Chiropractic treatment of idiopathic scoliosis with the CLEAR Institute method: a description of the protocol and the tenets behind its application

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Abstract

Chiropractic is a healthcare discipline that focuses upon the diagnosis and treatment of problems that affect the alignment of the muscles and bones of the body. According to the National Board of Chiropractic Examiners (NCBE), 2.7 million visits are made each year in the United States to chiropractors for scoliosis and scoliosis-related complaints [1]. Despite the frequency with which chiropractic services are employed for scoliosis, there is insufficient evidence to draw conclusions on the chiropractic treatment of scoliosis; the majority of published papers are case reports, with the only exception being a cohort study by Lantz *et al* [2] that finds little benefit to the practices commonly employed by most chiropractors in the treatment of scoliosis [3].

Recognizing this, a novel chiropractic protocol for the evaluation, assessment, and treatment of scoliosis was developed by the CLEAR Scoliosis Institute Non-Profit Organization. CLEAR is an acronym that stands for Chiropractic Leadership, Educational Advancement, and Research. Doctors of chiropractic become certified in these methods to provide care to scoliosis patients. The aim of this paper is to present a detailed description of this treatment protocol as well as the theory behind it.

This treatment protocol consists of a combined regimen of soft tissue therapy, chiropractic manipulative therapy (CMT), and neuro-muscular re-education therapy, in conjunction with a home exercise program. The goals of the protocol are to enhance motion in restricted areas of the spine, influence spinal alignment, and re-train the motor-sensory feedback loops involved with posture, balance, and proprioception.

The tenets behind the application of the protocol are:

1) Motion is essential for healthy spinal discs.
2) Hypertonic muscles impede spinal flexibility, and hypotonic muscles reduce spinal stability.
3) Ligamentous abnormalities contribute to proprioceptive feedback mechanisms and sensory dysfunction.
4) Posture, proprioception, balance, and equilibrium are involuntary mechanisms, regulated by the cerebellum, brain stem, and other automatic postural control centers.
5) Spinal misalignments are universally present in scoliosis; CMT treats spinal misalignments and their effects upon the body.

This protocol offers a possible alternative for patients with scoliosis who have elected not to undergo bracing or surgery, or those who find early intervention preferable to watchful waiting. Quantitative research is needed to evaluate its effectiveness.

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Introduction

Idiopathic scoliosis (IS) is the most common spinal deformity seen in school-age children [1]. According to the National Board of Chiropractic Examiners (NCBE), 2.7 million visits are made each year to chiropractors for scoliosis and scoliosis-related complaints [2]. Feise surveyed a random sample of chiropractors to determine how they would treat a hypothetical adolescent idiopathic scoliosis patient; 82% would utilize diversified full-spine CMT, 30% would utilize electrical muscle stimulation, and 87% would prescribe exercises [3]. A recent literature review by Negrini and Romano [4] was unable to find any papers involving IS patients treated exclusively with manual therapy, leading the authors to conclude that there is insufficient evidence to draw conclusions regarding the effectiveness of manual therapy when it is used alone. The literature does not support diversified full-spine CMT in conjunction with shoe inserts and postural counseling [5] or electrical muscle stimulation [6-8] as an effective treatment for idiopathic scoliosis. While scoliosis-specific exercise-based treatment for scoliosis has favorable evidence [9], there are currently no scoliosis-specific exercise-based treatment approaches that are taught in the standard curriculum at an accredited chiropractic institution.

The concept of Evidence-Based Practice (EBP) is a recent innovation in healthcare that strives to combine the best available scientific evidence with the doctor's clinical expertise, in line with the preferences of the patient, to improve treatment outcomes.[10] Nearly 3 million patients self-select chiropractic as their preferred treatment for their scoliosis every year; yet, many of the protocols currently being applied by chiropractors to treat scoliosis, such as diversified full-spine CMT and electrical muscle stimulation, have scientific evidence that suggests they may not be effective in managing scoliosis. Developing an evidence-based, scoliosis-specific chiropractic protocol to improve the quality of the care these patients receive is therefore a reasonable goal.

In the previously mentioned literature review by Negrini and Romano [4], three articles that utilized manual therapy in combination with other therapeutic approaches were selected as relevant to the study and discussed [5,11,12]. One of these papers was a case series that presented Cobb angle changes in 19 IS patients after 4 to 6 weeks of care with a preliminary version of the CLEAR Institute method [12]. The aim of this paper is to present a detailed description of this method and the tenets behind its application.

A description of the CLEAR Institute method

The CLEAR Scoliosis Institute is a Non-Profit Organization that developed the protocol described in this study. CLEAR is an acronym that stands for Chiropractic Leadership, Educational Advancement, and Research. Doctors of chiropractic become certified in these methods to provide care to scoliosis patients.

In the clinical practices of CLEAR-certified chiropractors, two different treatment plans are offered, termed Standard Treatment and Intensive Care (IC) Treatment. Patients self-select the CLEAR Institute treatment method and their preferred treatment plan. Standard Treatment is the recommended option for patients who live within a convenient travel distance; IC Treatment is typically recommended for patients who are not located near a CLEAR-certified doctor, but may also be selected as a convenient option by local patients if it better suits their personal schedule. IC Treatment is defined as twice-daily treatment sessions typically provided over the span of two weeks, followed by a subsequent high-priority home exercise component over three months (at which time a re-evaluation is performed and further recommendations made summarily), whereas Standard Treatment consists of regular treatment visits in conjunction with a lower-priority home exercise component over a four-and-a-half-month timeframe with subsequent periodic follow-up.

Goals of care

Scoliosis is a three-dimensional deformity that results in changes in the structure and function of the spine as well as the paraspinal soft tissue structures, and may be linked to imbalances or dysfunctions in the proprioceptive and vestibular systems. [15-18] In line with the Whole-Systems approach often employed by complementary and alternative medicine (CAM) practitioners, [19] the CLEAR Institute method has three primary goals, intended to be achieved in tandem:

1) To encourage motion in restricted areas of the spine through soft tissue therapies such as massage, as well as both passive and active spinal mobilization exercises.
2) To influence spinal biomechanics and neurophysiology through chiropractic manipulative therapy (CMT).
3) To rehabilitate neuro-muscular function and motor-sensory feedback through balance-training exercises and whole-body vibration therapy.

Part One: Patient evaluation

The initial examination of the scoliosis patients consists of two parts: a physical examination and a radiographic examination.

The physical examination consists of:

1. Spirometry [20,21]
    a. Purpose: To quantify objective measures of lung function, including: forced vital capacity (FVC), forced expiratory rate (FER), peak expiratory flow (PEF), and; forced expiratory volume in one second (FEV1).

2. Chest Expansion [22]

    a. Purpose: To quantify the differences in circumference of the chest at maximal inhalation and exhalation.

3. Timed one-legged stability (TOLS) [23]

   a. Purpose: To evaluate balance (eyes open) and proprioception (eyes closed) objectively.

4. Modified Clinical Test for Sensory Integration and Balance (m-CTSIB) [24]
   a. Purpose: To assess a patient's balance and proprioception under static and dynamic conditions.
5. Scoliometry [25]
   a. Purpose: To quantify rotation of the rib cage/spine at three distinct vertebral levels (T6, T12, and L3).
6. Superficial Abdominal Reflex (SAR) testing [26,27]
   a. Purpose: To serve as one possible clinical indicator for myogenic scoliosis and/or underlying syringomyelia, Chiari malformation, and/or spinal cord tethering.
7. Grid Photography [28]
   a. Purpose: To document the patient's posture in three dimensions, while standing and also in Adam's Forward Bending position
8. Dual Inclinometry [29]
   a. Purpose: To evaluate spinal ranges of motion, including cervical flexion [30]
9. Temporo-mandibular Joint (TMJ) Evaluation [31]
   a. Purpose: To observe dysfunction of the TMJ if present
10. Genetic saliva-based prognostic testing [32]
    a. Purpose: if an adolescent patient fulfills the criteria for the performance of a prognostic test to evaluate their genetic potential for progression, this test is recommended to the parents/guardians to aid the clinician and the parents/guardians in making informed treatment decisions for the patient

The radiographic examination consists of the following radiographs:

1. Cervical series (5 views, seated)
    a. Lateral Cervical Neutral
    b. Lateral Cervical Flexion
    c. Lateral Cervical Extension
    d. A-P Open Mouth Cervicodorsal
    e. Base Posterior
2. Lumbar series (2 views, seated)
    a. A-P Lumbar
    b. Lateral Lumbar
3. Scoliosis series (3 views, standing)
    a. P-A Scoliosis [33]
    b. P-A left and right lateral bending [34]

Focal film distance, center ray position, patient position, and cassette size are standardized on these radiographs to ensure consistency in the analysis (see Table 1). The total amount of radiation exposure from the initial examination is approximately 1.55 mSv (155 millirem). [35] All patients sign an informed consent to radiography form prior to the radiographic examination. Scoliosis radiographs are taken in accordance with the American College of Radiography – Society for Pediatric Radiography (ACR-SPR) Practice Guidelines for the Performance of Radiography for Scoliosis in Children. [36]

Lateral bending scoliosis radiographs are taken standing rather than supine to include the effect of gravity in the analysis.

A total of 77 measurements are made to quantify misalignments of the patient's spine in three-dimensions. These measurements dictate the individualized and specific application of the treatment protocols for each patient. [37, 38]

1. Cervical series
    a. Lateral cervical neutral: 11 measurements
    b. Lateral cervical flexion: 13 measurements

c. Lateral cervical extension: 13 measurements
d. A-P Open Mouth cervicodorsal: 6 measurements
e. Base Posterior (Vertex): 3 measurements

2. Lumbar series
    a. A-P lumbar: 8 measurements
    b. Lateral lumbar: 8 measurements
3. Scoliosis series
    a. P-A scoliosis: 11 measurements
    b. P-A left and right lateral bending: 4 measurements

The purpose behind taking these radiographs in a standardized fashion and making consistent measurements upon specific landmarks is three-fold:

First, to use this information to direct the application of CMT and other therapies to customize the treatment to the patient's specific spinal and postural presentation.

Second, to compare the patient's individual findings to what the literature suggests is the ideal sagittal and coronal spinal alignment for obtaining the best possible treatment outcomes and providing the patient with the best possible long-term quality of life. [39-43]

Third, to search for consistencies in misalignment patterns in the spines of idiopathic scoliosis patients that may help to provide insight into the condition of idiopathic scoliosis; for example, doctors utilizing the CLEAR method have consistently reported a misalignment of the upper cervical spine in IS patients, not previously described in the literature, which could suggest a possible mechanism for restrictions in cervical flexion observed in patients with thoracic scoliosis. [44]

Part Two: Patient treatment

In line with the three primary goals (soft tissue rehab, spinal biomechanics, and neuro-muscular function), the CLEAR method of treatment is divided into three phases of care. The soft-tissue mobilization and relaxation therapies designed to improve spinal motion and decrease soft tissue resistance include active spinal mobility exercises, passive vibration therapy, active spinal traction exercises, and passive spinal mobilization therapy. Various types of CMT are then applied, based upon the patient's radiographic presentation, with the goal of influencing spinal biomechanics. The third phase of care, designed to influence neuromuscular function, includes isometric spinal exercises, whole-body vibration, and balance training exercises.

To begin, active spinal mobility exercises are performed with the patient seated upon a chair with a seat that pivots in a 360-degree range of motion. Initially, the patient performs general stretching exercises, followed by spinal range of motion exercises. Lastly, repetitive lateral bending exercises are performed in the direction of the convexity of each curve with the patient's hand positioned at the apex.

Passive vibration therapy consists of the patient lying supine with a padded cylinder below the cervical and/or lumbar lordosis that oscillates at a frequency of 4 Hertz, which was reported to have a lengthening effect upon the spine. [45] Additional supports and/or wedges may also be utilized to create a "mirror-image" position of the patient's typical posture (for example, if they present with anterior rotation of the right hip, a foam wedge will be placed under the left hip on the side of posterior rotation while the patient lies supine).

Active spinal traction exercises are performed by the patient in a standing position. While positioned in a cervical traction device, the patient bends the knees to gently traction the spine, then straightens the legs and repeats this maneuver 60 to 100 times.

Massage therapy is applied to the paraspinal muscles by hand and with the aid of a percussive massage device ('tapotement'), focusing upon the muscles along the convexity of the curve(s).

Spinal mobilization therapy is performed with the patient lying supine on a specialized, motorized therapy table. Lateral traction straps and raised wedges are used to create a "mirror-image" of the patient's postural configuration. While in this position, the motor flexes the lower section of the table repeatedly by approximately 30 degrees, then returns to neutral, providing continuous passive motion that intermittently axially tractions and relaxes the spine.

CMT is then applied, first to the shoulders, torso, and/or pelvis with a motorized drop piece; second, to the thoracic spine manually; third, to the lumbar spine and/or shoulders manually with the aid of a non-motorized drop piece; fourth, to the pelvis manually; and fifth, instrument-assisted CMT is applied to the cervical spine using a mechanical adjusting instrument. Instrument-assisted CMT may also be applied to the TMJ if dysfunction is present, and instrument-assisted, drop-assisted, and/or manual CMT may also be applied to the elbows, wrists, knees, and ankles, if clinically indicated.

In the application of CMT with the motorized drop piece, the patient is positioned supine with a motorized wedge placed underneath the shoulders, torso, and/or pelvis. This wedge has an electric motor that raises and lowers approximately ½-inch six times per second. The goal is to duplicate the effect of CMT; for instance, by placing it underneath the right side of the torso, the rotation of the thoracic spine and rib cage may be addressed. Additional foam wedges are positioned beneath the patient for stability and to enhance the "mirror-image" effect.

In instrument-assisted CMT, a handheld motor-driven instrument with a changeable stylus is used to apply CMT to the cervical spine while the patient is in a seated position. Excessive rotation and lateral flexion of the cervical spine is avoided during CMT and throughout the treatment.

In drop-piece assisted manual CMT, the patient is positioned on a raised segment of the table that lowers or 'drops' approximately an inch when sufficient force is applied; the CMT is then delivered manually. This may be performed on the lumbar spine while the patient is prone when the patient's radiographs demonstrate a hypolordosis of the lumbar spine; when the patient's lumber lordosis is within normal limits or excessive, this maneuver is avoided. Drop-assisted CMT is also be applied to the shoulders in a supine position when the patient demonstrates internal rotation of the gleno-humeral complex ('rounded shoulders').

Manual CMT is applied in the thoracic spine with the patient in a supine position to reinforce the thoracic kyphosis, and to the pelvis with the patient in a side-lying position to correct rotation and/or misalignment of the pelvis.

After CMT, the patient performs isometric lateral flexion and/or rotation exercises with the aid of elastic exercise bands while positioned on a whole-body vibration platform. These exercises are performed seated or standing, and either laterally flexed or rotated to the left or the right, depending upon the patient's presentation.

The patient is then positioned in an adjustable chair that combines axial traction with lateral traction, de-rotation, and whole-body vibration. The armrests are adjustable, and are raised to provide traction to the spine, with the armrest on the side of the postural low shoulder positioned slightly higher than the other. The backrest is positioned and rotated forward on one side to constrain the rib arch. Straps are applied on the convexities of the curve(s), and a halter and pulley system are used to traction the head. A motor attached under the seat of the chair induces vibration at a frequency of 30 Hertz. The patient is seated upon an air-filled disc, and performs isometric rotation exercises while in the chair.

Finally, weights and/or cantilevers are strategically placed on the head, shoulders, torso, and/or hips, according to the patient's clinical and radiographic presentation, and the patient performs balance-training exercises while standing on an unstable surface (such as an air-filled balance training disc), placed on top of a whole-body vibration platform.

Patient-specific isometric spinal exercises are also prescribed for the patient to perform at home on a regular basis.

Discussion

The Anatomy and Physiology of Idiopathic Scoliosis

By definition, idiopathic scoliosis involves an incomplete understanding of its etiology. A more comprehensive approach to patient evaluation and assessment may be considered justified in the management of idiopathic diseases to ensure individual patient expectations of care are met. A thorough patient evaluation consisting of multiple pre- and post-treatment outcome assessments may be considered especially useful when a novel method of treatment is being introduced for an idiopathic condition.

Before the CLEAR Institute method can be adequately understood, it is vital to identify the tenets behind its application.

1) *Motion is essential for healthy spinal discs.*
2) *Hypertonic paraspinal muscles impede the spinal flexibility, and hypotonic muscles reduce spinal stability.*
3) *Ligamentous abnormalities contribute to proprioception feedback mechanisms and sensory dysfunction. [46-48]*
4) *Posture, proprioception, balance, and equilibrium are involuntary mechanisms, regulated by the cerebellum, brainstem, and the automatic postural control centers. [49-51]*
5) *Spinal misalignments are universally present in scoliosis; the purpose of CMT is to treat spinal misalignments and their associated effects upon the body.*

It is unlikely that one therapy could address all of the components involved in IS. A multifactorial, "Whole Systems" approach [19] to treatment involving a series of therapies designed to work in conjunction with each other may be of benefit in the management of complex, multifactorial diseases such as IS.

Intervertebral discs in the scoliotic spine

Axial loading of growth plates influences growth in accordance with the Heuter-Volkmann law. [52,53] Asymmetric loading of the spine causes asymmetrical wedging of the discs resulting in scoliosis, which eventually leads to vertebral wedging. [52,54] Intra-discal pressures and stresses upon the discs in scoliosis are high, and remain high even in the absence of significant muscle loading and gravitational forces. [55] One suggested explanation for this could be dehydration of the annulus (especially on the concave side of the disc), contributing to soft tissue changes in the discs and ligaments, and alterations in the fascial mechanics. Nutrient supply to the disc may play a role in this process. [56] Widespread changes in the endplate and nucleus pulposus of the scoliotic disc have been found even when minimal wedging is present, suggesting nutritional factors as the primary mechanism of degeneration induced by mechanical stress. [57] The water content of the scoliotic disc has been found to be lower than normal [58], turnover of the proteoglycan matrix is impaired, and there is decreased permeability of the end-plates. [59,60] The permeability of the end-plates is essential for normal fluid and nutrient transport [61,62], and calcification of the end-plate could initiate and promote degeneration of the intervertebral disc. [63] It has been suggested that the process of disc degeneration can be accelerated if motion is restricted, and can be avoided if motion is preserved, [64-67] the implication being motion may be essential to maintaining ideal hydration and nutrient supply to the intervertebral disc.

While intervertebral discs cultured under high amounts of dynamic, cyclic compressive stress exhibit decreased collagen and glycosaminoglycan content, discs cultured under smaller amounts of cyclic compressive stress actually exhibit increased collagen and GAG content. [68] Dynamic compression facilitates the diffusion of nutrients and thus increases the nutrition level around the cells of the intervertebral disc. [69] Cyclic loading and unloading of the intervertebral disc restores normal disc mechanics through fluid transport; fluid exudation and recovery may be integral to maintaining adequate disc nutrition and preventing degeneration. [70]

Conservative treatment of idiopathic scoliosis is designed to counter-act the asymmetrical forces acting upon the growth plates, in an attempt to alter growth mechanics through the Heuter-Volkmann law. The majority of studies have focused upon the paraspinal musculature (and to a lesser extent gravity) as the origin of the asymmetrical loading; however, the presence of significant, high-magnitude stresses upon the disc even in the absence of gravity and muscle loading is interesting. These stresses may exist due to degradation of the scoliotic disc structures caused by insufficient fluid and nutrient transport. Based upon this, it may be possible to reduce stresses upon the disc by stimulating hydration and nutrition through exercise and gentle, repetitive cyclic loading and unloading.

Paraspinal muscles surrounding the scoliotic spine

Cheung *et al* observed asymmetrical electromyographic (EMG) activity in AIS patients, and found that higher imbalances were strongly predictive of curve progression [71-73]. In these studies and in others [74,75], the muscles on the convex side of the curvature demonstrated increased EMG activity. Cheung *et al* agreed with the point of view expressed by Riddle and Roaf [76], namely that this increased EMG amplitude indicated that the muscles on the convexity of the curve were stronger or more hypertonic than the muscles on the concave side. This is further supported by histological evaluation of muscle tissue in the concavity of the curve, which finds a decreased proportion of oxidative slow-twitch (type 1) fibers [77], suggestive of decreased tonic activity.

Schmid *et al* evaluated EMG amplitudes of paraspinal muscles during exercise, and found that certain exercises increased the EMG amplitudes of the paraspinal muscles in the concavity[78]; the authors hypothesized that, by strengthening the weaker side, improved muscle-performance capacity could be responsible for the 20% improvement of the scoliotic curvature observed by Mooney *et al* [79] and the short-term reduction in progression observed by McIntire [80]. Weiss has shown that an intensive inpatient rehabilitation program based on asymmetrical exercises can improve the muscle-performance capacity of the paraspinal muscles, and suggested that this could lead to a functional correction of the scoliotic curve [81]. Schmid *et al* suggested that weights and exercises could be individually adapted to each patient for maximum benefit, which concurs with the Cochrane Review by Romano *et al* [82] that found evidence of increased effectiveness of scoliosis-specific exercises (SSE's) as compared to general physiotherapy. While additional research on SSE's is needed, it can be said that decreased EMG activity in the concave paraspinal muscles in scoliotic patients exists; that this imbalance may be linked to progression; and, that certain exercises may increase EMG activity asymmetrically in the paraspinal muscles. The hypothesis is that increasing EMG activity in the concavity through SSE's may have a beneficial effect upon the functional aspect of the curve and possibly reduce the risk of progression.

The role of ligaments in the neurology and physiology of the scoliotic patient

Ligament laxity is a common finding in IS patients [83], as are proprioceptive deficits [15-17]; a correlation between the two may exist. In one study, 48% of children diagnosed with joint hypermobility (JH or 'ligament laxity') were considered 'clumsy,' and 36% demonstrated problems with co-ordination [84]. Ligaments are well-innervated, and play an important role in the neurological feedback mechanisms responsible for the protection and stability of the spine; although traditionally considered only as a mechanical structure, there is increasing evidence to suggest that ligaments participate in neuromuscular reflexes [48]. Patients with idiopathic scoliosis show a degeneration of the neural ligaments, and a significantly lower density of Ruffini corpuscles, single nerve fibers, and total neural elements when compared to controls [46]. Ruffini corpuscles are involved in providing awareness of joint position and movement (proprioception), and are particularly common in articulations where static position sense is necessary for the control of posture [48, 85]. In the supra-spinous and infra-spinous ligaments, innervation of the Ruffini corpuscles plays a key role in ensuring symmetry of the spine in the coronal plane, and may participate in active balancing of the spine laterally [48]; dysfunction in the innervation of these ligaments may contribute to imbalances in neuromuscular function.

When CMT is delivered to the cervical spine manually by rotating and/or laterally flexing the patient's head, it is possible that this maneuver could place stress upon certain ligaments or aggravate pre-existing hypermobility. As stated by the World Health Organizations' Guidelines on Basic Training and Safety in Chiropractic, successful spinal mobilization and/or manipulation [CMT] involves the application of a force to the areas of the spine that are stiff or hypomobile, while avoiding areas of hypermobility or instability [86]. The protocols described in this study are designed to evaluate and address upper cervical instability/hypermobility. If cervical hypermobility is present, specific exercises aimed at activating the muscles of the sub-occipital triangle are prescribed in an attempt to increase stability and protect the ligaments from additional injury.

Neuromuscular re-education

The hypothesis that a sensorimotor integration disorder underlies the pathogenesis of IS has been gathering increasing evidence. [87] As mentioned earlier, IS patients demonstrate a wide variety of neurophysiological deficits related to balance and postural control [15-17]; these deficits tend to be more pronounced in dynamic conditions [88, 89].

It has been classically assumed that one or a few balance centers in the central nervous system (CNS) were responsible for the control of balance; however, this viewpoint fails to capture the integrative nature of all of the neural systems responsible for balance, proprioception, co-ordination, equilibrium, and posture. Although referring to balance control in an elderly population, Horak states, "[P]eople with balance disorders suffer from multiple impairments… it is often assumed that these impairments lead directly to functional loss…. Too often we forget that impairments alone do not lead to functional deficits because some people with a particular impairment have much better function than others, depending upon the type of impairment and the strategies each uses to compensate for the impairment." [90] Clinically and scientifically, how we quantify and measure the functional aspects of any underlying sensorimotor integration disorder(s) in IS is extremely important. In the paper by Horak, the first sentence states "our assumptions concerning how balance is controlled shape how we assess and treat balance disorders." Therefore, the broad term "balance control" is broken down into six primary resources required for postural stability and orientation as described in this paper, and each individual component examined as it pertains to the specific deficits observed in IS. Those six aspects of balance are: cognitive processing (attention, learning); biomechanical constraints (degrees of freedom, strength, and limits of stability); movement strategies (reactive, anticipatory, voluntary); sensory strategies (sensory integration, sensory reweighting); orientation in space (perception, gravity/surfaces/vision, verticality); and, control of dynamics (gait, proactive).

Applying this analysis to IS, it would be reasonable to exclude deficits in cognitive processing from the focus of rehabilitative approaches, as no such deficits have been observed to occur consistently in IS populations in the literature.

While biomechanics influences balance in IS, treatment of biomechanics alone does not appear to resolve balance deficits. De Abreu *et al* commented on the effect of surgical treatment on postural control, and their findings suggested that the balance control deficits they observed in their population were more likely due to sensory issues rather than biomechanical [91]. This is further supported by papers on the effect of bracing on balance [92-94]; there is no immediate effect of bracewear on balance control strategies, and influencing spinal biomechanics alone does not appear to resolve the functional deficits in IS patients; the paper on bracing and balance by Chow *et al* suggests that the action of a TLSO may aggravate rather than reduce these deficits by adding biomechanical constraints to the spine, reducing its ability to react in dynamic conditions: "[B]racing may affect balance function by limitation of the trunk motion between the thoracic and sacral spine, which may in turn restrict the ability of the trunk to contribute to the maintenance of balance."

The role of movement strategies could be considered to play a role in IS, particularly with reactive and anticipatory strategies. An example of a voluntary movement strategy could be the motion that occurs in the ankles as the subject stands on a firm surface and compensates for postural sway. While AIS patients have greater amounts of postural sway in a standing position [95,96], there is no clinical or scientific evidence to suggest that they exhibit an increased risk of falling, suggesting that the voluntary movement strategies are not impaired, or that the impairment is so minimal that compensatory mechanisms are able to adapt and prevent measurable functional deficits. In either scenario, it is unlikely that rehabilitation of voluntary movement strategies would be productive.

Reactive and anticipatory (or predictive) strategies, in contrast, typically take place only in unstable conditions or after perturbations. In IS patients, both reactive and anticipatory strategies show earlier onset and prolonged activation of muscles, particularly on the concave side [97]. As these deficits are measurable, and functionally this increased muscle activity creates a reduction the efficiency of the body's ability to maintain an upright posture, rehabilitation on compliant surfaces and/or with perturbation could be considered worthy of further research.

Deficits in sensory integration have been measured and documented to occur in IS, particularly in the integration of vestibular signals [98]. While the exact cause of this vestibular impairment is not yet known, if the vestibular system is intact and capable of rehabilitation, specific exercise-based approaches to vestibular rehabilitation have been shown to be effective in improving balance in other populations with documented vestibular dysfunction [99-101]; this could be considered sufficient evidence to explore the effect of vestibular rehabilitation in patients with IS to determine if these vestibular integration deficits are reversible.

One etiologic theory for AIS postulates that one of the reasons why AIS develops more predominantly in females rather than males has to do with the timing of the maturation of the proprioceptive systems in regards to the onset of the growth spurt [102]. Some evidence suggests that the proprioceptive processing systems of adolescents are not fully developed [88] and that adolescents, given only proprioceptive cues, cannot effectively control their postural orientation, and so tend to rely more upon visual cues [103]. While deficits in postural control can be observed in AIS populations even when vision is not inhibited, these deficits do worsen when only proprioceptive feedback is allowed [15-17], suggesting that rehabilitation performed in the absence of visual cues may be of benefit in AIS.

Abnormalities in gait are a common finding in AIS; so much so that they could be used as a diagnostic factor [104]. Typically noted are decreased pelvis, hip, and shoulder mobility, as well as increased muscle activation and energy expenditure [105]. These findings are present in mild scoliosis, and become more severe as the deformity progresses [104]. Conflicting results are reported post-surgery, with no significant differences observed between anterior or posterior approaches [105-107]. Bracing appears to further reduce mobility in the shoulders and pelvis [108]. Neither intervention affects energy expenditure [105,108]. While there is no research on the effect of exercise-based approaches to gait rehabilitation in scoliotic populations, there is evidence suggesting that backwards-walking can improve balance in school-age children [109]. It has not been researched if similar results would occur within a scoliotic population.

Applying this information in a clinical environment, it would appear that strategies aimed at rehabilitating anticipatory/reactive movement strategies, performed both with postural feedback or body schema awareness to address vestibular deficits or under visual deprivation to stimulate proprioceptive function, may be a promising beginning in functional rehabilitation approaches to AIS. It may also be of interest to explore whether backwards-walking could have a beneficial effect upon gait and/or balance in AIS.

Smania *et al* described the neurophysiological basis of the rehabilitation of AIS; the authors concluded that neural control could play an important role in postural rehabilitation [110]. Romano *et al* described a spinal straightening reflex that occurs when AIS patients were placed on an unstable surface [111]. In this paper, the effect was small and difficult to predict; nevertheless, it suggests that there may be a way to improve spinal alignment through activation of the body's own reactive mechanisms. If patterns in how certain configurations of scoliosis react to specific combinations of stimuli can be identified, this may provide insight into opportunities for neurophysiological rehabilitation of scoliosis. Ongoing clinical research conducted by the CLEAR Scoliosis Institute with the participation of chiropractors applying the CLEAR protocols is currently aimed at achieving this goal.

WBV therapy is currently being researched for its effect upon postural control and other balance-related parameters, particularly in the elderly population and in patients with neurodegenerative disorders. While no definitive conclusions can yet be drawn, WBV therapy may be effective in improving balance and mobility in some populations [112,113]. Using WBV therapy to influence postural control and balance in AIS patients is a novel concept which has not been explored in the literature. The intended goal of incorporating WBV with the described exercise and neuromuscular rehabilitation protocols is to add an additional perturbation to enhance balance training, facilitate motor-sensory feedback communication between the brain and body, and to increase EMG activation of the targeted muscle groups. It is important to note that concerns have been raised that certain WBV therapy products may exceed established safe limits for WBV exposure [114]; this is the primary reason for the specific settings (30 Hz, 0.3 G's) utilized in the CLEAR protocols; to ensure patient safety, especially in a pediatric population. Evidence suggests that 30 Hz is also the ideal frequency for increasing EMG amplitudes with vibration exercise [115]. Data regarding the effect of specific vibratory settings remains inconclusive to-date; however, many studies that investigate the effect of WBV therapy on balance, postural control, neuromuscular performance, and the skeletal system utilize frequencies in the vicinity of 30 Hz [116].

Conclusion

The described method is based upon five tenets which are supported by anatomical and physiological research.

Research on spinal intervertebral disc biomechanics suggests that motion is designed to occur in the spine and that cyclic repetitive loading and unloading, through the process of osmosis and imbibition, may positively influence disc function.

Paraspinal muscle imbalances are well-documented to occur in scoliosis, and evidence indicates they are linked to the risk of progression. Some exercises designed for scoliosis patients have the ability to activate specific muscle groups in an asymmetrical fashion. Therapeutic stretches are also commonly used to rehabilitate hypertonic muscles; these stretches can similarly be done in an asymmetrical manner.

Ligaments are not purely a mechanical structure, but also play a role in posture, proprioception and sensory integration. Ligamentous abnormalities are well-documented to occur in scoliosis patients, and may be linked to problems with sensory integration. Rehabilitation of documented impairments is the desired goal, but initially the poorly-functioning ligaments must be identified and injury/aggravation of any existing issues avoided.

If a sensorimotor integration disorder is involved in the etiopathogenesis and/or progression of idiopathic scoliosis, approaches such as vestibular rehabilitation, balance training exercises, and whole-body vibration (WBV) therapy are currently being investigated for their effect in improving function in populations with vestibular impairment; it may be worth the effort of further research to determine if these approaches may be of benefit in the management of IS.

The likelihood of a successful treatment outcome for the person living with scoliosis increases when scoliosis-specific approaches are applied. Evidence does not support diversified full-spine CMT for mild cases of scoliosis. In the same manner that scoliosis-specific exercises are more likely to be of benefit in the management of IS, more specific applications of CMT may be worthy of further investigation to determine if the same principle applies.

The CLEAR Institute scoliosis treatment method aims to treat disc problems through motion, muscle imbalances through exercises and stretching, spinal biomechanics through specialized CMT procedures, and neuromuscular function through balance exercises and WBV therapy. It focuses upon the inclusion of functional, cosmetic, and quality-of-life indices alongside radiographic measurements. It is intended to provide an evidence-based option to scoliosis patients who wish to self-select chiropractic treatment for their condition. Quantitative research is needed to evaluate its effectiveness.

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