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The use of exercises in the treatment of scoliosis: an evidence-based critical review of the literature

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Summary

The loss of flexibility in a spinal curvature defines it as a structural spinal deformity; a curvature sufficiently mobile to resolve with a change in posture is a non-structural or 'functional' scoliosis which is within the normal limits of movement for a human spine. It, therefore, seems logical that exercise-based therapies designed to improve and/or maintain flexibility and range of motion of the spine and thorax would be useful in the treatment of scoliosis. Recognition of the importance of maintaining flexibility of the thoracic spinal column to avoid scoliosis-associated pulmonary dysfunction made the use of exercise-based therapies a topic of clinical interest in ancient Greece. In recent years, successful prevention of polio epidemics has resulted in a stable change in patient populations such that most individuals diagnosed with scoliosis do not suffer from irreversible central nervous system compromise. As a result, realistic opportunities to examine the role of exercise in treatment of scoliosis are available for the first time in history. A growing body of evidence from independent sources is consistent with the hypothesis that exercise-based approaches can be used effectively to reverse the signs and symptoms of spinal deformity and to prevent progression in children and adults.

The purpose of this review and methods for survey of the literature

Information available to scoliosis patients and their families in the US is summarized by the following statements from the web-sites of the American Physical Therapy Association (http://www.apta.org/Consumer/ptandyourbody/scoliosis) and the National Institutes of Health (http://www.niams.nih.gov/hi/topics/scoliosis/scochild.htm), respectively: 'Exercises are *not* a treatment and do *not* prevent or cure scoliosis' and 'Studies have shown that exercise alone will not stop progressive curves'. The purpose of this literature survey was to identify studies in support of the premise that studies have shown that exercises are not a legitimate approach to use in the treatment of scoliosis. The scientific and medical literature of the English language were searched using Premedline and Medline (1966–2003); CINAHL (1982–2003); PubMed Central; Science Citation Index (1945–2003); HealthStar (1975–2003); PsychInfo (1872–2003); Cochrane Central Register of Controlled Trials; Cochrane Database of Systematic Reviews and Allied and Complementary Medicine (AMED) (1985–2003). Key words were 'scoliosis' or 'scoliosis and . . . treatment; therapy; exercise; physical therapy; physical methods; osteopathy; chiropractic; manipulation; massage; non-surgical; conservative and early intervention'. Older literature cited in articles obtained through electronic searches was procured from the University of Arizona Health Sciences Center Library collection in Tucson, Arizona or through the AHSC interlibrary loan service. Also surveyed were proceedings of meetings of the Scoliosis Research Society, the International Research Society for Spinal Deformity and the Phillip Zorab Symposium; contemporary (1950s–present) physical therapy, pulmonary, orthopaedic and other medical textbooks including issues dedicated to scoliosis and other spinal deformities; popular and scholarly books on scoliosis available commercially through Amazon.com or the University Library system, including English translations of the writings of ancient Greek physicians including Hippocrates. Over 10 000 original articles on 'scoliosis' were identified by this method and surveyed for information about research

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Table 1 Published statements about the role of exercises in treatment of scoliosis

'Exercise alone is to be vigorously condemned' [18 (p. 1523)];
'. . . exercises only treat the psyches of the parents and help the muscle coordination of certain poorly muscled children, who are overweight and underexercised' [19 (p. 153)];
'From before the dawn of orthopaedics in the 18th century, physicians and surgeons (as well as other members of the "healing arts") have attempted to treat idiopathic scoliosis with exercises. There has never been a single scientific article documenting the value of exercise. Conversely, there have been publications comparing the results of exercise treatment with a simultaneous control group. No differences have been shown' [20 (p. 239)];
'Today, most experts agree that exercise alone will not affect the progression of a structural scoliosis' [21 (p. 903)].
'Time and common sense prevent me from discussing any other [conservative] treatment modality than bracing' [22 (p. 2603)].

(case reports, reviews, descriptive surveys, cohort series, epidemiological surveys, controlled trials or basic science) examining the use of exercises as a treatment. To identify research that may remain unpublished to date, or may have been published in documents unretrievable by standard methods, internet searches for 'scoliosis' were conducted. Finally, personal letters were sent to authors who have stated or implied in articles published in peer reviewed journals that research has shown that exercises are ineffective in the treatment of scoliosis (e.g. table 1).

The role of exercise in treatment of scoliosis: an unsupported consensus

This article critically evaluates a long-standing bias regarding the use of exercise in the treatment of scoliosis. The term 'exercise' is defined by the American Medical Association [1] as 'The performance of any physical activity that improves health or that is used for recreation or correction of physical injury or deformity. Different types of exercise affect the body in one or more of the following ways: some improve flexibility, some improve muscular strength, some improve physical endurance and some improve the efficiency of the cardiovascular and respiratory systems. Exercises may be passive, in which a therapist moves parts of the patient's body, or active, in which the patient is taught to contract and to relax certain muscle groups or to perform specific movements' (p. 425).

For many years, the English-language medical and scientific literature of the spine community has dismissed every type of exercise as a legitimate avenue to employ in the treatment of scoliosis (table 1). Virtually every review of scoliosis treatment published in recent decades either states explicitly that exercise is of no use in the treatment of scoliosis or does not mention it at all [2–17]. With the exception of physical therapy, which is occasionally mentioned in the peer-reviewed spine literature as a way to help patients cope with the complications of brace and surgical treatment, avenues that involve physical methods of treatment by a professional have been ignored almost entirely.

In the US, an uncritical acceptance of this 'expert opinion' underlies a clinical impasse so bleak that some have argued that screening to diagnose scoliosis in early stages might as well be eliminated [23–39]. In fact, the dogma that exercises are without potential benefit is so entrenched that possible effects of such therapies in patient outcomes are simply ignored. Thus, 'natural history' surveys describing outcome in purportedly 'untreated' populations generally have included patients who used exercises or received therapeutic treatment by professionals other than surgeons [16, 40–50]. These patients were presumed to exhibit the same disease course as an untreated patient and were included within the 'natural history' populations. For example, in Bunnell's [44] study of 123 female patients, 'the only forms of non-operative treatment prescribed were exercises or shoe lifts. For this reason, all patients were regarded as demonstrating the natural history of idiopathic scoliosis' (p. 773). Shoe lifts and exercise might have improved the outcome [51, 52] and some exercise programmes might have made the problem worse [53, 54]. However, in every situation where the authors chose to ignore the potential impact of such therapies, it is impossible to rule out the possibility that divergent outcomes within patient populations were influenced by exercise regimens some individuals used [55, 56].

In the following paragraphs, the historical background to this situation will be summarized and the small number of original publications which have been cited in support of the dogma that exercise-based therapies have been proven ineffective will be critiqued. Finally, evidence consistent with the hypothesis that active and passive exercise-based therapies can be used successfully to treat the signs and symptoms of spinal deformity in children and adults will be outlined.

Historical perspective on scoliosis treatment in Western medicine

Scoliosis is a three-dimensional deformity in which the spine deviates from its normal sagittal and coronal positions in the upright human posture and becomes

fixed in this unbalanced posture [57–60]. The mechanical imbalance inherent in scoliosis, irrespective of its cause, results in asymmetric loading which constitutes a 'vicious cycle' with an inevitable tendency to worsen with time [61–63]. In fact, most cases of scoliosis do continue to progress throughout the life of the patient [16, 40, 42, 45, 64–66]. Symptoms that occur in association with scoliosis include pain [40, 45–47, 67–78] and psychological distress [14, 16, 24, 49, 79–87]. In curvatures involving the thoracic spine, reduced chest wall mobility and impaired excursion occur as a secondary effect of reduced spinal flexibility [88–90]. Reduced chest excursion causes restrictive lung dysfunction which is proportional to magnitude of curvature and death by cardiac or respiratory failure can occur when Cobb angle is $> 70^{\circ}$ [78, 91–95]. Even mild or moderate cases that remain stable are associated with pulmonary dysfunctions including reduced vital capacity, reduced exercise capacity and recurrent respiratory infection [96–107]. Impaired respiratory function in scoliosis generally develops gradually over time and, therefore, is 'symptomless' because patients adapt to reduced function and remain unaware of their limitations; therefore, cardiopulmonary failure may occur unexpectedly in response to onset of respiratory infection [91, 93, 108–111].

It is the loss of flexibility in a spinal curvature that defines it as a spinal deformity [11]. A curvature that is sufficiently mobile to resolve when the patient lies down or bends sideways is a 'functional' or non-structural curvature which is within the normal limits of movement for a human spine and does not qualify formally as a spinal deformity. Moreover, the flexibility of the spinal curvature is inversely correlated with progression and pain: the more rigid the curve, the more likely it is that the curvature will worsen and the patient will suffer from symptoms [20, 112]. It, therefore, seems logical to predict that exercise-based therapies designed to improve and/or maintain flexibility of the spine and thorax would be useful in the treatment of scoliosis.

An awareness of the dangers of scoliosis-associated pulmonary dysfunction and the importance of maintaining flexibility of the chest wall made the use of exercise-based therapies a topic of long-term clinical interest by the time the Hippocratic Collection was assembled in 500 BC [113]. Galenus (AD 131–201), who first used the term 'scoliosis' to define a lateral curvature in the spine, followed up on this published body of work by using ambulatory corsets and jackets to control spinal curves. He also advocated the use of respiratory exercises including loud singing [114]. Ambrose Pare (1510–1590) recognized the potential for progression of curvatures during growth and worked on improved corsets as a method to control it. In 1741, Nicholas Andre gave birth to the discipline of 'orthopaedics' by way of his treatise on scoliosis, which he believed to be a result of faulty posture leading to a muscular imbalance.

From 500 BC, then, through the early 1900s, the basic principles of scoliosis treatment remained the same as the common-sense approaches attempted by Hippocrates: Traction, manipulation and supportive braces made of everything from iron to plaster were used to reverse the rigidity and push the torso back into alignment in the absence of any knowledge of what caused the problem in the first place [61]. No one knows whether any of these treatments was effective or not. Occasionally an effort was made to use drawings or sculpture to illustrate treatment successes, but such reports are dismissed out of hand as exaggerations based on contemporary biases that nothing but bracing and surgery can influence spinal deformity [115].

Changes in the modern era

Efforts to treat scoliosis with surgery were initiated in the 19th century and, for more than a century now, orthopaedic surgeons have remained at the centre of protocols for screening, diagnosis, treatment, research and publication on every aspect of scoliosis [34]. With the exception of a short-lived and fruitless effort in the 1980s to use 'electrical stimulation' of lateral spinal musculature as a therapy [10, 21, 34, 115, 116], the principles underlying scoliosis treatment have undergone no significant changes since the time of Hippocrates: Treatments including spinal fusion surgery are still based on trying to force curvatures back into alignment in the absence of any scientific or practical understanding of what caused the curve in the first place and what forces may still be at work holding it that way [61, 62, 111].

The only fundamental changes that have occurred in the world of scoliosis treatment, notwithstanding continual efforts to develop surgical approaches that will address the signs and symptoms of spinal deformity in a meaningful way [117, 118], involve diagnosis and demographics. Throughout recorded history, cases of spinal deformity have comprised a heterogeneous mixture of aetiologies including everything from quadriplegia to catastrophic genetic mutations to leg-length discrepancies to nutrient deficiencies. Not only was there no mechanism to distinguish different kinds of spinal deformity, but there was no reproducible means to define the magnitude of the spinal curvature or to

assess whether it was getting worse. In the early 1900s, X-ray technology was developed and suddenly it became possible to distinguish different categories of scoliosis based on magnitude and also to distinguish among cases caused by congenital bone deformities, arthritis, infections, tumours, rickets and other known causes.

A second major change has been in the makeup of scoliosis populations who seek medical advice. This has been in part a result of improvements in treating infectious diseases that cause scoliosis. Throughout most of recorded history, people who had been infected with polio and tuberculosis predominated among populations of patients seeking relief from spinal deformity [18, 61, 111]. For paralytic polio patients especially, a drastic surgical intervention might offer the only hope for survival, let alone a semblance of a normal social life. Thus, the likelihood that a traumatic surgical intervention might be fatal was a risk worth taking. Over the course of this century, vaccinations and antibiotics have narrowed scoliosis populations more and more such that, in the current generation, for the first time in history, the vast majority of cases are 'idiopathic', meaning the cause is unknown and the patient appears to be perfectly healthy except for the presence of a spinal curvature.

A final important change resulting in a quantum shift in the makeup of patient populations has been the advent of widespread programmes for early diagnosis [28, 119, 120]. Thanks to school screening programmes, for the first time in history, most spinal curvatures are now detected in early stages. Before such programmes were initiated in the 1970s, curvatures were generally not detected until they already were at least moderately severe and there was an obvious deformity which was apparent to family members or physicians [111]. Thus, as recently as 30 years ago, a large percentage of patients seeking help already suffered from advanced cases of spinal deformity, many of which involved irreversible muscular and nervous system damage.

Unfortunately, screening programmes in the US have been of limited success in improving the outcome for those found to have mild curvatures, at least in part because no effort is made to treat those found to have a curvature. Instead, patients are advised to do nothing but wait till the curvature either stabilizes spontaneously or progresses to a point of severity at which bracing or surgery can be justified [121]. This clinical approach is based on a presumption that therapies other than bracing and surgery have no role in the treatment of scoliosis except in support of bracing and surgery. Although such claims are made routinely in reviews, books and other surveys of the literature, only a few original publications have been cited in support of the premise that early proactive treatments involving exercise-based interventions do not work. These published papers which have been cited in support of statements that exercise cannot be used effectively to treat idiopathic scoliosis are summarized below.

Published evidence against exercises as treatment for scoliosis

The term 'treatment' is used in the same sense it is used in these studies, to refer to effects on progression, stabilization or reversal of the spinal curvature and its associated deformities and dysfunctions.

In 1941, a committee of orthopaedic surgeons compiled results describing 425 case histories of patients seen in 16 orthopaedic clinics throughout the US [122]. Results from 185 patients 'originally treated by exercises of all types' were obtained through interviews with clinicians. Curvature magnitude ranged from less than 20° to greater than 40°, age at diagnosis ranged from 2–19 years and outcome ranged from progression of more than 20° in 27% of patients to improvement of 10° in one patient. The authors reported that 'most men believed a mild curve should be treated with posture exercises' and that 'Most men agree that postural improvement can be expected from a regimen of exercises, but the curve itself cannot be decreased by this means'. No data or citations are provided in support of these statements. Similarly, the advice that 'Strenuous exercises should be prescribed cautiously, since they may mobilize a rigid curve and allow further collapse' is offered, but it is not clear if this reflects a consensus opinion of the committee or the personal opinion of one or more of the surveyed clinicians. Because detailed information describing methods, supervision, compliance, follow-up or duration of treatment is not provided, no conclusions about the use of exercises to treat scoliosis can be drawn from this study.

The paper most often cited in support of claims that exercises cannot be used to treat scoliosis is a small, well-planned pilot study by a group of physical therapists [123]. This appears to be the only study ever published in the US which documents efforts to use clinical research approaches to test the hypothesis that exercise alone can influence curvature progression. Over the course of a 1-year period, children in two groups matched with respect to age, degree and shape of

curvature were treated with exercise (42 subjects) or no exercise (57 subjects). At the end of the 1-year period of evaluation, there was no difference in curvature progression between the two groups. Unfortunately, because only four of the 41 children in the test group even claimed to have done the exercises 'daily or almost daily', as prescribed, the authors acknowledged that 'Based on this study, we cannot conclude that exercise has no effect on change in curvature in patients with minimal idiopathic scoliosis' (p. 763). They proposed a follow-up study that would include a longer-term, more intensive regime in which children were supervised to make sure the exercises were actually being carried out.

Two papers from a long-term study by a spine clinic in Iowa [45, 48] were cited by Dworkin *et al.* [124] in support of the following statement: 'Intensive programmes of exhortation, verbal instruction and exercises have generally been recognized to be without any effect on the condition of the spine ... On the questionable assumption that idiopathic scoliosis is at least partially caused by muscular weakness, a variety of exercise programmes to treat scoliosis have been proposed and tested. These programmes have met with little, if any success' (p. 2497). Ponseti and Friedman [48], who stated that 'While conservative therapy may improve body posture, it has never been found—or claimed—to decrease the size of a spinal curvature' (p. 381), actually offer no references or data to support this statement and make no claims to have provided such supportive information in the paper. Among 444 patients whose case reports were analysed, it is stated that 'a great number received conservative treatment consisting of exercises designed to increase muscle strength and to correct postural imbalance'... and 'were taught to shift their thorax into proper alignment with the pelvis. Braces were often given to help maintain body posture' (p. 381). No details are provided, and the possibility that a relationship might exist between the use of bracing and exercise by some individuals and widely divergent outcomes within the population was ignored.

More recent follow-up studies of sub-sets of this original cohort [45, 48] have confirmed that long-term outcome in adolescent idiopathic scoliosis ranges from benign to lethal for unknown reasons [16, 49, 65, 66, 78]. The authors of the Iowa series have continued to ignore the possible role of exercise-based treatments in these divergent outcomes, referring to the patients as 'untreated' because they did not receive spinal fusion surgery [56]. This omission was justified based on the premise that 'there is no evidence that exercise results in sustained flexibility and benefits over a 50-year period (p. 2644)' [50]. Whether these patients were among the 'great number' who originally were taught postural exercises and whether such routines were continued in adulthood is not addressed.

Rinsky and Gamble [14] cite two papers [125, 126] in support of the following statement: 'Exercise alone does not halt the advance of progressive scoliosis... Though there is a natural tendency to "do something" there is no proof that prescribed exercises help, even if done on a regular supervised basis'. The paper by McCollough *et al.* [125] deals with the use of bracing in scoliosis therapy. Exercises were not a part of the treatment regime, in keeping with their stated opinion: 'The authors do not believe that exercises influence the course of scoliotic spine deformity' (p. 145). No references are offered in support of this belief and no claims are made for its being anything other than personal opinion. Carman *et al.* [126] also deal with the use of exercise in conjunction with brace therapy and have no bearing on the issue of whether exercise alone can influence outcome in scoliosis.

In summary, an intensive review of the English-language scientific and medical literature pertaining to scoliosis has been carried out. Based on that review, it appears that there is not one single published study, let alone a body of interpretable scientific research, which can be construed as evidence to support the hypothesis that scoliosis cannot be treated with exercise-based therapies.

Evidence consistent with the hypothesis that exercise-based therapies *can* improve the signs and symptoms of spinal deformity

Not only is it inaccurate to claim that scientific studies have ruled out the use of exercise in the treatment of scoliosis, but a small number of studies suggest that a range of physical methods can positively influence the course of spinal deformity [127–133]. For example, Ferraro *et al.* [129] report stabilization of spinal curvature and rib hump among 34 children with mild scoliosis over a 2-year period of treatment which included daily exercises taught by physical therapists. Participation in an intensive 5-month daily exercise programme was correlated with improved appearance and reduced spinal curvature in 10 children with mild scoliosis [133]. A recent abstract [130] reports intriguing results consistent with an older report [131] that side-shift exercises can stabilize curvature progression in adolescents. In that study [130], side-shift exercises were correlated with reduced curvature magnitude in young adults, with Cobb angle improvement of 10°

or more in some patients. In addition to such observations, several important studies, summarized below, constitute a strong conceptual and experimental basis for the proposition that the signs and symptoms of spinal deformity can be reversed without surgery.

Scientifically definitive evidence that scoliosis, in an animal model system, can result entirely from movement and postural imbalance and can be corrected simply by removing the postural imbalance was published more than 20 years ago. Harrington [134] used a population of inbred mice so closely related as to be functionally similar to identical twins. In one population, he inhibited spinal mobility and induced constitutive postural imbalance by surgically tying the right hind- and fore-quarters together at the knee and elbow joints, at different periods during development. At defined periods during growth, the imbalance was reversed by untying the front and hind legs and allowing normal movement. A matched population was used as a control for all aspects of the study. The results indicated that severe structural scoliosis with a Cobb magnitude of up to 90° and with associated morphological changes including compressed intervertebral disc space and wedged and rotated vertebrae could be induced within a defined period of growth and that all of these signs could be reversed completely when spinal mobility and postural balance were restored before growth was complete. The implications of this important paper are clear: *Scoliosis is reversible*, even when it is severe and even when it is accompanied by deterioration of the structures of the spinal column. It can occur in a perfectly healthy population in the absence of any genetic disorder and it can be prevented and it can be cured. Several recent studies using other model animal systems have confirmed the essential thesis of Harrington's work: Structural spinal deformity is reversible, if asymmetrical compression of vertebral structures is reversed before spinal growth is complete [62].

In humans, the most definitive example of a postural aetiology for scoliosis (and, by implication, the likelihood that correction will occur with exercises that correct postural imbalance) occurs in infants in association with a phenomenon called 'plagiocephaly' [121]. Plagiocephaly is a benign moulding of a child's head which commonly develops after birth during the first 6 months of life, in response to lying on its back ('supine') with the head to one side [135]. In surveys of several hundred babies under the age of three who had scoliosis, 97–100% also had plagiocephaly which matched to the sidedness of the curve [136–138]. This remarkable correlation apparently occurs because the same asymmetric posture which leads to head moulding also induces asymmetric moulding of the thorax, resulting in development of a spinal curvature [135, 139]. Mild cases of infantile scoliosis may resolve spontaneously, but 8–80% become progressive, a relentless and potentially lethal course that, according to Lloyd-Roberts and Pilcher [139] is 'established by the age of 2, for by this time all resolving curves are improving (p. 521)' [135, 136, 140–143]. A patient treated by Harrington developed progressive scoliosis following abdominal surgery and by the age of 2.5, she had a severe structural scoliosis measuring 75°. In response, Harrington treated her by 'protection of her spine from gravity loading'. By the time she was 15 years old, the scoliosis had resolved entirely. Similar results have been obtained by using serial casting of the torso to restore a balanced posture [121, 144]. These results constitute a powerful argument in support of the hypothesis that postural imbalance can cause severe structural scoliosis which is reversible in humans, just as it is in mice.

Other data supporting the hypothesis that postural imbalance alone can cause structural scoliosis which can be reversed when postural balance is restored are provided by an important case report series which followed the course of pain-provoked spinal deformity in five cases of structural scoliosis over a period of years [145]. This study yields several important conclusions: If a painful lesion causing scoliosis heals or is treated within 1 year, the spinal deformity may resolve spontaneously. On the other hand, if the pain and its associated scoliosis remain in place for longer than 1 year, the scoliosis is likely to remain even after the pain is gone and can become progressive. Indeed, even when bone tumours are diagnosed, it is frequently only after they first have been misdiagnosed as muscle strain, herniated disc, idiopathic scoliosis, arthritis, infection, spinal cord tumour or hysteria [146]. If the painful lesion is of a nature that never shows up on X-rays or if it heals leaving no trace or if the physician continues to dismiss and/or misinterpret the symptoms, an accurate diagnosis would be impossible. Mehta [145] cautiously points out that inducing forces parallel to those causing pain-provoked scoliosis may operate in some cases of 'idiopathic' scoliosis and highlights the implications for healing of structural scoliosis, irrespective of its primary trigger. Like Harrington's work, the results indicate that structural spinal deformity can stabilize or reverse given the right circumstances and that, therefore, 'The attainment of the limited goal of preventing progressive scoliosis by a combined programme of early detection and early curve correction would appear to be entirely feasible (p. 65)' [145].

Perhaps the most convincing evidence of the power of exercises to improve spinal deformity is a small randomized, controlled test by Dickson and Leatherman [147], which demonstrated that flexibility of fixed spinal curvatures can be increased by more than 30% by an 8-day programme of supervised exercises. Flexibility of the spine is the factor which defines whether or not it is a structural deformity and is a parameter that plays an important role in deciding the type of surgery that can be performed and the degree of correction that can be obtained [11]. Flexibility is assessed based on how much correction of the Cobb angle can be obtained when the patient lies down, bends to the side, or is placed in traction; an extremely rigid curve does not change in response to this maneouvre, whereas a non-structural curvature will resolve completely. In a preliminary evaluation, 10 patients (mean age 12.9 years) diagnosed with idiopathic scoliosis (mean curvature 43°) took part in an 8-day inpatient programme in preparation for spinal fusion surgery [147]. The programme included traction and exercises performed by the patients. The exercises were performed daily for two 1-hour periods, under the supervision of a physical therapist. Each session included 20 exercises with 15 replicates and concentrated on lateral bending to correct the curve and pelvic tilting to mobilize the lumbar lordosis. Flexibility of the curvature was assessed at the beginning and end of treatment. The results revealed that average flexibility was increased by 7° in only 8 days. That is, the average curve on lateral bending was 20° to start and at the end was reduced to 13°. The differences were highly significant ($p < 0.001$) based on standard statistical analyses. A follow-up study with a second group of patients yielded the same results: Traction had no measurable effect, but performance of an exercise regime for 8 days yielded a statistically significant improvement in flexibility of the curve. In this study, there was no improvement in the standing curvature and the data are derived from a small sample population. Nevertheless, the results reveal that exercises designed and supervised by qualified clinicians can be used to reverse the spinal rigidity which is the defining characteristic of a structural scoliosis, in a very short time.

A case report demonstrates that pulmonary dysfunction associated with structural spinal deformity also can be alleviated quickly using physical methods to mobilize a severe thoracic curve [148]. The study reported that a 3-week period of traction significantly reduced the magnitude of curvature in a 49-year-old man who had developed severe scoliosis as a baby in response to polio. More importantly, the improvement in curvature was correlated with dramatically improved signs of respiratory dysfunction, including a nearly 100% improvement in vital capacity, from 0.77 to 1.4 litres (25% to nearly 50% of predicted). The symptoms of respiratory failure also improved: Upon admission, the patient reportedly 'could barely breathe at rest' and after treatment he reported relief from his shortness of breath. The potential application of physical methods in treatment of spinal deformity is obvious from these results [148]. Of most importance was the demonstration that (1) even severe long-standing spinal deformity was reversible by physical methods applied for a few weeks; and (2) the corresponding long-standing life-threatening cardiopulmonary dysfunctions were also rapidly reversible. The authors explicitly expressed their hope 'that this report may stimulate similar attempts leading to a more meaningful evaluation of the long-term potential improvement (p. 1522)' to be achieved by such methods.

These papers [134, 144, 147–150] comprise a small yet compelling body of research consistent with the most straightforward prediction of the 'vicious cycle' model for spinal deformity development and progression [61, 62, 151]: Irrespective of the inciting trigger that causes a spinal curvature to develop, removing the resultant asymmetric gravity loading by restoring postural balance can improve signs and symptoms of scoliosis even after it has progressed to being a fixed spinal deformity [134, 145, 149]. If the asymmetric loading is removed before growth is complete, before too much time has passed, the spinal deformity can be completely eliminated [134, 144, 145, 148, 149]. In moderately severe curvatures in the range which warrants surgical intervention, the loss of spinal flexibility which defines a curvature as a spinal deformity can be reversed by more than 30% in response to treatment consisting of exercises performed daily for 8 days [147]. Even in long-standing, severe thoracic scoliosis whose associated pulmonary dysfunctions have progressed to the point of near-lethality, a dramatic reversal of the signs and symptoms can be accomplished in a matter of weeks in response to physical therapies which mobilize the curvature [148]. It is significant that the conclusions to be drawn from these studies apply to spinal deformity ranging from early mild cases to longstanding cases of catastrophic magnitude, in individuals ranging in age from babies to adults.

In the past decade, the Schroth Clinic in Bad Sobernheim, Germany, has published a series of studies exploring the use of exercise-based therapies in the

treatment of scoliosis. The Schroth programme is based on the principle that spinal deformity, irrespective of its cause, by definition comprises a postural disorder and that patients will benefit from correction of that disorder. Scoliosis inpatient rehabilitation (SIR) essentially accomplishes the goals proposed by Stone *et al.* [123] following their preliminary survey: Those goals include more intensive exercise-based treatment, supervised by physical therapists over a defined period, with subsequent long-term follow-up. Clinical studies with large populations of children and adults have examined structure-function relationships between spinal curvature and symptoms, including the dynamics of posture and breathing as they relate to the mechanics of spinal deformity. Other studies have measured the impact of treatment by comparing the magnitude of scoliosis signs and symptoms before and after treatment. Papers published in peer-reviewed English-language medical journals during the past decade report quantitative, statistically significant improvement in pain [152–154] stabilization or improvement in curvature magnitude and torso deformity [154–158], reduced psychological distress [159–161] and measurably improved chest expansion and cardiopulmonary function [162, 163].

Conclusions

After nearly 100 years of domination of scoliosis research by the orthopaedic surgery community, one principle has been established without question: A structural deformity which is present at skeletal maturity and remains untreated is a life sentence, at best [66]. Like cancer, infections and other disorders of the human condition, scoliosis develops at a particular point in an individual's development in response to a particular combination of environmental and genetic influences and, as in other diseases and dysfunctions, early detection and early treatment in scoliosis can be predicted to be a key to successful outcomes. A small body of clinical and basic research now supports the hypothesis that exercise-based therapies can be used to reverse the signs and symptoms of scoliosis in children and adults [100, 127–134, 145, 147, 148, 154–163, 166–168]. Conversely, there does not appear to be a single study supporting the dogma that scoliosis will not respond to exercise-based therapies applied early in the disease process. Given the known risks of curvature progression, chronic pain, psychological distress and reduced pulmonary function [50, 73, 87, 164–165, 169–172] and the likelihood that early treatment can foster the long-term health and productivity of scoliosis patients, multidisciplinary research by physical therapists, physiatrists, exercise scientists, respiratory therapists and other qualified professionals is long overdue. The need for research is especially urgent in the US, where a successful campaign to reduce sudden infant death syndrome (SIDS) by convincing parents to place their babies in the supine position for sleeping has been underway for the past decade [173]. Unfortunately, use of the supine position in the past almost certainly underlies the fact that infantile scoliosis was prevalent in Europe where babies traditionally slept in the supine position and almost non-existent in the US where babies traditionally slept face-down ('prone') [139]. Infantile scoliosis reportedly has almost disappeared from Europe with adoption of the prone sleeping position for babies [135, 174]. As a result of a 'back to sleep' campaign which has failed to consider the known dangers of inducing infantile scoliosis [121, 135], this potentially deadly disorder can be predicted to be on the rise in the US, where it used to be extremely rare [140]. The children who are victims of this policy are going to need reliable non-surgical therapeutic intervention to prevent tragic consequences [144, 150].

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