09	1.72 ± 0.5	2.21 ± 1.2	0.36	1.49 ± 1.3	1.72 ± 0.5	0.74
7.Scapula/Acromion (°)	2.61 ± 1.0	3.15 ± 2.2	0.39	3.09 ± 1.8	3.12 ± 2.1	0.92	2.61 ± 1.0	3.09 ± 1.8	0.35
8.Acromion/Pelvis (°)	2.84 ± 2.5	3.44 ± 2.9	0.30	3.36 ± 2.8	2.75 ± 1.7	0.41	2.84 ± 2.5	3.36 ± 2.8	0.37
Sitting									
Sagittal									
9.Thoracic Angle (°)	153.99 ± 8.3	153.33 ± 6.5	0.80	154.80 ± 5.0	154.12 ± 5.7	0.53	153.99 ± 8.3	154.80 ± 5.0	0.73
10.Lumbar Angle (°)	165.63 ± 15.4	172.81 ± 2.7	0.13	166.62 ± 8.0	168.91 ± 4.0	0.49	165.63 ± 15.4	166.62 ± 8.0	0.80
Walking (value in range)									
Frontal									
11.Acromion (°)	8.19 ± 3.3	7.12 ± 2.2	0.06	8.09 ± 3.6	8.24 ± 3.8	0.82	8.19 ± 3.3	8.09 ± 3.6	0.92
12.Pelvis (°)	7.39 ± 2.0	6.39 ± 1.9	0.16	8.31 ± 3.0	7.10 ± 2.1	0.04	7.39 ± 2.0	8.31 ± 3.0	0.17
Horizontal									
13.Acromion (°)	18.51 ± 4.6	16.35 ± 5.2	0.20	20.29 ± 5.3	18.11 ± 5.4	0.26	18.51 ± 4.6	20.29 ± 5.3	0.58
14.Pelvis (°)	15.39 ± 4.5	14.79 ± 4.9	0.47	17.53 ± 4.7	16.57 ± 5.0	0.64	15.39 ± 4.5	17.53 ± 4.7	0.32
Bending									
Frontal									
15.Max. Anterior Bending (°)	83.28 ± 22.7	74.80 ± 15.4	0.03	79.06 ± 17.4	73.70 ± 14.6	0.01	83.28 ± 22.7	79.06 ± 17.4	0.29
Horizontal									
16.Max. Lateral Bending (°)	38.18 ± 9.8	26.57 ± 3.7	0.00	41.91 ± 6.6	30.56 ± 6.0	0.00	38.18 ± 9.8	41.91 ± 6.6	0.18

Comparison of results at 3 months

The mean of the posture parameters of the *standing* posture in the horizontal plane (except for the scapula), and the *walking* and *bending* postures in both the frontal and horizontal planes, is generally decreased, while the mean of the lumbar angle of the *sitting* posture in the sagittal plane is increased after the subjects wore the posture correction girdle in comparison with the results obtained before they wore the girdles at 3 months. This shows that the posture corrective girdle is still helpful for improving imbalance problems, controlling motion range and straightening the lower back in the sagittal plane of the subjects after 3 months of the wear trial. Although the posture improvements are not obvious in relation to the results at 0 month, significant differences are still found on the pelvis in the frontal plane during *walking* with p = 0.04 (d = -0.47), anterior *bending* in the frontal plane with p = 0.01 (d = -0.33) and lateral *bending* in the horizontal plane with p = 0.00 (d = -1.8). This indicates that the subjects have reduced pelvis obliquity during *walking*, and also constrained anterior and lateral *bending* ranges with acceptable constraint levels after they wore the girdle.

Comparison of results at 0 and 3 months

As shown by a comparison of the results between the subjects who took the posture corrective girdle off at 0 month and after 3 months, the mean of the posture parameters of the *standing* posture in the horizontal plane and *bending* posture in the frontal plane is generally decreased, while the mean of the thoracic angle of the *sitting* posture in the sagittal plane is increased. This shows that posture improvements are still found by the controlling of motion range during body rotation in the horizontal plane and anterior *bending* in the frontal plane, and the subjects have straighter upper backs in the sagittal plane even when they took off the posture correction girdle after 3 months of girdling. Although the posture improvements were less obvious here, a significant difference was still found on the acromion in the frontal plane during *standing* with P = 0.02 (d = -0.68). This indicates that the subjects have more balanced shoulders during *standing* even without the aid of the posture correction girdle after 3 months of girdling.

Discussion

The main objective of this study is to evaluate the short-term effectiveness and practical use of a posture correction girdle with three-dimensional motion capture. Static posture is the state of muscular and skeletal balance within the body and this creates 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 [50]. It has been mentioned that the 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 [51, 52]. 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 [53].

With regards to the results shown in Table 3, the posture correction girdle shows an improving trend in addressing the imbalance problems of the acromion and pelvis in the frontal plane during *standing*, controlling the motion range in the frontal and horizontal planes during *walking* and *bending*, and straightening the lower back in the sagittal plane during *sitting* at the beginning of the wear trial (0 month). The key factors that affect the efficiency of the posture correction girdle are the design and fit of the garment and corrective force mechanism provided by the EVA paddings. These 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 bands. The resin bones that were inserted in the back and front helped to create supportive forces. These mainly helped to improve the posture problem of imbalance in the sagittal plane with the aid of the wrapped elastic bands. The tight-fitting girdle base worked together with the shoulder straps, waistband, additional EVA foam pads and resin bone insertions, and complemented each other to bring out the optimum function of the girdle. The base balanced the body, and stabilized and controlled the motion angles and ranges in the three planes.

The results of the posture improvements after the subjects wore the girdles for 3 months are not as obvious as the results at 0 month. This might be due to the deterioration of the girdles, i.e. loosening of the fabric and elastics, and repeated pulling and washing. Girdle deterioration might lower the intensity and stability of the supportive and corrective forces, and thus affect the posture correction function of the girdle. Moreover, growth of the body could be another factor that weakened the corrective function of the girdle. According to the demographic data in Table 1, some of the subjects grew taller after the 3-month wear trial period. This growth in height might affect the fit of the girdle on their body and hence the corrective function of the girdle. This is because the length of the girdle also affects the covered area of the body, which further affects the exertion of corrective forces from the base (pelvis) to the top (shoulder). Furthermore, growth might continuously change the spinal conditions of the subjects, which means the parts that are needed for the corrective point-pressure might also need to be changed. Therefore, adjustment of the girdle is suggested every 3 months in the case of a longer girdling period, so as to ensure that the girdle fits and the supportive and corrective forces are optimum. Generally, new girdles should be made for subjects who have grown 5 cm or more in height as it is the maximum tolerance of the girdle length. Moreover, hand washing is suggested as the cleaning method of the girdle, in order to reduce the possibility of dimensional deformity.

It has been considered that children bodies are “moldable”, which means that their body postures could be improved and trained by using different methods, including exercises, physiotherapy, and rehabilitation programs [6]. It is also believed that “reminders” of a good posture may be an acceptable prophylaxis [11], which can be provided by parents or training devices. In this study, tailor-made posture correction girdles have been provided to subjects for a 3-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. According to the results shown in Table 3, the *standing* posture in the horizontal plane, *bending* posture in the frontal plane and *sitting* posture in the sagittal plane (thoracic part) show improving trends even when the girdles are not worn after undergoing posture training by girdling for 3 months. More importantly, a significant improvement has been found on the acromion in the frontal plane during *standing*, which indicates that the subjects have balanced shoulders during *standing* even when they are not wearing the girdles following girdling after 3 months. These improvements might increase even more so if posture training is provided with the girdle, as it is believed that the back muscles of the subjects themselves could be trained to keep the spine within the natural curvature, thus, the corresponding imbalanced postures might be prevented with the awareness of posture as the subjects might learn good postural habits that could carry over into their daily life [11, 14, 15].

Finally, the spinal conditions and the corresponding postures of the subjects were evaluated by a radiographic method as traditionally, it is considered to be the most accurate method to observe changes in the bone structure. However, the radiographic method is invasive and cannot be used for repeated measures of body segment posture within a short period of time [49]. In this study, as the two evaluation tests (carried out at 0 month and 3 months) were carried out within a relatively short period of time on the posture of the subjects, only a non-invasive and repeatable evaluation method, i.e. motion capture, could be carried out in such a short span of time, while the radiographic method was only used during the recruitment stage. It has been mentioned that the error of the evaluated results from motion capture would be substantially minimized with training [49]. Therefore, although there is a lack of evaluated results from the radiographic method, the reliability of the evaluated results from motion capture is still high with a well-trained research team. Further studies could include 3 more months of wear trial and then motion capture testing, and use of the radiographic method after 6 months of the wear trial on the same subjects, in order to more accurately evaluate the effectiveness of the girdle.

Conclusion

Posture could be improved with posture training. This study has recruited a total of 10 subjects who are female adolescents with symptoms of early scoliosis to undertake a 3-month wear trial with a posture correction girdle, with 9 of them who completed the entire process. The results show that there is an obvious effectiveness of the posture correction girdle on improving posture and controlling motion range at an acceptable level. A significant improvement is especially evident in the acromion in the frontal plane even without wearing the girdle after the subjects in this study have undergone 3 months of posture training through girdling. According to the results, the girdle has a better performance at the beginning of the wear trial (0 month) in improving imbalanced posture and motion range control in comparison to that after 3 months of the wear trial. This may be due to different factors, including the deterioration of the girdle and the growth of the subjects. Thus, it is suggested that adjustment of the girdle should be carried out every 3 months. Deterioration of the girdle might have been a limitation of the present study, as it could have been induced by numerous variables, including material properties, washing practice, etc. The findings in the present study indicate that the "reminder" aspect of posture training is helpful for those who have imbalanced postures.

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