Prosthetics and Orthotics International, 2001, 25, 60–70

Effectiveness of audio-biofeedback in postural training for adolescent idiopathic scoliosis patients

M. S. WONG*, A. F. T. MAK*, K. D. K. LUK**, J. H. EVANS*** and B. BROWN****

**The Hong Kong Polytechnic University, Rehabilitation Engineering Centre, Hong Kong, China*
***The University of Hong Kong, Department of Orthopaedic Surgery, Hong Kong, China*
****Queensland University of Technology, Centre for Rehabilitation Science and Engineering, Australia*
*****Queensland University of Technology, School of Optometry, Australia*

Abstract

The possibility of using learned physiological responses in control of progressive adolescent idiopathic scoliosis (AIS) was investigated. Sixteen (16) AIS patients with progressing or high-risk curves (Cobb's angle between 25° and 35° at start and reducible by lateral bending) were fitted with a device with tone alarm for poor posture. In the first 18 months of application, 3 patients defaulted and 4 showed curve progression > 10° (2 changed to rigid spinal orthoses and 2 underwent surgery). The curves for the other 9 patients were kept under control (within ±5° of Cobb's angle) and 5 of them have reached skeletal maturity and terminated the application. The remaining 4 patients were still using the devices until skeletal maturity or curve progression. The curve control rate was 69%. A long-lasting active spinal control could be achieved through the patient's own spinal muscles. Nevertheless, before the postural training device could become a treatment modality, a long-term study for more AIS patients was necessary. This project is on-going in the Duchess of Kent Children's Hospital, Sandy Bay, Hong Kong.

Introduction

Scoliosis is a three-dimensional spinal deformity. The cause of most scoliotic curves is idiopathic. Rogala *et al.* (1978) pointed out that idiopathic scoliosis could produce a truncal deformity which might progress throughout the rapid growth period of adolescence. In a child with a progressive spinal deformity, if the curvature is detected early in adolescence while still moderate, progression may be halted non-surgically by the use of a rigid spinal orthosis. Rigid spinal orthoses have been demonstrated to be effective for the majority of moderate adolescent idiopathic scoliosis (AIS) patients, providing that treatment is begun early enough and the orthosis is worn compliantly (i.e., wearing the orthosis 23 hours a day and under properly applied controlling forces) (Wong *et al.*, 2000; Lonstein and Winter, 1994; Edmonson and Morris, 1997; Blount and Schmidt, 1957.)

On the other hand, rigid spinal orthoses have their drawbacks as the child will have to wear the orthosis for several years until growth has ceased. Both cosmetically and physically teenaged patients do not readily accept them. These orthoses are made of rigid plastic material and/or metal bars (e.g., Milwaukee braces) which encircle the whole patient's trunk. Forming a thick body cage as the brace stabilises the spine by exerting pressure/force on the trunk at certain critical points, it is necessary to envelop the trunk and to do so it must be bulky and frequently uncomfortable. Ventilation is greatly reduced which makes them even less well tolerated especially during hot humid weather. In stabilising the spine, the orthosis will restrict trunk motion, may cause atrophy of spinal musculature and the spine also becomes less flexible (Berger *et al.*, 1983).

All correspondence to be addressed to Dr. M. S. Wong Assistant Professor (Prosthetics and Orthotics) Rehabilitation Engineering Centre, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China. Tel. No.: (+852)-2766-7680, Fax. No.: (+852)-2362-4365, E-mail: rcmswong@polyu.edu.hk

In addition, for a spinal orthosis to be effective, it is generally believed that it should be worn 23 hours per day, 7 days a week, until full skeletal maturity, usually a period of 3-4 years. Unfortunately, this treatment is undertaken during the most psychologically sensitive period of life. The bulkiness of the orthosis will detract from the youngster's appearance at a time when outward appearance is of extreme importance (Fallstrom *et al.,* 1984; Wickers *et al.,* 1977; Myers *et al.,* 1970). This social stigma causes psychological disturbance in some children. The orthosis may identify the child as being different at a time of life when it is most painful to be so. It is, therefore, understandable that the failure of orthotic treatment may be due to the lack of the patient's compliance. Keiser and Shufflebarger (1976) reported that only 59% (73 out of 123) of patients demonstrated satisfactory compliance with orthotic treatment. Cosmetic acceptability as an important factor in determining compliance was demonstrated in the report by Wickers *et al.,* (1977) where it was found that less "objectionable" bracing methods, such as the "Boston Brace", were associated with higher levels of compliance.

Clearly there is room for improvement especially in terms of devising a more acceptable mechanism for the patient to control spinal deformity at the same time reducing the possible need to resort to surgery. The effectiveness of a spinal orthosis could depend on its ability to remind the wearer of spinal curvature through increased discomfort at the pressure points. This would serve to alert the child of a poor posture as well as motivating him/her to straighten up the spine. If this is the case, is is arguable that the postural training of a child might be performed as well or conceivably even better by a much less cumbersome, less cosmetically disfiguring device. Azrin *et al.* (1968) applied an automated electronic instrument for postural training. They successfully corrected slouching in 25 subjects by an average 86% through the use of an audible tone that was activated on slouching. An electronic postural training devide for scoliosis was first developed by Dworkin (1982). In 1993, the device was further developed and termed as "Micro Straight" by Micro Straight Incorporated, Kansas City, Missouri, USA. It was aimed to substitute for the conventional rigid spine orthosis in the treatment of idiopathic scoliosis and kyphosis. This device is a small microprocessor based postural training device, which provides continuous information to patients about their posture through an audio biofeedback system, so that they are encouraged to straighten their spines.

The use of such device might also lead to a refined proprioceptive awareness and thus continuing possible benefit might result even after use of the device had ceased. Perhaps, individuals would learn good postural habits that would carry over into their adult lives. Therefore, the hypothesis of this study was that a permanent control of the scoliotic curves would come from the appropriate and continuous training of spinal muscles through an audio biofeedback system. Thus an active correction by internal forces (spinal muscular contraction) could be accomplished.

In 1995, the current study on the effectiveness of the postural training device on scoliotic patients was initiated with funding from the Society for the Relief of Disabled Children. All the curve-controlled cases were followed at least 18 months after application of the postural training device. The objectives of the study were to evaluate the effectiveness of the audio biofeedback postural training device in the control of adolescent idiopathic scoliosis and to study the compliance; with using the device appropriately and patients' acceptance of the device via feedback survey.

Materials and methods

Patient selection criteria

The postural training device Micro Straight is a relatively new device and its effectiveness in the treatment of idiopathic scoliosis has not yet been shown. Therefore, the patient selection criteria were relatively strict and its application on patients was handled with great care. Their scoliotic deformities were either deteriorating as judged from two successive follow-ups or their deformities were large and at high-risk of further deteriorating. The selection criteria were as follows:

- adolescent idiopathic scoliosis;
- Cobb's angle between 25°-35°:
  - with documented curve progression, or
  - high-risk curve with Risser Sign ≤ 1 and menses not yet started;
- apical vertebra below T5;

- bone age between 9 – 14 years;
- Risser sign ≤ 2.

In this study, the patients were selected from those persons attending the Scoliosis Clinic of the Duchess of Kent Children's Hospital, Sandy Bay, Hong Kong. All the selected patients had flexible curves that could be easily reduced by lateral bending. The patients and the parents had given informed consent. All patients would be followed until either the completion of their growth potential or removal from the programme (with curve progression) for other treatments such as orthotic or surgical treatment.

Sixteen (16) AIS patients were fitted with the devices. In the first 18 months of device application, 3 patients defaulted and 4 patients showed curve progression more than 10°. The curve for the remaining 9 patients were well controlled. Their mean chronological age is 12.1 (±1.2) years and ranged from 10.5 to 14.0 years.

Parameters and methods of measurement

In the study, both radiographic and anthropometric measurement were taken as the clinical assessment parameters to evaluate the efficacy of the postural training device. They were as follows:

- AP Cobb's angles were measured using Cobb's method from standing antero-posterior (A-P) radiographs. The Cobb's method was also used in the measurements of sagittal curvatures including thoracic kyphosis and lumbar lordosis from standing lateral radiographs (Cobb, 1948);
- apical vertebral rotations were measured using Perdriolle's method from standing A-P radiographs (Perdriolle and Vidar, 1985);
- trunk listing was measured using the plumbline method (Rudicel and Renshaw, 1983);
- angle of trunk inclination was measured using a Scoliometer (Bunnell, 1984, Tachdjian, 1990).

Measurements were obtained pre-application and at every follow-up clinic. The minimum study period for each case was 18 months.

A successful treatment could not be accomplished without the patient's involvement. Therefore, evaluations on the patient's compliance with and acceptance of the postural training device were conducted. In considering the compliance of the patient for the postural training device, the number of hours the device was worn was counted. Compliance was recorded using the data logger contained within the postural training device. The data was read into a PC every 3 months. A questionnaire was devised to ascertain the reaction of the patient to the postural training device. The questions were mainly related to the device appearance, comfort, self-adaptation to daily activities, period of wearing and overall acceptance.

Features of the postural training device

Dworkin (1982) first developed a postural training device for scoliotic patients (Fig. 1). The rationale of design was that the device measured the spinal length continuously and compared it with an optimum length (Dworkin, 1982). The attainment of a satisfactory position was signaled to the patient by the immediate termination of an audible tone associated with the incorrect posture. The dimension of the device is 5.0 x 12.0 x 2.5cm and its mass is 133gm. A simple circumferential torso harness, 1000pA, (Fig. 2) from the seventh cervical vertebra to the pubis, is used to detect when the patient extends the major axis of his/her body by straightening the spine. Such an extension of the harness is judged a postural "success", because it can reduce spinal curvature. However, another effective but undesirable method of extending the harness is by expansion of the chest circumference, loop B, (Fig. 2.) during respiration. To eliminate this problem, an electronic device was developed to subtract a suitable fraction of the lengthening of the torso

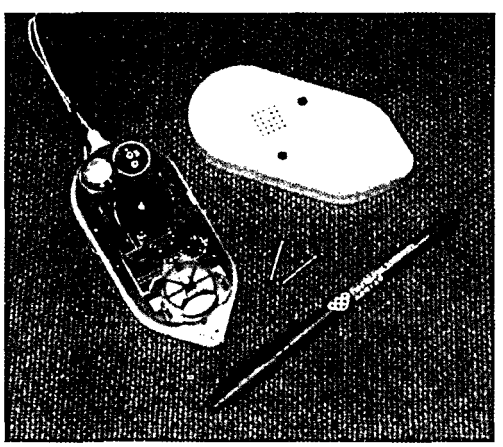

Fig. 1. The casing of the device is removed to reveal the inside components.

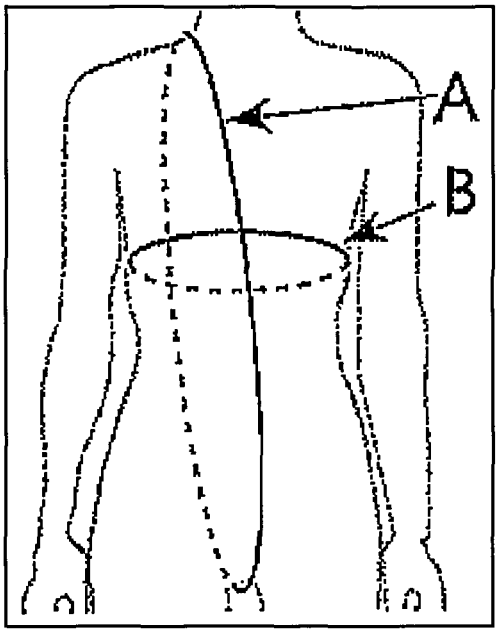

Fig. 2. Positions of Loop A and Loop B.

circumference (A), due to respiration from the chest circumference (B). The loop harness is adjusted individually to fit each patient. Periodic adjustment of the postural criteria is needed, as the patient will grow in both chest and torso dimensions. As the wearer becomes more adept at keeping the spine straight, the performance level of the device can be set higher. The device can also be transferable if a user completes his/her protocol.

The postural training device incorporates an integrated circuit that produces a barely audible tone when an incorrect posture has been assumed for more than 20 seconds. This tone becomes louder if the poor posture is maintained for an additional 20 seconds. The tone terminates immediately the child adops a satisfactory posture. The first tone is a signal of strength likely only to be heard by the child wearing the unit. The louder tone may be heard by others near the child and so it can serve as a mild punishment for failing to terminate the first tone. The 20-second delay in onset of the first tone allows the child to briefly assume postures that are incorrect but necessary, such as bending to tie shoelaces or to pick up a coin from the floor.

The internal structures of the device are shown in Figures 3 and 4. There are five main components including a casing, an integrated circuit board, a torso and respiration encoder board, a torso spool and a respiration spool. There are ten levels of difficulty that can be adjusted and set according to the performance of the individual patient. The anterior and posterior views of the patient with the postural training

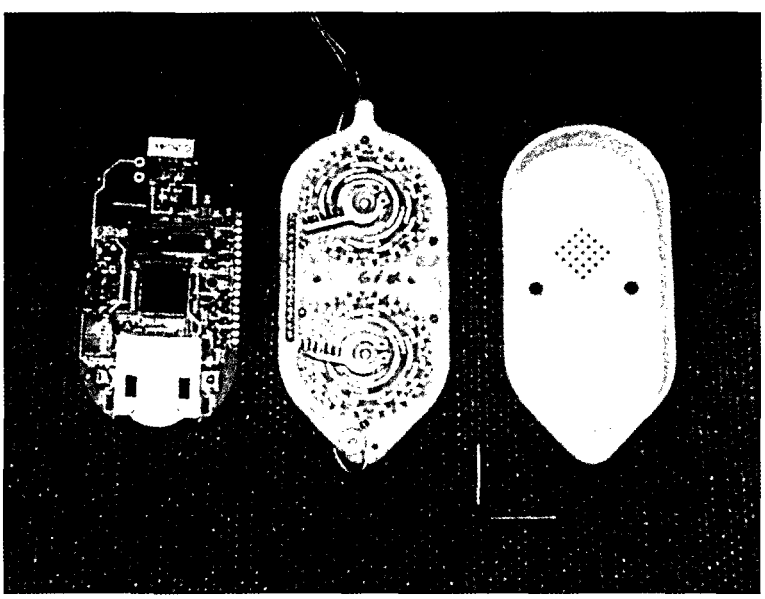

Fig. 3. The circuit board (left), the encoder board (middle) and the casing cover (right) are shown.

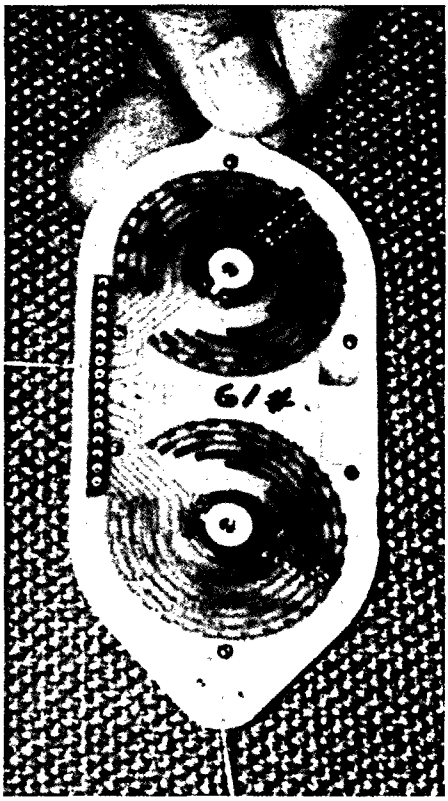

Fig. 4. A patient's posture is detected by changes in the loops' length, which are represented by the corresponding positions of the brushes in the encoders.

device are shown in Figure 5. The device is furnished with lightweight nylon fishing line harness, which slides inside the small Teflon tubes that locate at the groin area and lateral sides of the chest. This can eliminate abrasion between the fishing line harness and the skin due to contact. Therefore, the trunk movement will not be hindered.

Protocol of application of the postural training device

The protocol for application of the postural training device was designed as follows:

- once the patient met the selection criteria, two options are available - application of the postural training device or rigid spinal orthosis. The patient and the parents gave informed consent if the postural training device was selected;
- the patient had to wear the device 23 hours a day and the rest hour was for doing physical exercise and bathing;
- routine checking, adjustment and battery renewal were arranged at every 6-8 weeks;
- scoliosis clinic was arranged for the pre-application visit, the 1st month of application and then every 3 months, and the data was downloaded at every clinic day;
- other treatment modalities such as rigid spinal orthosis or surgery had to intervene once the

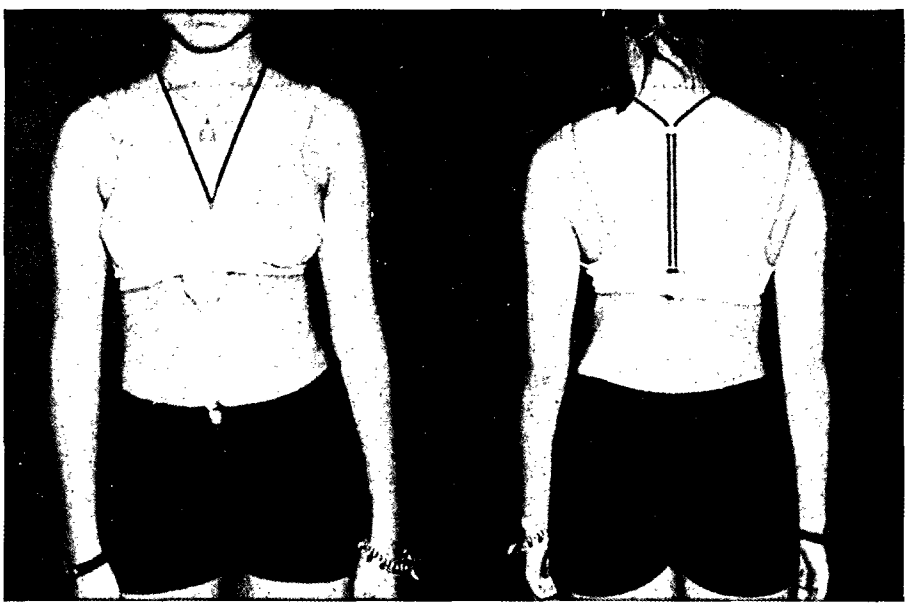

Fig. 5. The anterior and posterior views of a patient with the postural training device.

Cobb's angle increased > 10° or the absolute angle > 40°;
- the weaning off procedure started at Risser sign 4, closure of distal ulnar epiphysis or 3 years post menarche and wearing time was 16 hours a day (off at school) till Risser sign 5.

Method of data analysis

For this study, the data of the first 18 months of device application were considered. The data were analysed using the Statistical Package for Social Sciences (SPSS) Version 9.0 A general linear model with within-subjects analysis was used. Repeated measures of analysis of variance (ANOVA) were applied to compare the mean differences for the above parameters at the pre-application stage and at the six subsequent visits in the first 18 months of application (data taken at every 3-month interval). In the within-subject analysis, the Mauchly's Test of Sphericity was applied and the Huynh-Feldt Test was used for Mauchly's W < 0.05 while the Sphericity Assumed Test was applied for Mauchly's W ≥ 0.05. The confidence interval was set at 95% ($p<0.05$). For the evaluation of the short-term effectiveness of the postural training device, the Binomial Test was used to compare the difference between the successful group and the failed group.

Results

In this prospective study, the effectiveness of the postural training device in controlling AIS and the patient's reaction to the device were investigated. Within the study period, 16 AIS patients with progressing curves or high-risk curves were selected and fitted with the devices. There were 1 male and 15 female patients. Interestingly, half of the patients had a family history of scoliosis. In the first 18 months of device application, 3 patients defaulted within 3 months (1 did not show up afterwards and 2 changed to spinal orthoses because of lack of confidence in this new device) and 4 of them showed curve progression more than 10° (2 changed to rigid spinal orthoses and 2 underwent surgical treatment). The curves for the remaining 9 patients are well controlled so far (change within ±5° of Cobb's angle) and 5 of them have reached skeletal maturity and terminated the device application. The remaining 4 patients would keep using the devices till skeletal maturity or curve progression. Therefore, the curve control rate was 69% (9 out of 13, when defaulted cases were not included). For worst case analysis (all defaulted cases included), the curve control rate was 56% (9 out of 16).

Table 1. Patients' maturity as measured just before commencement of device application (1SD = 1 Standard Deviation).

Assessment of maturity	Mean (±1SD)	Range
Chronological age (year, n=9)	12.1 (1.2)	10.5 – 14.0
Bone age (year, n=9)	12.9 (0.9)	11.7 – 14.7
Menarche (year, n=8)	12.6 (0.8)	11.0 – 13.5
Risser sign (grade, n=9)	0.6 (0.7)	0 – 2

For the selected patients, their maturity was measured in terms of chronological age, bone age (Greulich and Pyle, 1959) and Risser sign (Risser, 1958) while the menarche of the female patients was also recorded. For the curve controlled group, their means, standard deviations and ranges are shown in Table 1. The mean bone age was 0.8 years greater than the mean chronological age, and the date of menarche of the patient group was 0.5 years after the commencement of device application. The distribution of curve pattern was 6 right thoracic, 2 left lumbar and 1 left thoracolumbar curves. Analysis was performed only on the major curves as the compensatory curves might have different responses.

Effectiveness of the postural training device

In the investigation of treatment effectiveness of the postural training device for the nine controlled cases, the parameters: standing AP

Table 2. Mean standing AP Cobb's angles at the visits of 4 months before pre-application, pre-application and during the first 18 months of application (1SD = 1 Standard Deviation, n=9).

Visit	Standing AP Cobb's Angle (°)	
	Mean (±1SD)	Range
4 months before pre-application	24.0 (6.8)	14 – 31
Pre-application	27.9 (2.4)	25 – 31
3rd month	26.6 (5.8)	15 – 35
6th month	26.0 (4.3)	19 – 33
9th month	26.9 (5.0)	21 – 36
12th month	27.3 (4.2)	22 – 32
15th month	26.1 (4.4)	17 – 32
18th month	27.1 (3.6)	22 – 33

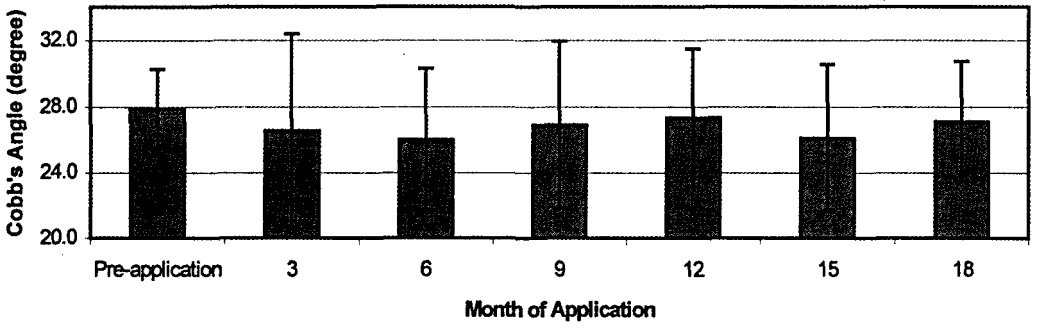

Fig. 6. Mean standing AP Cobb's angle of AIS patients under the application of postural training device (n=9).

Cobb's angle, thoracic kyphosis, lumbar lordosis, apical vertebral rotation, trunk listing and angle of trunk inclination were considered.

Standing AP Cobb's angles

The mean, standard deviation and range of the standing AP Cobb's angles of the 9 controlled cases at the visits of 4 months before pre-application, pre-application and the first 18 months of application (with visits at every 3-month interval) are shown in Table 2 and Figure 6. There was an average of 3.9° curve progression at the pre-application visit (including those 5 cases with high-risk curves that were intervened at once without the necessity of documented progression). The mean value of curve progression was 10.6° if only those 4 progressing curves were considered.

For the standing AP Cobb's angle, comparisons of the pre-application values among the 6 successive visits were made using repeated measures ANOVA. There were no statistically significant differences between the pre-application standing AP Cobb's angles and the standing AP Cobb's angles at the 6 successive visits.

Standing thoracic kyphosis

The mean, standard deviation and range of standing thoracic kyphosis at pre-application and at 3-month intervals in the first 18 months of application are shown in Table 3. Comparisons of the pre-application values among the 6 successive visits were made using repeated measures ANOVA. There were no statistically significant differences between the pre-application standing thoracic kyphosis and the standing thoracic kyphosis at the 6 successive visits. However, a few spines with thoracic hypokyphosis were noted after the device was fitted and close attention would have to be paid as they might cause trunk instability in later life (Dansereau *et al.*, 1996).

Standing lumbar lordosis

The mean, standard deviation and range of standing lumbar lordosis at pre-application and at 3-month intervals in the first 18 months of application are shown in Table 4. Comparisons

Table 3. Mean standing thoracic kyphosis at the pre-application and during the first 18 months of application (1SD = 1 Standard Deviation, n=9).

Visit	Standing thoracic kyphosis (°)	
	Mean (±1SD)	Range
Pre-application	22.7 (11.8)	0 – 37
3rd month	20.0 (10.4)	0 – 33
6th month	15.6 (11.7)	-10 – 30
9th month	17.0 (10.0)	-5 – 30
12th month	17.1 (16.6)	-8 – 37
15th month	18.1 (10.9)	-5 – 28
18th month	19.2 (10.7)	-6 – 28

Table 4. Mean standing lumbar lordosis at the pre-application and during the first 18 months of application (1SD = 1 Standard Deviation, n=9).

Visit	Standing lumbar lordosis (°)	
	Mean (±1SD)	Range
Pre-application	48.9 (9.7)	32 – 67
3rd month	48.2 (8.3)	40 – 62
6th month	46.0 (7.5)	35 – 61
9th month	44.6 (10.7)	30 – 60
12th month	47.4 (8.4)	38 – 62
15th month	47.7 (8.2)	36 – 63
18th month	43.2 (6.8)	32 – 53

of the pre-application values among the 6 successive visits were made using repeated measures ANOVA. No statistically significant differences were found between the pre-application standing lumbar lordosis and the standing lumbar lordosis at the 6 successive visits.

Standing apical vertebral rotation

The mean, standard deviation and range of standing apical vertebral rotation at pre-application and at 3-month intervals in the first 18 months of application are shown in Table 5. Comparisons of the pre-application values among the 6 successive visits were made using repeated measures ANOVA. No statistically significant differences were found between the pre-application standing apical vertebral rotation and the standing apical vertebral rotation at the 6 successive visits.

Trunk listing and angle of trunk inclination

There were no statistically significant differences between the pre-application value and the values at the 6 successive visits.

Perhaps, it should not be surprising to find no significant decreases in the Cobb's angle, apical vertebral rotation and other clinical assessment parameters because the control of scoliotic curvature totally fell upon the patient's own spinal musculature. This is unlike the situation of applying a rigid spinal orthosis in which case external forces would be applied to the patient's torso to reduce the deformities. This passive correction cannot be maintained once the rigid orthosis is removed. However, in the case of postural training to stabilise a deteriorating curve there is an implication of an active control of that curve. It is believed that this dynamic postural monitoring is a method of active muscle training and its effectiveness would persist even after the postural training regime.

Table 5. Mean standing apical vertebral rotation at the pre-application and during the first 18 months of application (1SD = 1 Standard Deviation, n=9).

Visit	Standing apical vertical rotation	
	Mean (±1SD)	Range
Pre-application	9.4 (6.8)	0 – 25
3rd month	10.0 (4.3)	5 – 20
6th month	9.4 (5.3)	0 – 20
9th month	8.9 (5.5)	0 – 20
12th month	8.9 (5.5)	0 – 20
15th month	8.9 (5.5)	0 – 20
18th month	8.9 (4.9)	0 – 15

In this study, the standing AP Cobb's angle was considered (as is clinical routine) whether the treatment was deemed successful or had failed. Four (4) out of 13 patients (the 3 defaulted patients were not included) had the Cobb's angle increase ≥10° or the absolute value ≥40°, thus their biofeedback treatment was assumed to have failed. The Cobb's angles for the other 9 patients were well controlled. The Binomial Test was used to compare the successful group and the failed group in the first 18 months of device application so as to find out the short-term effectiveness of the device. In this test, the patients who failed in this intervention were assumed to have a test probability of 0.5 while the patients whose curves were well controlled were assumed to have a test probability of 0.5. It was found that 4 out of 13 patients fell into the failed group. The probability associated with n=13 (number of patients) and X=4 (number of failed patients) was found to be 0.133 (p=0.133) (Table D in Siegel S., Castellan N. J.: Nonparametric Statistics for the Behaviour Sciences, 2nd ed. New York, McGraw-Hill 1988). This probability value was interpreted in terms of a conventional upper limit of p=0.05. As the probability found exceeded the value, it was considered that no significant difference existed between the successful and failed groups. This showed no significant improvement rendered by the postural training device. However, the curve control rate was 69% (9 out of 13 patients were well controlled) which was close to the results (72%) found by Carr *et al.* (1980) in evaluating rigid spinal orthoses (Milwaukee Braces).

Compliance

In every visit, the data for the past 10 days were downloaded. The mean, standard deviation and range of wearing time for the first 18 months of application (with visit at every 3-month interval) are shown in Figure 7.

For the wearing time of the postural training device of the 9 controlled curves, comparisons among the 6 successive visits were made using repeated measures ANOVA. There were no statistically significant differences among the wearing time of the postural training device

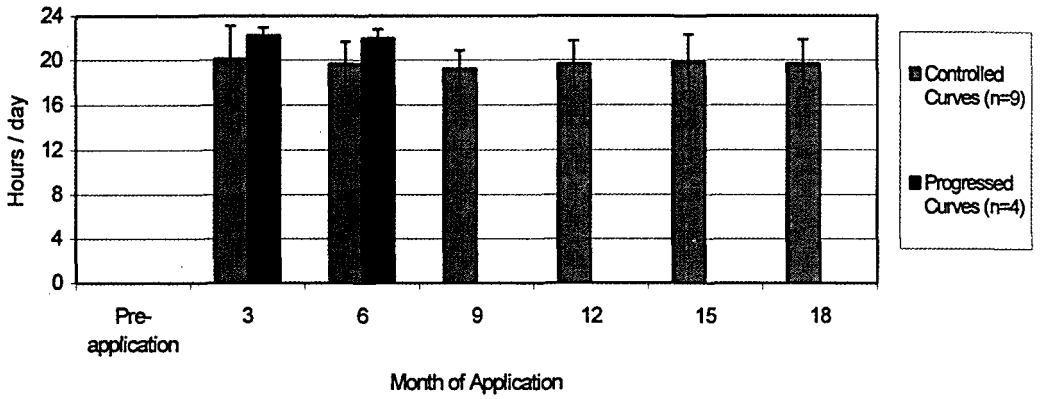

Fig. 7. Mean wearing time of the postural training device.

of the 9 controlled curves at the 6 successive visits.

Acceptance

A questionnaire was designed to collect the patients' feedback on the acceptance of the device. There were 18 questions, which included information about the duration of wearing the device, physical constraint, problems in activities of daily living, difficulty of donning and doffing, difficulty of stopping tone and general dislike of the device. This questionnaire was administered at the 6th month of device application.

For this group of patients, there was no direct comparison between the postural training device and the conventional rigid spinal orthosis, as they only had the experience of using the postural training device. However, the impression of all the 13 AIS patients (9 controlled and 4 progressed) was that they preferred using the postural training device for their treatment to wearing a rigid orthosis (their own choice). This might be attributed to the inconspicuous appearance and small size of the postural training device. All patients easily learned to make necessary postural adjustments under the initial setting criterion. A common complaint during the first three weeks was fatigue, which diminished gradually as they gained more experience in using the device.

After the initial training period, a majority of the patients found the device comfortable, except one (8%) who complained about the pressure abrasion from part of the harness at the groin area and gluteal cleft which was mainly due to the tension in the torso loop. One (1) patient felt the harness of the device caused breathing difficulty. A low-friction bearing system was introduced to improve the recoiling mechanism and thus to reduce the tension developed in the torso loop. Another patient complained of difficulty in sleeping in the prone position. Two (2) of them (15%) found some hindrance in doing sports and thus would temporarily take off the device for such activities. Two (2) of them had a general dislike of the device because of the tone and the bulkiness of the device. However, they would prefer wearing the device to a rigid orthosis.

In general, patients could develop and maintain an upright and straight posture, which was especially obvious when they dealt with certain daily activities like picking up a coin, during which their backs tended to remain straight as they were flexing their legs instead of bending their trunk forward. Moreover, the patients learned that the use of some furniture made it practically difficult to control their postures. For instance, they found it difficult to lengthen their spine adequately while sitting in a very soft chair, compared to sitting on a hard surface.

Discussion

The ultimate criterion of effective control of AIS using the postural training device was whether a patient could pass through the critical period of adolescent growth spurt without significant curve progression that required the intervention of rigid orthosis or surgical treatment. From the results of this study, 69% (or 56% for worst case analysis) of the cases were successfully under control in the first 18

months of application. Among them five patients had completed their skeletal growth and curve progression had been successfully prevented and 4 patients still kept on using the device as they were still skeletally immature. In the remaining 7 patients, 4 had curve deterioration and 3 had defaulted.

For the current study, the group had a mean pre-application Cobb's angle of 29.1°. Dworkin *et al.* (1985) carried out a similar study with the mean follow-up period of 21 months but they recruited a group of AIS patients with a mean Cobb's angle of 20.3°. This increase of 8.8° could be taken as a more demanding test for the efficacy of the device in altering the natural history of those progressive AISs. In this analysis, the situation for the first 18 months of application was monitored.

From the existing results, 38% of the patients (5 out of 13) had completed their skeletal growth, and curve progression had been successfully prevented. Four (4) other patients are still under application and their preliminary results have been encouraging, and none of them have shown curve progression so far. The remaining 4 patients showed curve progression, in which 2 changed to rigid orthoses and the other 2 underwent surgical treatments. For the 4 progressed curves (3 right thoracic and 1 left thoraco-lumbar curves), their mean pre-application standing AP Cobb's angle was 31.8° (±3.9°) and the range was 27°-35°. Two (2) of them showed progressive curves and the other 2 showed high-risk curves of 35° at the time of admission to this programme. Their mean Cobb's angle was 3.9° larger than that of the other 9 patients with controlled curves. It seemed that the curves > 30° could be more difficult to control.

The postural training device had several advantages over the conventional rigid orthosis. The data-recording capability of the device could allow the practitioner to assess a patient's compliance and progress. It could be easily adjusted to keep the patient at the best performance level and to allow for body growth. The device would be more favourable than a rigid orthosis, which might cause atrophy of spinal musculature after prolonged physical constraint, deformation of the rib cage, and skin breakdown and gastrointestinal complications (Dworkin, 1985). Psychologically, the device was found to be more acceptable because it was inconspicuous in social functions. Hence the compliance could be better with this type of device than with the rigid orthoses.

Physical therapy was often rendered together with orthotic treatment in management of AIS. However, specific physical exercises would be performed once or twice a day for about 15 minutes provided that the patient was compliant enough. The continuous postural monitoring could give real time assessment and audible tone to alert the patient for keeping a good posture via the patient's own spinal muscle contraction. After such an intensive training phase in the high-risk period of puberty, the patient could learn to maintain a good posture afterwards even without the warning of the device. The trained spinal musculature together with the learned posture should greatly alleviate the opportunity of significant curve progression in the patient's puberty and later life.

The postural training was a non-invasive method, even compared to the method of using electrical stimulation (ES) on the spinal muscles, which might cause skin irritation. Moreover, the effectiveness of ES on AIS could not be shown (Durham *et al.*, 1990; Bertrand *et al.*, 1992).

In this study, some patients commented that the tone embarrassed them especially in quiet environments. Conversely, other patients commented that they could not be alerted, as the environment was too noisy. Improvement could be made. Vibration would be a better method to alert the adult users or patients with poor hearing but not for adolescence as they might easily learn to ignore the vibration. It was suggested that for alerting to poor posture, a vibration method should be used first and if the prompting was ignored, an audible tone would then be used. However, the energy consumption of a vibration method would be much higher than that of the tone method. Frequent battery renewal might be necessary.

One of the major deformities found in scoliosis was trunk listing. As the device tracked the vertical and horizontal circumferences only, any change in trunk listing could not be measured directly. A further development of the device in tracking this parameter was important. It was suggested to add two diagonal loops on the trunk instead of one vertical loop so as to track the change of the upper trunk in relation to the pelvis. Its feasibility requires a more thorough study.

On the whole, early intervention in AIS is particularly desirable because a smaller curve requires less corrective forces to control. For mild to moderate curves, muscular efforts might be sufficient to control curve progression and encourage correct posture. The application of the postural training device might also lead to a refined proprioceptive awareness (a possible additional benefit) after the use of the device ceases.

Conclusion

All 13 patients in this study preferred the appearance and size of the postural training device to the conventional rigid spinal orthosis. These patients learned easily how to make the necessary postural adjustments upon hearing the audible indication of poor posture. Self-adaptation and psychological adjustment in the first two weeks of treatment solved most of the discomforts and complaints. In this study, it was not possible to judge the therapeutic value of the postural training device for spinal deformity because of the small number of patients involved and relatively short follow-up period. A longer-term study for more AIS patients was necessary.

REFERENCES

Azrin N, Rubin H, O'Brien F, Ayllon T, Roll D. (1968). Postural training by automated electronic instrument. *J Appl Behav Anal* **1**, 99-108.

Berger N, Edelstein J, Fishman S, Krebs D, Springer W. (1983). Spinal Orthotics. Prosthetics and Orthotics. *New York University, Post-Graduate Medical School*.

Bertrand SL, Drvaric DM, Lange N, Lucas PR, Deutsch SD, Herndon JH, Roberts JM. (1992). Electrical stimulation for idiopathic scoliosis. *Clin Orthop* **276**, 176-181.

Blount WP, Schmidt AC. (1957). The Milwaukee brace in the treatment of scoliosis. *J Bone Joint Surg* **39A**, 693.

Bunnell WP (1984). An objective criterion for scoliosis screening. *J Bone Joint Surg* **66A**, 1381-1387.

Carr WA, Moe JH, Winter RB, Lonstein JE (1980). Treatment of idiopathic scoliosis in the Milwaukee Brace: long-term results. *J Bone Joint Surg* **62A**, 599-612.

Cobb JR (1948). Outline for the study of scoliosis. Instr Course Lect. **5**, 261-275.

Dansereau J, Labelle H, Bellefleur C, Poitras B. (1995/96). Immediate effect of Boston brace treatment on 3-D shape of scoliotic spine and rib cage. *Orthop Trans* **19**, 591.

Dworkin B (1982). Postural training device. *Health Psychol* **1**, 45-59.

Dworkin B, Miller NE, Birbaumer N, Brines ML, Jonas S, Schwentker EP, Graham JJ (1985). Behavioral method for the treatment of idiopathic scoliosis. *Proc Natl Acad Sci* **82**, 2493-2497.

Durham JW, Moskowitz A, Whitney J (1990). Surface electrical stimulation versus brace in treatment of idiopathic scoliosis. *Spine* **15**, 888-892.

Edmonson AS, Morris JT (1977). Follow-up study of Milwaukee brace treatment in patients with idiopathic scoliosis. *Clin Orthop* **126**, 58-61.

Fallstrom K, Nachemson AL, Cochran TP (1984). Psychologic effects of treatment for adolescent idiopathic scoliosis. *Orthop Trans* **8**, 150.

Greulich WW, Pyle SL (1959). Radiographic atlas of skeletal development of the had and wrist. – *Standford: Standford University Press.*

Keiser RP, Shufflebarger HL (1976). The Milwaukee brace in idiopathic scoliosis-evaluation of 123 completed cases. *Clin Orthop* **118**, 19-24.

Lonstein J, Winter R (1994). The Milwaukee brace for the treatment of adolescent idiopathic scoliosis: a review of one thousand and twenty patients. *J Bone Joint Surg* **76A**, 1207-1221.

Myers BA, Friedman SB, Weiner IB (1970). Coping with a chronic, disability: psychosocial observations of girl with scoliosis treated with a Milwaukee brace. *Am J Dis Child* **120**, 175-181.

Perdriolle R, Vidal J (1985). Thoracic idiopathic scoliosis curve evolution and prognosis. *Spine* **10**, 785-791.

Risser JC (1958). The iliac apophysis: an invaluable sign in the management of scoliosis. *Clin Orthop* **11**, 111.

Rogala EJ, Drummond DS, Gurr J (1978). Scoliosis: incidence and natural history. *J Bone Joint Surg* **60A**, 173-176.

Rudicel S, Renshaw TS (1983). The effect of the Milwaukee brace on spinal decompensation in idiopathic scoliosis. *Spine* **8**, 385-387.

Tachdjian MO, (1990). Pediatric orthopedics. – Philadelphia: Saunders Co.

Wickers FC, Bunch WH, Barnett PM (1977). Psychological factors in failure to wear the Milwaukee brace for treatment of idiopathic scoliosis. *Clin Orthop* **126**, 62-66.

Wong MS (1995). Orthotic management of adolescent idiopathic scoliosis-M. Phil Thesis. The Hong Kong Polytechnic University.

Wong MS, Mak A, Luk KDH, Evans JH, Brown B (2000). Effectiveness and biomechanics of spinal orthoses in the treatment of adolescent idiopathic scoliosis (AIS). *Prosthet Orthot Int* **24**, 148-162.