Behavioral method for the treatment of idiopathic scoliosis
(biofeedback/posture training/automated therapeutic training in daily life)

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ABSTRACT  Idiopathic scoliosis was treated by an automated portable posture-training device that incorporated precise behavioral principles and enabled therapeutic training to be given in the patients' normal environment throughout the entire day. Twenty-one patient-years of training were completed with a group of 12 adolescent girls selected as being imminently likely to require a brace because of the way their spinal curves had been progressing. As an alternative to conventional brace therapy, patients found the posture-training device considerably less physically restraining and more cosmetically acceptable. Most patients wore it 23 hr per day for at least 1 year and adapted well to the constant physical and psychological presence of the instrument. For 10 patients, the outcome was entirely successful; they were discharged from this pilot study as satisfactorily corrected. Progression of the scoliotic curve was arrested; in fact, there was an average slight improvement in the Cobb angle (a measure of spinal curvature) as measured by x-ray radiography.

Scoliosis is a pathologic lateral curvature of the spine; in the idiopathic or familial variety, 80% of the patients are female. In all its degrees of severity, it affects approximately 2–4% of the adolescent population (1). In approximately 6.8% of those affected (0.2% of the general population), idiopathic scoliosis will produce a trunical deformity which progresses throughout the rapid growth period of adolescence (2).

In a child with a progressive deformity, if the curvature is detected early in adolescence while still mild, progression may be halted non-surgically by the use of a scoliosis orthosis. These braces have been demonstrated to be effective for the majority of patients, providing treatment is begun early enough and the orthosis is worn faithfully (3, 4).

Conventional brace therapy has several significant drawbacks, however; because the brace stabilizes the spine by exerting pressure on the thorax at critical points, it must envelop the trunk and to do so it must be bulky and uncomfortable. In stabilizing the spine, the orthosis restricts truncal motion, causing atrophy of truncal musculature. As an end result, the spine becomes limited in its flexibility. Finally, the constant pressure of the brace, in some cases, may cause permanent deformation of the rib cage or the soft tissues directly under the pressure points. Such secondary deformities are less serious than the spinal deformity of scoliosis, but they are, nonetheless, of concern. For a scoliosis orthosis to be effective, it is generally believed that it must be worn 23 hr per day, 7 days a week, until full skeletal maturity, usually a period of 3–4 years. Unfortunately, this treatment must be undertaken during the most psychologically sensitive period of life. The bulkiness of the brace distorts the youngster’s appearance at a time when outward appearance is of extreme importance. The brace identifies the child as different at a time of life when it is most painful to be different. It is, therefore, understandable that the chief cause of failure of brace treatment is failure of patient compliance.

One study, for instance, reported that only 59% (73 out of 123) of patients demonstrated satisfactory compliance (5). That cosmetic acceptability is an important aspect of compliance is shown by reports that less objectionable bracing methods, such as the “Boston Bucket,” are associated with higher levels of compliance (6, 7).

In addition, controversy exists about how the brace functions to reduce the scoliotic curve. Those patients who passively slouch into it, developing thick enough calluses so that its pressure points are not uncomfortable, usually do not benefit from the brace. There is a growing conviction among orthopedists specializing in scoliosis that the brace’s action is not primarily passive via direct mechanical forces on the spine, but that its effectiveness requires the active cooperation of the patient using it (4)—i.e., that the patient use her own muscles to reduce the spinal curvature as she holds her body away from the pressure points.

In light of the foregoing, it seemed plausible to us that the effectiveness of the brace could depend on its ability to signal spinal curvature through increased discomfort at the pressure points. This would serve to inform a cooperative child of her poor posture as well as motivate her to straighten up. If this were the case, we thought 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. That postural training can be easily accomplished with an automated electronic instrument has been shown by Azrin et al. (8). These investigators successfully corrected slouching in 25 subjects by an average of 86% through use of a tone that was activated by slouching. With a device providing continuous information about the appropriateness of her posture, the scoliotic child could learn to use her muscles to straighten herself. Use of such a device might also lead to a refined proprioceptive awareness; thus, an additional possible benefit might exist after use of the device has ceased—perhaps individuals would learn good habits of posture that would carry on into their adult lives.

We report here on the design, therapeutic results, and patient acceptance of a posture-training device used as a substitute for the brace. Our primary aim, the goal of brace therapy, was to retard the progression of curvature. In this pilot study, 12 female patients with idiopathic scoliosis were followed until either their growth potential was completed or they were removed from the program and braced. These data represent more than 21 patient-years of wearing a posture-training device.

MATERIALS AND METHODS

The Device. The device, developed by two of us (B.D. and N.E.M.), and the rationale for its use have been described in detail elsewhere (9). In brief, the device measures the spinal...
curvature continuously in real-time; the instantaneous spinal length is compared with a criterion and the attainment of satisfactory position is signaled to the patient by immediate termination of a tone associated with the incorrect position. To accomplish the spinal measurements, we devised a simple circumferential harness from the seventh cervical vertebra to the pubis (Fig. 1, loop A) which is lengthened as the patient extends the major axis of her body by straightening her spine. Such an extension of the harness is a postural “success,” because it reduces spinal curvature. However, another efficient but undesirable method of extending the harness is expansion of the chest circumference (Fig. 1, loop B) by respiration. To eliminate this problem, we developed a simple electronic device to subtract a suitable fraction of the lengthening due to respiration (Fig. 2B) from the torso circumference (Fig. 2A). This subtraction yielded a pure measure of trunk length (Fig. 2C) to within 0.5 mm.

Selection of the operating range of the instrument is accomplished by changing the length of the measuring loops. These loops are adjusted individually to fit each patient so that initially the tone is activated by an erroneous posture approximately 50% of the total wearing time. Subsequent lengthening of the loops allows for periodic adjustment of the postural criterion as the patient grows and becomes more adept at keeping her spine straight. The device includes a digital recording system that accumulates total time of erroneous posture relative to the criterion. This measure of the patient’s performance allows for accurate criterion advancement.

The remainder of the posture-training device consists of integrated circuits that produce a barely audible tone when an incorrect posture has been assumed for more than 20 sec. This tone becomes louder if the poor posture is maintained for an additional 20 sec. All tone terminates immediately when the child adopts a satisfactory posture. The first tone is a signal likely to be heard only by the child wearing the unit. The louder one serves to attract the child’s attention when the louder one, in addition, since this louder tone may be heard by others near the child, it can also serve as a mild punishment for failing to terminate the first tone. The 20-sec delay in onset of the first tone (i) allows the child to assume briefly postures that are incorrect but necessary, such as when tying a shoe, and (ii) shifts the bulk of the task from one of being punished for poor posture, something which made our patients edgy, to the more satisfying one of being rewarded for attaining good posture.

To avoid learning the bad habit of making momentary postural adjustments every 20 sec, each second of delay to the specified maximum must be earned by maintaining a good posture for at least twice that long. Therefore, phasic posture adjustments turn the tone off only momentarily, whereas tonic posture adjustments can serve to keep the tone off for up to an additional 20 sec after lapse of correct posture. An accessible button on the instrument serves to inactivate the tone for 20 sec when the child cannot straighten up or in embarrassing or disturbing situations, such as in the school classroom. However, inactivation is delayed for an interval which varies randomly from 1 to 5 sec, which effectively prevents the development of dependence on the switch.

The device without the lightweight nylon fishing line harnesses, which slide in small Teflon tubes, measures 6.5 × 9.0 × 1.0 cm and weighs 175 g. Fig. 3 shows how the entire arrangement is worn.

Selection and Evaluation of Patients. The 12 patients reported on here were selected from five private and institutional practices on the basis of being judged by the referring orthopedists to be on the verge of requiring bracing; i.e., they were progressively deteriorating as judged from several examinations, but bracing was not yet mandatory. All had flexible curves that could be easily reduced, and all patients and their parents gave informed consent.

The orthopedists agreed to follow these patients in the conventional manner and to supply us with duplicate records of periodic visits, including necessary radiographic data. Osteoporosis, the standard Cobb angle (15) determined from the anteroposterior radiograph, always taken in the same way on standard 14 × 17-inch (1 inch = 2.54 cm) or 14 × 36-inch film with the patient instructed to stand straight and tall, facing the tube 40 inches from the plate. The interval between x-ray evaluations was at the discretion of the referring orthopedist, because the rate of progression varied significantly from patient to patient. More frequent x-ray exposure might have been ethically questionable.

Given the present environment of committees overseeing human investigations, this pilot study did not include an active control group. However, intensive programs of exhortation, verbal instruction, and exercises have generally been recognized to be without any effect on the condition of the spine (10, 11).

Posture Training: Initiation. During the first 2 weeks, each child was adapted to the physical presence of the device and the routine associated with its use. The data-recording system was operational, but the tone signal was inactivated.

Fig. 1. Torso showing the harness arrangement. See text for explanation of loop designations.
Data collected during this period were used to determine a base line for the initial criterion setting (i.e., the trunk length that the patient was required to maintain). This determination was based directly upon the data recorded by the digital timing mechanism, which was the amount of time that the patient successfully reached the criterion of spine lengthening.

Although the training device is specifically sensitive to the desired postural behavior (a straightening of the spine), we have found that an initial period of guidance (shaping) is helpful in increasing the rate at which the child acquires efficient use of her muscles. With an appropriate starting point established, the training procedure consisted of gradually adjusting the criterion setting to develop the skill and muscle strength necessary for maintaining a steadily improved performance. These later adjustments were also based on the data from the digital recording apparatus. At the same time, patients were instructed to observe themselves in a mirror in order to help eliminate an obviously bad posture.

The device was worn for 2 hr per day the first week, 4 hr the second, and so on, up to 24 hr per day for most patients. All patients learned to control the device while asleep. Before the sleep period, during which the spine naturally elongates due to reduced loading, it was necessary for most patients to attach a 1- to 2-cm spacer to the measuring harness so that the device could function properly.

Termination. When and how each patient ended participation in the clinical program was determined by each consulting orthopedist. Although a few patients merely stopped wearing the device when they reached skeletal maturity, most were weaned slowly, just as is conventionally practiced in bracing.

RESULTS

Curve Measurements. Table 1 summarizes the results of posture-training treatment on the Cobb angle for the 12 patients of this pilot study. Ten individuals remained in our program until they reached skeletal maturity and were discharged by their orthopedists as satisfactorily corrected. Two patients were removed from this study by their attending physicians and fitted with braces. The range of starting Cobb angles was 11°–28° (mean = 20.3°; SD = 4.6°); the final Cobb angle was 8°–30° (mean = 19.3°; SD = 6.9°). Overall, for the 12 patients during the period of treatment, the average change was a 1° improvement (SD = 7.5°) in the measured Cobb angle; i.e., the progression was stopped. The behavior of the individual curves is shown in Table 1, where it can be observed that a number of patients showed initial improvements in spinal curvature that tended to be lost during continued participation in the program, whereas another group of patients showed initial increases in curvature that were later reduced or stabilized.

Patient Acceptance. All patients initially found the use of the device for their treatment preferable to the thought of having to wear a brace. They learned very quickly to make necessary postural adjustments under the initial, easy criterion settings. A common complaint during the training period was one of fatigue, which quickly lessened, however, as they became more experienced with use of the device. After the initial training period, all found the device comfortable, except for a few sporadic problems with pressure soreness.

Table 1. Pilot study of posture-training device for scoliosis

<table>
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<tr>
<th>Patient (months in treatment)</th>
<th>Initial</th>
<th>Final*</th>
<th>Net change*</th>
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*At termination of posture-training-device therapy.
†During posture-training-device therapy.
‡These patients displayed motivational problems (see text).
from part of the harness in the superior gluteal cleft. Although some individuals adopted inappropriate postures early in treatment, such as prolonged shrugging of their shoulders, these postures generally were quickly extinguished as the patients learned how to perform efficiently the specific correct postural adjustments that terminated the tone. All children developed an upright, very straight posture, which was especially obvious when they dealt with common problems like bending to pick up a ball, during which their backs tended to remain very straight. In addition to the specific skeletal muscular behavior, the children also learned very quickly that various postures and/or use of some furniture made it practically impossible to control the device. For example, they found that sitting in very soft chairs made it very difficult to lengthen their spine adequately, whereas sitting on a hard surface eased their task considerably. A number of individuals reported regularly sitting on the floor to do their homework, using their beds as 'desks.'

All individuals learned rapidly to reach criterion while sleeping. Again, patients reported that certain body positions made the task easier or harder. For example, successful operation of the device while lying on one's stomach was found to be virtually impossible. Patients wore the device during almost every physical activity—e.g., exercise/dancing classes and basketball—except swimming.

Except under the lowest-cut tops, the device could not be noticed easily by other people while it was worn. Although most patients found the device completely acceptable to wear in public, all patients were instructed to wear it during school, three found themselves inhibited. These individuals constantly avoided wearing the device and, as a consequence, required much parental intervention. We felt that their final compliance level was not satisfactory. The remaining patients understandably exhibited some initial inhibition about wearing the device in public but soon were able to wear it under practically all circumstances with no problems.

In this pilot study, we found that wearing the device for virtually 24 hr a day is important for several reasons, in addition to the medical requirement that the device be worn constantly. First, patients consistently reported both an increased ease in managing the device and decreased fatigue. Second, compliance was more easily monitored by the parents when it was understood that the child was supposed to wear the device at all times.

A relationship between the apparent motivation of the patient and the resulting effect on the Cobb angle seemed quite strong and positive and was often observed by the trend between radiographic evaluations. Patient K.C., for example, possessed a starting curve of 20° and initially took a somewhat noncompliant attitude toward working with the device. She initially wore it only while at home. Her curve progressively worsened to 32° over the next year, when she was very close to the end of her growth. At this point she was told by her orthopedist that if her next measurement had worsened, she would be braces. This stimulated her to work actively with the device and wear it 23 hr a day. Her next x-ray, 2 months later, showed a 6° improvement to 26°, and she was discharged as satisfactorily treated a few months later.

DISCUSSION

There are at least two ways to judge the effect of any therapeutic modality on the progression of a scoliotic curve. One, of course, is to evaluate statistically any changes that might occur in the Cobb angle measurements. This was not possible in the present study, because the small number of patients involved and inherent inaccuracies in determining the Cobb angle resulted in too much variability. However, an ultimate criterion of success is whether a patient can pass through the critical period during adolescent growth without requiring bracing and/or spinal-fusion surgery. As described above, each of our patients was selected on the basis of exhibiting documented progressive changes that would soon mandate use of a brace. Thus, if the experimental treatment were ineffective, we would have expected that all or most of the 12 children would have been removed from our program. The observed result of 10 individuals successfully avoiding wearing a brace strongly suggests that the posture-training device is efficacious ($P < 0.01, \chi^2$ test).

The extensive experience of Blount and Moe (4) would indicate that, in fact, we selected the worst curves to treat. [This selection was determined by the fact that the Committee on Human Experimentation (The Rockefeller University) did not want pilot patients who had larger curves to use our experimental treatment instead of the brace.] When small flexible curves such as those which were treated are braced, they often show little or no final correction yet still may be prevented from progressing. In addition, flexible curves treated by bracing were found to stabilize later and lost more of the correction later. Thus, successful end results for the patients we report here are all the more impressive and suggest that treatment with a posture-training device offers a therapeutic result comparable to using a brace, at least in terms of halting curve progression.

The posture-training device may offer specific advantages over the conventional bracing techniques. First, its data-recording capabilities can offer the practitioner a safe way of frequently assessing short-term progress. Second, unlike a brace, it is easily adjustable and thus can keep individuals at the point of best performance. (In fact, a brace may conceivably retard progress, if it is not adjusted frequently enough and thus, in effect, limits the child.) Third, adjustments of criteria can be easily made by the practitioner in his office, which confers a greater degree of control over all aspects of the therapy of each patient. Fourth, it is now clear that many patients benefit from part-time therapy while they are young adults in their twenties; e.g., Salanova (12) advocates that the mature scoliotic wear a brace at night. Our device provides an inexpensive, comfortable manner in which to accomplish this.

Finally, compared with other non-surgical alternatives, the posture-training device is extremely benign. As discussed above, a brace may cause atrophy of truncal muscle, deformation of the rib cage, and skin ulceration and, in some cases, has produced significant gastrointestinal complications. Paraspinal stimulation techniques involve either surgical implantation of electrodes or regular application of transcutaneous electrodes; in either case, the long-term consequences of frequent stimulation with relatively strong electric currents, including the electrochemical effects on skin and deeper structures, have not been evaluated.

CONCLUSIONS

In recent years, there has been interest in using learned control of physiological responses as a treatment modality. These techniques, usually referred to as "biofeedback therapies," have typically required cumbersome laboratory-based apparatus for measuring and analyzing the target response. As a consequence, the training time available to each patient has been limited to several hours per week. Under these constraints, only a few biofeedback therapies have produced clearly useful results (13). Learning creates a reversible equilibrium state. Consequently, a major increase in training time could be expected to increase significantly the effec-
tiveness of certain biofeedback therapies; evaluation of that possibility was what, in part, motivated us to undertake the present study. Thus, aside from its specific function as a treatment for scoliosis, the posture-training device (PTD) was more generally intended as a prototype or experimental model for automated portable treatment systems, incorporating the principles of instrumental learning for extended and continuous training of medically desirable responses (14).

The feasibility of the general approach is confirmed by the data and experience described above: 21 patient-years of training in a group of 12 adolescent girls were completed; most patients wore the device 23 hr per day for at least 1 year and adapted satisfactorily to the constant physical presence of the instrument and the artificial reinforcement contingency that it imposed.

The posture-training device therapy is different in principle from and should not be confused with a regime of exercises. On the questionable assumption that idiopathic scoliosis is at least partially caused by muscular weakness, a variety of exercise programs to treat scoliosis have been proposed and tested. These programs have met with little, if any, success (10, 11). Although the posture-training device depends on the patient's own muscular effort to correct spinal curvature, the continuous automated evaluation of the actual physiological effect of that effort distinguishes this method from simple exercise, which is performed without moment-to-moment feedback.

Nevertheless, our device does not employ radically new principles for treatment of scoliosis. To the extent that a brace works by enhancing the patient's perception of incorrect posture and encouraging her to correct the position of her spine, the therapeutic mechanism of the posture-training device resembles that of a brace; similarly, the posture-training device shares with the paraspinal stimulator the activation of specific groups of the patient's muscles to correct scoliotic curvature. However, the posture-training device develops learned muscle control through the patient's own nervous system rather than forcing contraction with extrinsic electric currents.

The posture-training device is safer than paraspinal stimulation and more comfortable and cosmetically acceptable than bracing. Thus, if more extensive clinical trials confirm the results of this study and of a recently completed collaborative European study involving a total of 32 cases of kyphosis or scoliosis (unpublished data), the device may have the potential for replacing conventional non-surgical therapy for the treatment of idiopathic scoliosis and certain types of kyphosis.

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