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Research Article

Myofascial and Articular Treatment of Adolescent Idiopathic Scoliosis (AIS)

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Abstract

Background: In addition to brace usage, a consensus is emerging that individualized exercise focusing on addressing muscle imbalances, thereby decreasing asymmetrical loading of the spine, can improve outcomes of scoliosis care and reduce need for corrective surgery [1-4]. There has not, however, been exploration of treating asymmetrical tensions on the spine due to myofascial dysfunction and fascial constriction.

Purpose: This study was designed to develop individualized treatment based on fascial science to reduce rate of scoliosis progression and/or reduce degree of curvature and possibly reduce need for corrective surgery.

Study Design: This is a Randomly Controlled Trial (RCT) of subjects with (AIS), randomly assigned to a Control Group (CG) and an Active Treatment Group (ATG). CG subjects received standard care. ATG subjects received myofascial and articular treatment 2x/month for 6 months, with individualized home exercise. Subjects in both groups who had been prescribed braces continued bracing throughout participation.

Study selection criteria: age 10-15 years, curvature of 15 to 30°, no other disorder responsible for spinal curvature, bone growth not completed. Measurements were performed at the beginning and after 6 months of participation, at a university children's hospital to assess results in the CG and the ATG. Self-reported Measurements: subjects filled out visual analog pain questionnaire and quality-of-life questionnaire: SRS 22. Physiologic Measurements: X-rays (Cobb angle measurements); scoliometer measurements of degree of rib prominence.

Results: The COVID pandemic affected recruitment of subjects: 9 in the CG, 10 in the ATG. When 2 crossover subjects were added to the ATG there were 2 statistically significant differences: rating of pain; SRS-22 questionnaire responses. There were unusual decreases of spinal curvatures in 40% of ATG subjects: -13° in 2 subjects, -10° in 1 subject, -9° in 1 subject. Only 1 subject in the CG experienced a significant decrease of spinal curvature: -7°.

Conclusion: It would not have been possible to produce these decreases of scoliotic curvatures if structural changes in the spine (collapse) accounted for the development of scoliotic curvatures. Furthermore, the study allowed for systematic clinical observations that shed light on the etiology of AIS and may inform future treatment to reduce or reverse progression of AIS.

Keyword: Adolescent idiopathic scoliosis; Myofascial dysfunction; Fascial dysfunction; Muscle imbalance; Ligamentous laxity; Imbalance of pelvis; Biotensegrity; Over-pronation

Background Context

Defining the problem and gaps in current knowledge

The Scoliosis Research Society has defined Adolescent Idiopathic Scoliosis (AIS) as a lateral curvature of the spine equal to or greater than 10° as measured using the Cobb method on standing radiograph, when this curvature is accompanied by vertebral rotation [5,6]. Scoliosis is present in 2-4% of children between 10 and 16 years of age [7]. Curve progression in adulthood is related to the degree of curvature at skeletal maturity. Curves of less than 30° at maturity are unlikely to progress. Curves of 30-50° progress at an average of 10-15° over a lifetime. Curves greater than 50° at maturity progress steadily at a rate of 1° per year [8]. Curve progression in adulthood is a key factor in chronic pain and disability. Clinically significant rib cage distortion can result in respiratory insufficiency and cor pulmonale [9].

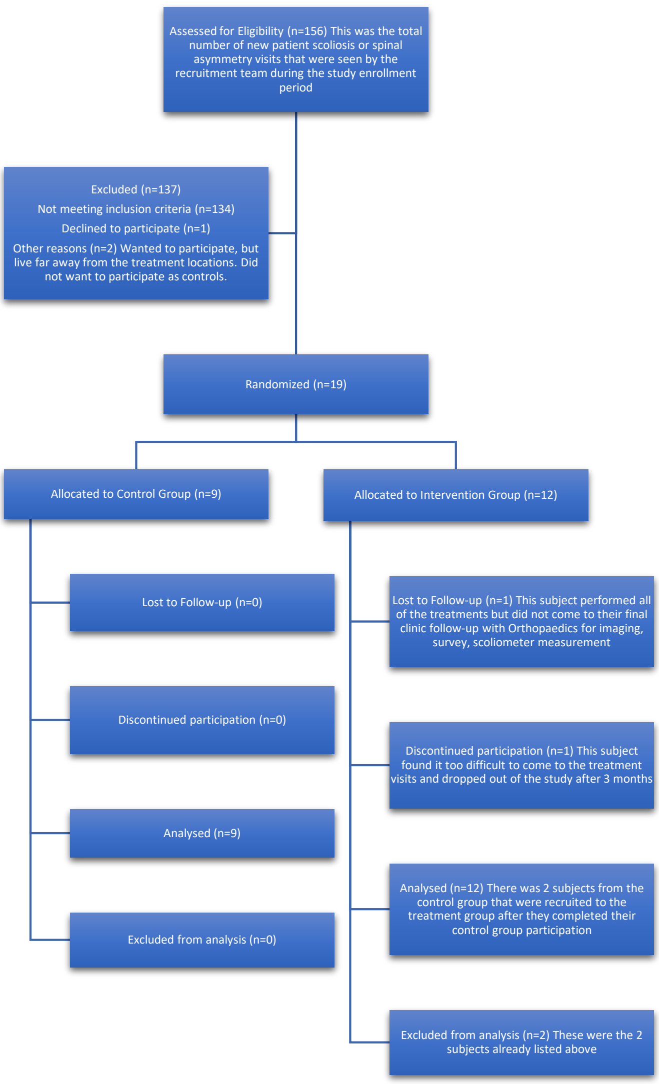
In the last 25 years, there have been significant advances in our understanding of genetics and biochemistry correlated with scoliosis. Multiple studies have identified abnormalities of spinal bone tissue and density, and disc wedging has also been implicated, as well as hormonal and genetic abnormalities found in AIS [10-12]. Proprioceptive deficits have been identified in AIS patients and some have theorized that this may be a causative factor, but it may be a consequence of the development of AIS [13]. Unfortunately, no successful new intervention strategies based on this new knowledge have been developed to date. The use of bracing has been documented to assist in decreasing progression of the curvature and avoid spinal surgery. This treatment has been shown to be effective for a significant portion of adolescents with scoliosis [14-17]. Existing treatments are focused on slowing progression of curvature, because no treatments have been shown to actually stop or reverse the condition.

The one notable recent addition to the therapeutic options is the emerging consensus that individualized exercise focusing on addressing muscle imbalances, and thereby decreasing asymmetrical loading of the spine, can improve the outcome of scoliosis care and reduce the need for corrective surgery [1-4].

Purpose

There is a continuing need to identify more of the contributing factors to the development of AIS and craft comprehensive treatment that is both individualized and multifactorial. This research study was designed to contribute to this endeavor. By utilizing recent emerging fascial science and implementing a myofascial and articular approach to treatment, it may be possible to successfully reduce the rate of progression of scoliosis and/or reduce the degree of curvature. Successful application of such an approach may have the potential to reduce need for corrective surgery.

[Flow Chart]



Flow Chart

Background

The existing literature basis for myofascial care of AIS

Muscle imbalances: Research on muscle imbalances related to AIS has focused primarily on the paraspinal muscles and has failed to establish that there are any significant histological or muscle fiber activity differences between the muscles on the convex and concave sides of the spine. Further, differences in muscle character on each side of the spine could as easily be explained as the result of the curvature rather than contributing to its causation [18]. Attempts to stimulate changes in paraspinal muscle tension in order to alter progression of AIS have not shown any additional benefits compared to bracing [18,19,].

Importantly, recent genetic studies have provided evidence that skeletal muscle dysfunction could be a contributory factor in AIS susceptibility: rare variants in fibrillin-1 and fibrillin-2 have been found to be associated with severe AIS. These glycoproteins form key components of skeletal muscle myofibrillar structure and abnormality of fibrillin-1 is associated with the connective tissue disorder, Marfan's. Importantly, 60% of patients with Marfan's develop scoliosis [20]. Recent research reported signs of muscle myopathy and muscular atrophy on both the convex and concave sides of the scoliosis apex [21]. These findings accentuate the fact that muscle and soft tissue abnormalities are the norm in severe AIS, but this does not explain the dynamics of the development of the AIS.

Research is starting to address the role of muscles that are attached to the spine, but that are at an angle to the spine such as the Quadratus lumborum and Iliopsoas muscles. It is suggested by the authors that the greater activity of the Quadratus lumborum on the side of the lumbar convexity may account for the lower rib asymmetry, due to the fact that the Quadratus lumborum is the largest of the muscles that attach to the ribs, as well as to the spine and the ilium [22]. When researchers used Botulinum toxin A to temporarily paralyze the Psoas major in 9 AIS subjects, radiographs taken 6 weeks later showed a significant decrease in both the lumbar and the thoracic spine Cobb's angles, with a non-significant decrease in both lumbar and thoracic derotation [23]. Whyte Ferguson addressed myofascial trigger point activity in muscles at an angle to the spine to treat adults with scoliosis and chronic spinal area pain who had not had spinal surgery, and the severe post-surgical pain of adolescents after spinal stabilization surgery with rod placement for uncontrolled AIS. In each of these case series, she treated myofascial dysfunction not just in the psoas and quadratus lumborum, but also in latissimus dorsi, anterior serratus, levator scapula, and scalene muscles and trigger points (TrPs) in each of these muscles have been identified as potentially referring pain into the spine [24,25]. Whyte Ferguson also explored the role of treating muscle imbalances plus fascial spirals in a case series of 22 adolescents who appeared to be developing AIS. Whyte Ferguson documented reduction of both spinal curvatures in certain instances, and reduction of associated paraspinal rib prominence or deformity in other cases. The challenge in treating AIS during adolescent spinal development is that pain is not a frequent symptom, and when myofascial TrPs are treated and released to address any pain condition, this is not sufficient to address the role of muscle imbalance and fascial constriction on progression of AIS [26].

Individualized exercises prescribed were designed to sustain muscle and fascial release to reduce asymmetrical tensions on the spine. Manual muscle testing was used to identify weaknesses that may contribute to postural instability. Strengthening exercises were prescribed to correct weaknesses.

Pelvic obliquity: Research has corroborated the association of sacral slanting with pelvic obliquity (tilting and twisting) and lumbar curvature in AIS and there is also some correlation between leg length difference and sacral slanting [27]. Pelvic rotation has been found to correlate with rotational status of both the lumbar spine and thoracic spine [28].

Most of the literature supposes that pelvic imbalances are a compensation for the curvatures of the spine. However, because the sacrum provides the base for the spine, if the sacrum is lower on one side or is rotated posterior to the plane of the spine and therefore does not as successfully support the spine, the lumbar spine may tend to deviate to the less supported side. The articular treatment employed in this study explores the possible effect of restoring pelvic balance on progression of AIS.

Ligamentous laxity and over-pronation: Researchers have confirmed the correlation of ligamentous laxity with development of AIS [29-33]. Whyte Ferguson also identified ligamentous laxity in 21 out of 22 research subjects (one subject was not evaluated) in the study described above, and all of the subjects had significant arches in their feet that fully collapsed when they were weight bearing. Exercises were not found to be effective to counter over-pronation. Arch supports were prescribed to address over-pronation. Joint Hypermobility Syndrome (JHS) is one of the most common diagnoses in adolescents with chronic back pain [34]. Imbalances in pronation can be related to pelvic obliquity [35]. Individuals with JHS often present with very pronated flat feet, contributing to altered gait pattern. This often responds very well to the use of shoe orthotics-heel cups or arch supports-that support the subtalar joint and the medial arch. Rather than encouraging weaker foot muscles, correcting the biomechanics of the foot has such a positive effect upon the whole gait pattern that it is the preferential course of treatment [36]. This also reduces the abnormal forces and pain throughout the other joints further up the kinetic chain [37]. Considering the possibility that AIS may involve a connective tissue disorder may help researchers and clinicians develop an understanding of dynamics of the development of AIS. Control of over-pronation may be one factor that assists in improving gait and reducing stresses on other joints. Reducing over-pronation may be of importance in treating AIS.

Fascia and proprioception and biotensegrity: Muscle imbalances do not account for the dynamics of development of AIS because some stresses on the scoliotic spine appear to cross over the midline. Muscles do not cross from one side of the spine to the other. It is clear that a conceptual understanding of how the spine is supported that relies on hard elements: the spinal bones and soft elements: the muscles connecting the bones, is inadequate to explain support of the spine and coordination of movement of the spine and extremities. Fascia may help us understand the support of the spine and torso, and spiral fascia have been identified by fascial clinicians and researchers as part of a double helix structure that probably plays a significant role in the support of the spine and torso [38-40].

"Fascia forms a continuous tensional network throughout the human body, covering and connecting every single organ, every muscle, and even every nerve or tiny muscle fiber. In real bodies, muscles hardly ever transmit their full force directly via tendons into the skeleton, as is usually suggested by our textbook drawings. They rather distribute a large portion of their contractile or tensional forces onto fascial sheets. These sheets transmit these forces to synergistic as well as antagonistic muscles. Thereby they stiffen not only the respective joint but may even affect regions several joints further away. Fascia can actively contract and is densely innervated with mechanoreceptors and nociceptors [and is] one of our richest sensory organs [and] our most important organ of proprioception." Robert Schleip, 2009, page iii-iv, in: Stecco L, Stecco C, (Eds.), Fascial Manipulation: Practical Part. Piccin, Padova, Italy.

"The fascial system consists of the three-dimensional continuum of soft collagen-containing, loose, and dense fibrous connective tissues that permeate the body. It incorporates elements such as adipose tissue, adventitiae and neurovascular sheaths, aponeuroses, deep and superficial fasciae, epineurium, joint capsules, ligaments, membranes, meninges, myofascial expansions, periostea, retinacula, septa, tendons, visceral fasciae, and all the intramuscular and intermuscular connective tissues, including endo-, peri-, and epimysium. The fascial system surrounds, interweaves between, and interpenetrates all organs, muscles, bones, and nerve fibers, endowing the body with a functional structure and providing an environment that enables all body systems to operate in an integrated manner." Stecco et al 2018, page xx, in Robert Schleip, Carla Stecco, et al. 2022 Fascia: The Tensional Network of the Human Body, 2nd edition, Elsevier, London.

To understand how fascia may affect the developing spine and how ligamentous laxity may contribute to the development of AIS by contributing to strains on the spine, we need to explore how fascia responds to strain and may be able to transmit this strain to the spine. Tensegrity structures distribute strain throughout the entire structure. Furthermore, in classical physics, there is a straight-line relationship between change in length (strain) and the force applied (stress). In tensegrity models, however, the relationship is non-linear and tensegrities and biological tissues are different in that they can resist much higher strains for their size and weight. (sometimes up to 100%) and they actually become stiffer and stronger and also thicker instead of thinner, as they are stretched [41,42].

Furthermore, fascia has a fascinating ability to contract when under strain, that occurs on a cellular level. Fascia is made up of fibers and a gummy substance that is composed of mucopolysaccharides and glycosaminoglycans and Hyaluronic acid (like "snot") which is colloidal (particles suspended in jelly), hydrophilic (binds with water) and amorphous (assumes any form). Fibroblasts are cells within the fascia that have the role of making replacement fibers to maintain the fabric of the fascia. On the cell wall of the fibroblasts are sensors called integrins that sense and respond to strain. If strain increases, the integrins respond and communicate with the nucleus of the fibroblast, changing gene expression so now the cell produces myofibrils (contractile fibers) and the cell becomes a myofibroblast. We do not know whether this transformation can reverse if strain decreases [43].

It appears that the fascia in the torso may respond to increased strain by becoming denser and more contracted. It may be that the more distortion occurs in the spine, the more the fascial tension constricts. It appears that such fascial constriction may accompany each distortion of the spine in AIS. The challenge appears to be that there are a great variety of patterns of fascial constriction. The fascial spiral "key" proposed by Whyte Ferguson in her 2017 AIS case series referenced above appears oversimplified.

As mentioned above, abnormal proprioception has been documented as related to and possibly contributing to AIS. The focus of research on proprioception in AIS has attempted to identify abnormalities in the central nervous system versus abnormalities in the peripheral nervous system with no definitive resolution of the relative importance of each portion of the nervous system, and no consideration of the role of fascia in proprioception [44]. We know that fascia is richly innervated with proprioceptive nerves and is widely distributed throughout the body. Recent research indicates that the most numerous proprioceptive nerve endings found in fascia are found in the deep fascia and epimysium and it is therefore these portions of the fascia system that are most likely involved in mechanical coordination, proprioception, and balance [45,46]. None of the studies of the abnormal proprioception in AIS performed to date have considered the role of abnormal fascial constriction in abnormal proprioception.

AIS may be a connective tissue disorder: It may be that the studies that have identified genetic abnormalities in AIS subjects are actually documenting the cause of a connective tissue disorder that may contribute to ligamentous laxity, propensity for development of fascial constriction, and decreased spinal bone density. Afterall, the bones in general and the spine in particular can be considered from an embryological, biotensegrity, and logical perspective, as compartmental specializations of fascia (mineralized but still flexible) with their own parenchymal cells (osteocytes, osteoblasts, and osteoclasts) in which the connective tissue, fascia, interpenetrates the bone and delineates "bags" that are then filled with calcium in the form of hydroxyapatite [47,48]. Genetic research has suggested that the genetic abnormalities found in research to date may account for boney abnormalities that contribute to AIS, but it may help us to broaden our consideration of AIS as a connective tissue disorder where abnormal stresses may develop that play upon the spine and may distort patterns of growth and alignment.

Study Plan, Materials and Methods

Recruitment

The orthopedic clinic at the University of New Mexico Carrie Tingley Children's Hospital is a regional management center for AIS. Subjects were recruited starting in January 2021 from the usual population referred to the Principal Investigator at this center. Selection criteria for the study included: age 10-15 years of age, curvature of 15 to 30°, no other significant disorder contributing to spinal curvature, and not having completed bone growth. Those who met selection criteria were offered participation in the study and were presented with Consent Documents with appropriate discussion with the Principal Investigator. Unfortunately, with the onset of the COVID pandemic, the attendance of individuals to hospitals dramatically decreased, negatively impacting recruitment. Nine subjects were randomly selected to the Control Group (CG), and ten subjects were randomly selected to the Active Treatment Group (ATG). Two subjects dropped out of the ATG. One dropped out half-way through due to the need to concentrate on schoolwork. The other completed active treatment but did not return for the final measurements and questionnaires despite numerous encouragements. With approval of the alteration of study protocol, those who completed CG participation were offered crossover for an additional 6 months in the ATG group. Two subjects accepted this invitation. We have separated our analysis of the study results: tables based on the original random selection not including the crossovers, and supplemental tables with the crossovers included.

All aspects of this study were performed in compliance with relevant laws and institutional guidelines. Informed consent was required, and the privacy rights of subjects were observed at all times. The study design was reviewed and accepted through the Institutional Review Board (IRB), through the university Human Research Protections Office (HRPO). Unique Protocol ID: 20-228. Date of approval: June 2, 2020. Clinical Trials.gov ID: NCT05423509.

Measurements

Measurements were performed at the beginning of participation and 6 months later at the university children's hospital, to compare the results of care for each subject in the control group and active treatment group. Radiologists were blinded. Also, blinded Research Assistants were in charge of administering the questionnaires and scoliometer readings and performed Cobb angle measurements. Self-reported Measurements: subjects filled out a Visual Analog Pain Questionnaire and SRS 22 Quality-of-Life Questionnaire: SRS 22. Physiologic Measurements: X-rays with measurement of Cobb angles, and scoliometer readings to measure the degree of rib or paraspinal prominence. The elements of this study were designed to conform with the consensus document developed by the Scoliosis Research Society in conjunction with the Society on Scoliosis Orthopedic and Rehabilitation Treatment in 2014 [49].

Materials and methods for active treatment group

No medications were employed in this study. Those in the CG pursued usual care: some were referred for physical therapy and some were prescribed bracing according to clinical standards employed at the university hospital orthopedic clinic. Those in the ATG were prescribed bracing when indicated plus a regimen of treatment. Each participant in the active treatment group was evaluated at the beginning and every 2 weeks throughout the 6 months of study participation. Evaluation included identifying muscle weakness that might impact on spinal alignment, muscle hypertonicity with accompanying trigger points and patterns of fascial constriction that might impact on spinal alignment, as well as joint dysfunction such as pelvic obliquity and rib/spinal restriction at the location of rib prominence. Individualized treatment was designed around these findings: to balance the pelvis, and release the spine to become straighter, improve rib cage mobility, and improve strength of stabilizing muscles. Moist heat was applied to facilitate muscle and fascial release. Exercises were prescribed to address muscle weakness, to stretch constricted tissues, and to self-mobilize joint restrictions. Progress was assessed on each visit and release techniques were altered as necessary. Exercise performance was monitored to achieve the desired results. Arch support was provided for use throughout the study. Heel lifts and/or ischial lifts were dispensed as indicated for temporary use until the pelvis balanced standing and seated. The intervention regimen was standardized by being performed by a single provider with the requisite training and experience to employ this novel treatment approach. More detail about the treatment techniques and exercises is provided in the Appendix. (One crossover subject had initially entered the control group with a primary spinal curvature of under 30° but entered the active treatment group with the curvature increased to 33°. In view of this, the subject was offered weekly care during her 6 months of participation.)

All treatments also included myofascial release including muscle elongation and treatment of myofascial trigger points, and fascial elongation including release of fascial densification. The patterns of fascial constriction were individualized and as time progressed, it became evident that care had to be taken to perform balanced releases on each side of the torso and extending into the anterior and posterior torso. The patterns of fascial constriction frequently crossed over the spine posteriorly and often wrapped around and appeared to distort the rib cage, with ribs on one side of the torso closer together than on the other side, and with the rib cage more proximal to the iliac crest on one side than the other. The areas of fascial restriction that generally needed to be explored and treated are depicted in Figure 1. [Figure 1a-1d] The figure represents an amalgamation of likely locations of fascial constriction and no subject had constriction in all of these areas. On each visit, hydrocollator packs were used to apply moist heat to the torso to facilitate fascial release. (Appendix 1 presents a fuller discussion of myofascial and articular treatment procedures.)

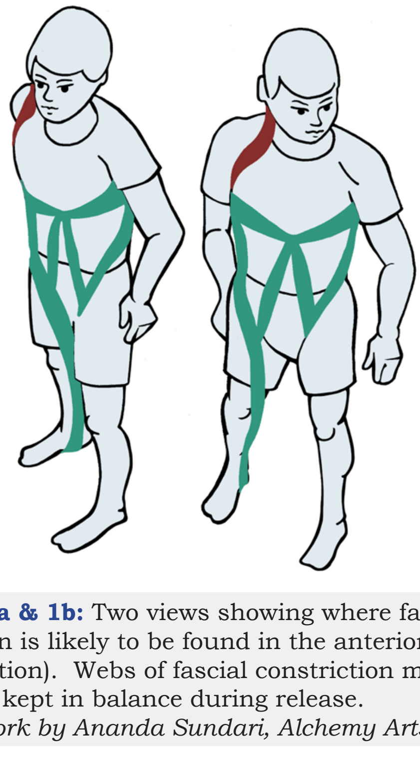


Figure 1a & 1b: Two views showing where fascial constriction is likely to be found in the anterior torso (amalgamation). Webs of fascial constriction must be kept in balance during release.
Artwork by Ananda Sundari, Alchemy Arts

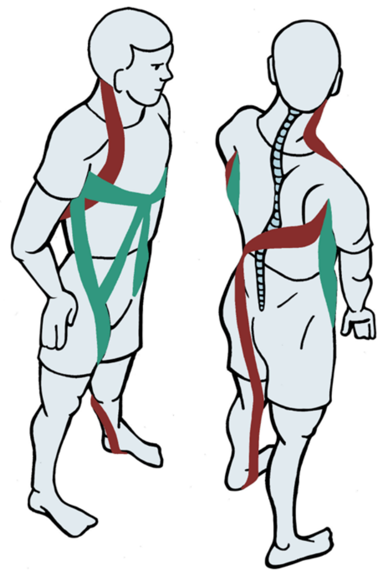


Figure 1c & 1d: Two views showing where fascial constriction is likely to be found in posterior torso (amalgamation). Webs of fascial constriction must be kept in balance during release.
Artwork by Ananda Sundari, Alchemy Arts

Each subject was also assessed with regard to muscle weaknesses. One common weakness encountered was gluteus maximus weakness on the side of the posterior rotation of the pelvis and the accompanying joint dysfunction represented by posterior flare of the sacrum. The other most common muscle weaknesses were of the middle or lower trapezius muscles or both, corresponding to the area of rib prominence and joint dysfunction at the rib/spinal joints. Scoliometer assessment was made of each subject, on each visit.

Each subject had arches that fully collapsed when weight-bearing, resulting in over-pronation. A set of significant OTC arch support was provided to each subject, to be worn in all shoes. Hip height imbalance was monitored seated and standing on each visit. A 7mm. heel lift was prescribed to be placed under the arch supports on the side of the standing low hip, to balance the pelvis. A 3/8" ischial lift was prescribed to be used under the seated low hip whenever the subject was seated for a length of time. These lifts were dispensed with as the pelvis balanced, seated and standing.

Exercises prescribed

Psoas stretches, lunges on a bench or sofa, were prescribed. Partial hanging while holding onto an over the door hanging bar with feet on the floor and knees bent was prescribed, to perform stretches performed at angles to release constricted fascia. Lying on a rug or exercise mat with a small ball (the size you would throw for a dog) placed at the rib/spinal prominence, under each rib, was prescribed. Reverse push-ups performed in a corner were performed to strengthen the weak middle and lower trapezius muscles. One-sided partial bridge was performed to strengthen the weak side of the gluteus maximus muscle.

Analysis methods

Frequencies and percentages were compiled for categorical variables, and continuous variables were summarized using means, standard deviations, medians and interquartile ranges. Distributions for variables were examined graphically. The SRS-22 health-related quality of life instrument contains 22 questions covering 5 domains: function/activity 5 items; pain 5 items; self-perceived image 5 items; mental health 5 items; and satisfaction with treatment 2 items. Each item is scored from 1 (worst) to 5 (best). Each domain has a total sum score ranging from 5 to 25, except for satisfaction, which ranges from 2 to 10. The sum of the first 4 domains gives a maximum subtotal of 100, and when the satisfaction domain is included as we did, the maximum total is 110. Change in Cobb angle was classified as improved if it was at least six degrees smaller in the final measurement, worse if at least six degrees larger in the final measurement and stable if change was plus or minus five degrees.

Participant characteristics at baseline for the two groups were compared using chi-square tests and Fisher exact tests for categorical variables. Primary analysis outcomes were all continuous variables: self-reported SRS-22 and pain scores, largest Cobb angles, and scoliometer readings. Baseline continuous variables were compared using t-tests and Wilcoxon rank-sum tests to assess sensitivity to analysis approach. Change in continuous outcomes was assessed using change scores calculated as post - baseline differences. Change scores for the two arms were compared using t-tests and non-parametric Wilcoxon tests, which requires participants to complete the post assessment. We also used repeated measures linear mixed models, which made use of all available data, to test whether the means for treatment and control groups changed from baseline to final and whether the change was different for the treatment group compared to the control group. The approach has factors for Treatment, Time and Time x Treatment interaction, where the interaction is the test for whether change is the same for the two groups. To further assess sensitivity of results to the analytical approach we used analysis of covariance (ANCOVA). In this linear model approach the final measure is the dependent variable, the baseline measure is an independent variable and there is an independent variable for randomized treatment to estimate how much adjusted final means differ between groups. Primary analyses took an intention to treat analysis of patients as randomized. Crossover patients were added to analyses in sensitivity analyses.

Statistical Power-Based on Schrieber et al. we assumed that repeated measurements of Cobb angles would have a correlation equal to 0.5 and that the standardized difference between groups would be at least 1.0. We planned to recruit 28 participants per group to account for dropouts and for potentially smaller effect sizes. This sample size was projected to have 80% power to detect a difference equal to 0.72 (two-sided α=.05).

Results

A total of 19 participants were recruited with 10 randomized to the active treatment group and 9 to the control group. Two control patients participated in the intervention later as crossovers. Demographic characteristics of study participants overall and by treatment group are shown in Table 1. No baseline characteristics were different for the two groups (p>0.33 for all). Eight out of 10 treatment participants and eight out of 9 control participants completed their final self-reported measures. Self-reported health-related quality of life estimated using the SRS-22 and visual analog pain score results by randomized group and time period are shown in Table 2. There were no significant intervention effects for total SRS-22 or for any of the subscales in the repeated measures analyses (p>0.18 for all). The adjusted mean treatment – controls differences for SRS 22 were positive but none reached statistical significance (p>0.12 for all). When two crossover patients were included in analyses the adjusted mean SRS-22 difference was 8.1 (95% CI 0.2, 16.1; p=0.045 Table 3). Point estimates for change in pain scores also did not show enough difference in change to be statistically significant better for the treatment group in repeated measures analyses (Table 2, p>0.07 for all), and adjusted mean differences were in the direction consistent with a treatment effect, however not statistically significant (p>0.057 for all). Including the two crossover patients resulted in very small changes in mean difference point estimates, but the small sample size increased changed p-values to p=0.032 for improved pain right now and p=0.035 for overall pain average (Table 3).

Table 1: Characteristics of study participants at baseline, overall and by randomized treatment group status.

	All (N=19)		Treatment(N=10)		Control[a] (N=9)	
	N	(%)	N	(%)	N	(%)
Sex						
Female	17	(89)	9	(90)	8	(89)
Male	2	(11)	1	(10)	1	(11)
Age [y, mean (sd)]	12.5	(1.3)	12.5	(1.4)	12.4	(1.3)
Race						
White	13	(68)	7	(70)	6	(67)
Black	2	(10)	2	(20)	0	(0)
No Answer	4	(21)	1	(8)	3	(33)
Hispanic						
No	9	(47)	4	(40)	5	(56)
Yes	8	(42)	5	(50)	3	(33)
No Answer	2	(11)	1	(10)	1	(11)
BMI [mean (sd)]	20.0	(5.1)	19.7	(5.8)	20.5	(4.5)
Risser Stage						
0	11	(58)	5	(50)	6	(67)
1	3	(16)	1	(10)	2	(22)
2	2	(11)	2	(20)	0	(0)
3	3	(16)	2	(20)	1	(11)
Post Menarche[b]						
No	6	(35)	2	(22)	4	(50)
Yes	11	(65)	7	(78)	4	(50)
Brace						
No	7	(37)	3	(30)	4	(44)
Yes	12	(63)	7	(70)	5	(56)

[a]All comparisons p>0.33

[b]Excluding males (N=2)

Table 2: Self-reported outcomes, health-related quality of life (SRS-22 total and subscales) and Visual Analog Pain Scale.

		Baseline		Final		Repeated Measures Analysis		Adjusted for Baseline	
Outcome	Group	N	Mean (SD)	N	Mean (SD)	Change Final - Baseline (95% CI)	Test equality of group changes, P-value	Final Adjusted Treatment-Control Difference Mean (95% CI)	Test for Difference = 0 P-value
Health-related quality of life									
SRS total	Treatment	10	85.6 (11.3)	8	87.9 (9.2)	2.2 (-5.5, 9.9)	0.267	6.6 (-1.9, 15.1)	0.118
	Control	9	84.2 (10.1)	8	80.9 (10.2)	-3.7 (-11.4, 4.1)			
SRS (functional)	Treatment	10	18.8 (1.8)	8	19.3 (2.4)	0.4 (-1.8, 2.5)	0.592	1.4 (-1.8, 4.6)	0.355
	Control	9	17.1 (2.4)	8	16.8 (3.8)	-0.4 (-2.6, 1.8)			

SRS (image)	Treatment	10	19.1 (3.8)	8	20.5 (5)	1.4 (-1.1, 3.9)	0.187	2.3 (-0.9, 5.5)	0.145
	Control	9	19.1 (3.7)	8	18.4 (3.1)	-0.9 (-3.4, 1.6)			
SRS (mental)	Treatment	10	20.4 (2.9)	8	19.6 (3.2)	-0.6 (-2.6, 1.4)	0.732	0.4 (-2.2, 3.0)	0.736
	Control	9	20.7 (3.2)	8	19.8 (3.6)	-1.1 (-3.0, 0.9)			
SRS (pain)	Treatment	10	20.9 (4.4)	8	22.1 (2.1)	1.2 (-1.8, 4.2)	0.264	2.3 (-0.7, 5.4)	0.122
	Control	9	20.9 (3.4)	8	19.8 (4.1)	-1.1 (-4.2, 1.9)			
SRS (satisfaction)	Treatment	10	6.4 (0.7)	8	6.4 (0.7)	-0.0 (-0.7, 0.7)	0.716	0.1 (-0.5, 0.7)	0.672
	Control	9	6.4 (0.7)	8	6.3 (0.5)	-0.2 (-0.9, 0.5)			
Visual Analog Pain Scale									
Pain, least last 24h	Treatment	10	0.6 (1.1)	8	0 (0)	-0.5 (-1.4, 0.3)	0.073	-0.9 (-1.9, 0.1)	0.083
	Control	9	0.3 (0.5)	8	0.9 (1.5)	0.5 (-0.3, 1.4)			
Pain, right now	Treatment	10	0.9 (1.3)	8	0.3 (0.5)	-0.6 (-2.0, 0.8)	0.238	-1.4 (-3.0, 0.1)	0.064
	Control	9	1.2 (1.5)	8	1.8 (2.1)	0.5 (-0.9, 1.9)			
Pain, worst last 24h	Treatment	10	2.4 (2.2)	8	1.1 (1.8)	-1.4 (-3.3, 0.6)	0.115	-1.9 (-3.9, 0.2)	0.072
	Control	9	2 (2.5)	8	2.9 (2.5)	0.8 (-1.2, 2.7)			
Pain, average	Treatment	10	1.3 (1.3)	8	0.5 (0.8)	-0.8 (-2.1, 0.4)	0.112	-1.4 (-2.8, 0.0)	0.057
	Control	9	1.2 (1.4)	8	1.8 (1.9)	0.6 (-0.7, 1.9)			

Table 3: Analysis of self-reported outcomes, health-related quality of life (SRS-22 total and subscales) and Visual Analog Pain Scale that includes two crossover patients after the main intervention.

		Baseline		Final		epeated Measures Analysis		Adjusted for Baseline	
Outcome	**Group**	**N**	**Mean (SD)**	**N**	**Mean (SD)**	**ChangeFinal – Baseline (95% CI)**	**Test equality of group changes,P-value**	**Final Adjusted Treatment-Control Difference-Mean (95% CI)**	**Test for Difference = 0 P-value**
Health-related quality of life									
SRS total	Treatment	12	85.1 (11.8)	10	89.1 (8.6)	4.0 (-3.1, 11.1)	.151	8.1(0.2, 16.1)	.045
	Control	9	84.2 (10.1)	8	80.9 (10.2)	-3.6(-11.7, 4.4)			
SRS (functional)	Treatment	12	18.3 (3.1)	10	19.1 (2.1)	0.8(-1.4, 3.0)	.437	2.0(-0.7, 4.7)	.139
	Control	9	17.1 (2.4)	8	16.8 (3.8)	-0.4(-2.9, 2.1)			
SRS (image)	Treatment	12	19.3 (3.5)	10	20.9 (4.5)	1.6(-0.5, 3.7)	.112	2.6(-0.3, 5.5)	.076
	Control	9	19.1 (3.7)	8	18.4 (3.1)	-0.9(-3.3, 1.5)			
SRS (mental)	Treatment	12	20.3 (2.7)	10	20.4 (3.3)	0.2(-1.7, 2.1)	.377	1.2(-1.5, 3.8)	.363
	Control	9	20.7 (3.2)	8	19.8 (3.6)	-1.0(-3.2, 1.1)			
SRS (pain)	Treatment	12	20.8 (4.4)	10	22.3 (2.1)	1.4(-1.1, 4.0)	.180	2.5(-0.2, 5.3)	.065
	Control	9	20.9 (3.4)	8	19.8 (4.1)	-1.1(-4.0, 1.8)			
SRS (satisfaction)	Treatment	12	6.4 (0.7)	10	6.4 (0.7)	-0.0(-0.6, 0.6)	.681	0.2(-0.4, 0.7)	.589
	Control	9	6.4 (0.7)	8	6.3 (0.5)	-0.2(-0.9, 0.5)			
Visual Analog Pain Scale									
Pain, least last 24h	Treatment	12	0.5 (1)	10	0 (0)	-0.4(-1.1, 0.3)	.068	-0.8(-1.7, 0.0)	.061
	Control	9	0.3 (0.5)	8	0.9 (1.5)	0.5(-0.3, 1.3)			
Pain, right now	Treatment	12	0.9 (1.2)	10	0.2 (0.4)	-0.7(-1.9, 0.5)	.171	-1.5(-2.9, -0.1)	.032
	Control	9	1.2 (1.5)	8	1.8 (2.1)	0.5(-0.8, 1.9)			
Pain, worst last 24h	Treatment	12	2.2 (2.1)	10	1.1 (1.7)	-1.1(-2.7, 0.5)	.120	-1.8(-3.6, 0.0)	(-3.6, 0.0)
	Control	9	2 (2.5)	8	2.9 (2.5)	0.8(-1.0, 2.6)			
Pain, average	Treatment	12	1.2 (1.3)	10	0.4 (0.7)	-0.7(-1.8, 0.3)	.095	-1.4(-2.6, -0.1)	.035
	Control	9	1.2 (1.4)	8	1.8 (1.9)	0.6(-0.6, 1.8)			

Largest Cobb angles and scoliometer measures did not show significant improvements in the treatment group compared to the control group (Table 4 & Table 5). When we categorized change in largest Cobb angle 33% (N=3) improved in the final measurement compared to 11% (N=1) for controls, and the frequency distribution was not different for the two groups (Fisher exact test p=.691). When crossovers were included 4 out of 11 (36%) improved (p=0.512) (Table 6).

Table 4: X-ray curvature (largest Cobb angle) and scoliometer outcomes.

		Baseline		Final		Adjusted for Baseline		Adjusted for Baseline	
Outcome	Treatment	N	Mean (SD)	N	Mean (SD)	Change Final – Baseline (95% CI)	Test equality of group changes, P-value	Final Adjusted Treatment-Control Difference Mean (95% CI)	Test for Difference = 0 P-value
Cobb Angle (largest curve)	Treatment	10	23.8 (5.9)	9	24.9 (14.4)	1.3 (-4.7, 7.2)	.780	-3.9 (-12.3, 4.5)	0.338
	Control	9	18.9 (3.1)	9	21.3 (6.3)	2.4 (-3.6, 8.4)			
Scoliometer	Treatment	10	7 (3.6)	8	6.5 (4.5)	-0.2 (-2.5, 2.0)	.727	0.5 (-2.5, 3.6)	0.709
	Control	8	7.4 (3.3)	7	6.7 (3.2)	-0.8 (-3.2, 1.6)			

Table 5: X-ray curvature (largest Cobb angle) and scoliometer outcomes when two crossover patients were included.

		Baseline		Final		Repeated Measures Analysis		Adjusted for Baseline	
Outcome	Treatment	N	Mean (SD)	N	Mean (SD)	Change Final – Baseline (95% CI) T	Test equality of group changes, P-value	Final Adjusted Treatment-Control Difference Mean (95% CI)	Test for Difference = 0 P-value
Cobb Angle (largest curve)	Treatment	12	23.8 (6.5)	11	25.3 (12.9)	1.6(-3.9, 7.1)	.836	-1.2(-9.8, 7.3)	.762
	Control	9	18.9 (3.1)	9	21.3 (6.3)	2.4(-3.7, 8.5)			
Scoliometer	Treatment	12	8.1 (4.4)	10	8.1 (5.2)	0.1(-1.9, 2.1)	.555	1.0(-1.9, 4.0)	.466
	Control	8	7.4 (3.3)	7	6.7 (3.2)	-0.8(-3.2, 1.6)			

Table 6: Change in largest Cobb angle for treatment and control participants. Frequency distributions were not different for treatment and control participants (Fisher exact test p=0.686).

Categorized change in largest Cobb angle	Treatment (N=9) N (column %)	Control (N=9) N (column %)
Improved (at least 6° smaller)	3 (33)	1 (11)
Stable (change ± 5°)	4 (44)	5 (56)
Worse (at least 6° larger)	2 (22)	3 (33)

X-ray curvature measurement results

Active treatment group:

a) 4 subjects who completed active treatment had significant and unusual decreases in their curvatures: 2 subjects had a -13° result, 1 subject had a -10° result, and 1 subject had a -9° result. (40%) One crossover subject was included.

(Figure 2- Figure 5)

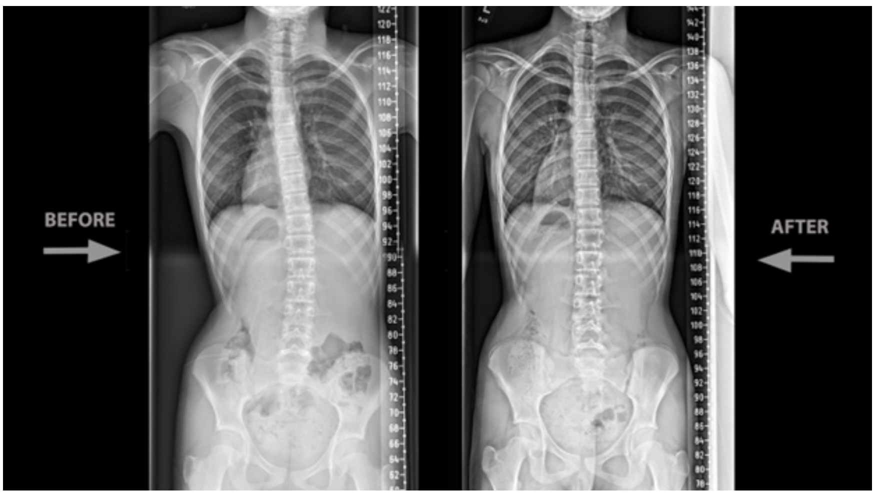


Figure 2a & 2b: Subject 3 age 12. Before: 15 degrees. After: 2 degrees: Result = -13 degrees.

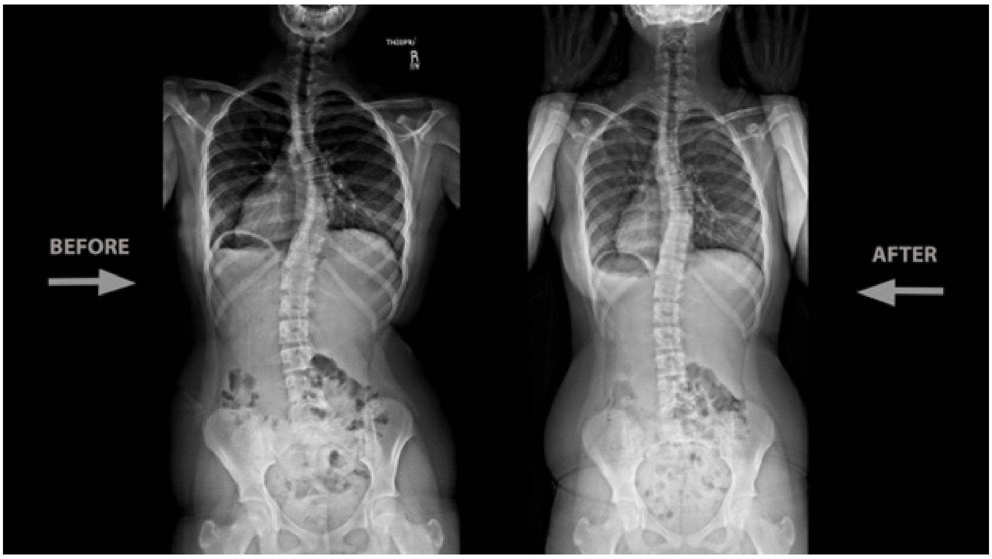


Figure 3a & 3b: Subject 20 age 13. Before: 33 degrees. After: 20 degrees: Result = -13 degrees.

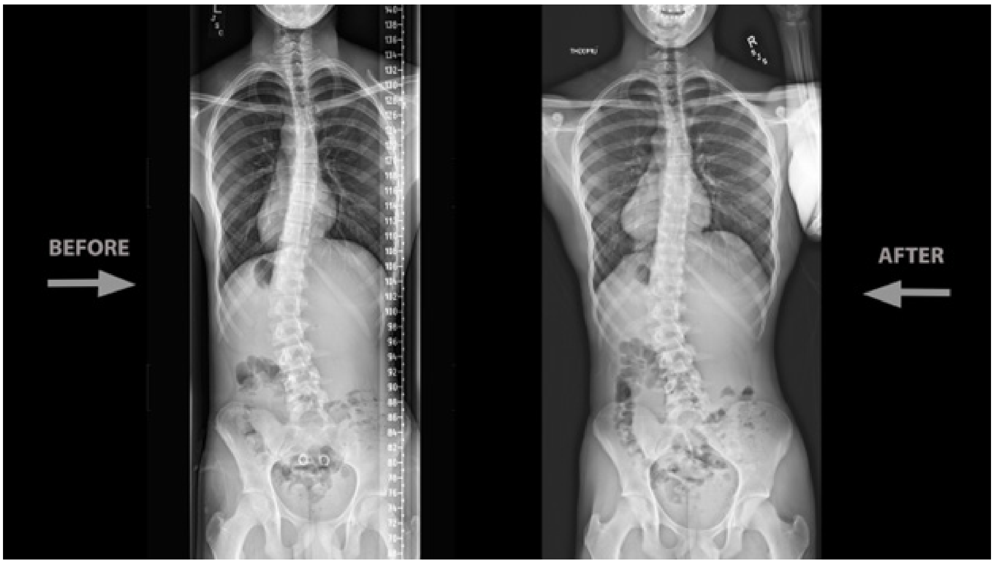


Figure 4a & 4b: Subject 18 age 13. Before: 17 degrees. After: 8 degrees. Result= -9 degrees.

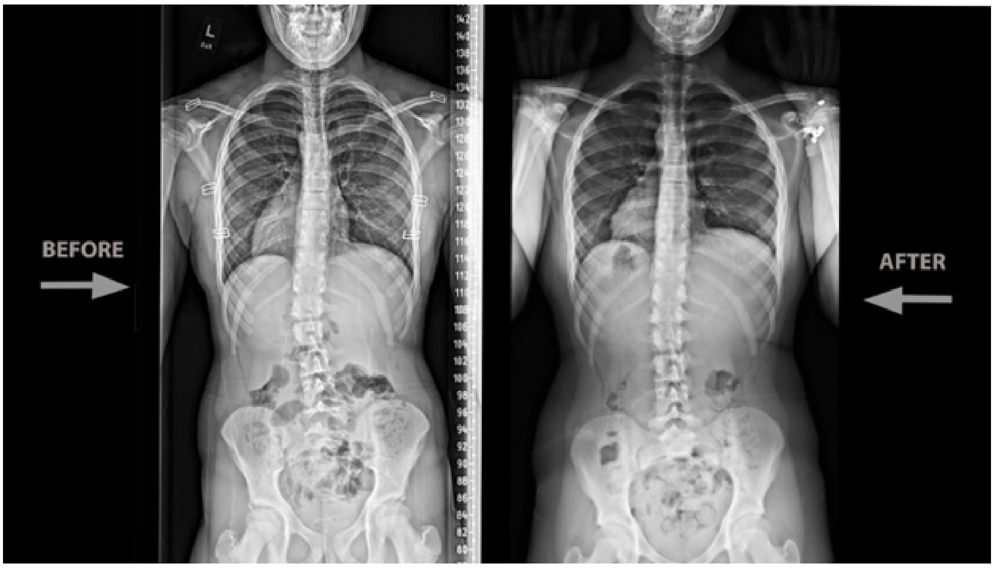


Figure 5a & 5b: Subject 18 age 13. Before: 17 degrees. After: 8 degrees. Result= -9 degrees.

b) 4 subjects who completed active treatment had curvatures that remained stable at the end of 6 months of care. (40%)

c) 2 subjects who completed active treatment had significant increases in their curvatures at the end of the 6 months of care: +15° (Both subjects wore their braces only 12 and 14 hours per day, and one had discontinued brace use in the last month prior to the final x-ray, and both subjects had atypical challenging patterns of curvature.) (20%) One crossover subject was included.

d) One subject dropped out half-way through, with only 3 months of care; had a follow-up x-ray taken 6 months after discontinuing active treatment, and 10 months after the initial x-rays, and her curvature increased +18°. Reason for discontinuing care: Subject needed time to improve schoolwork.

Control group

a) Subject 17 had a significant decrease of curvature: -7°, total of 11%.

b) Subjects 7, 12, 14, and 19 had curvatures that were stable over the 6 months of their participation for a total of 44% of total subjects.

c) Subject 5 had a change of curvature of +11°.

d) Subject 6 had a change of curvature of +6°.

e) Subject 16 had a change of curvature of +7°.

f) Subject 2 had a stable lumbar curvature of 15° but had a change of her thoracic curvature of +11°.

g) Subjects whose curvature increased total 44% of total subjects.

Assessing the importance of the unusual improvements in the 40% of subjects who completed active treatment: Schreiber et al. have recently provided an excellent summary of the research findings about the impact of Physiotherapeutic Scoliosis Specific Exercises (PSSE) on the progression of AIS.

"Monticone et al. in their long-term RCT found that PSSE consisting of active self-correction and task-oriented exercises consistent with Scientific Exercise Approach to Scoliosis (SEAS) [50,51] improved Cobb angles by 5.3° degrees at skeletal maturity in patients with AIS, while traditional exercises were associated with stable curves. [52] Kuru et al. in their 6-month long RCT [53] in patients with AIS concluded that Schroth PSSE improved the Cobb Angle by 2.5° in the supervised group, while the patients who were not supervised deteriorated by 3.3° degrees which was similar to controls (deteriorate by 3.1° degrees) receiving no treatment. Our RCT found that patients with AIS receiving Schroth PSSE for six months in conjunction with standard of care consisting of observation or bracing improved curves by 1.2°, while the controls receiving only standard of care deteriorated by 2.3°". Schreiber et al. [54] Schroth physiotherapeutic scoliosis-specific exercises for adolescent idiopathic scoliosis: how many patients require treatment to prevent one deterioration?- results from a randomized controlled trial- "SOSORT 2017 Award Winner". Scoliosis and Spinal Disorders (2017) 12:26.

While there are certainly outliers that improve more than these small but significant amounts, if the figures achieved in our small study: 2 subjects who improved by 13°, 1 subject who improved by 10°, and 1 subject who improved by 9° could be replicated in a larger RCT, for 40% of the participants undergoing active treatment as well as standard care, then we could make a significant contribution to future successful care of AIS. These unusual improvements may be attributed to the possibility that we may have identified fascial constriction as one of the multifactorial causes of the development of AIS and addressing a cause and not just trying to control a result may provide a very powerful intervention and contribute to reduction of the suffering caused by AIS.

Clinical Findings

It was possible to make systematic clinical observations during this study, because we had regular access to each subject every 2 weeks over the course of their 6 months of participation. Also, the research funding made it possible to provide each subject with necessary home exercise equipment, arch supports, and heel and ischial lifts. In usual clinical practice it is often not possible to provide all of these elements to each child so this research was a unique opportunity to make clinical observations under ideal conditions.

1) The Beighton Scale was used to assess each subject's ligamentous laxity at the initial examination visit. All of the subjects were categorized as having ligamentous laxity, and some were at or very close to the top of the Beighton Scale. Also, each subject has arches in the feet that significantly collapse upon weight-bearing (as distinct from having flat feet). This information was used to plan clinical care. For example, one of the cross-over subjects had a curvature that significantly increased during the period of her participation in the control group, and she entered the active treatment group with the highest curvature: 33°. She has Beighton Scale ligamentous laxity of 6/9, and she has very over-pronated ankles and collapsed arches. On this basis, she was offered weekly treatment rather than every 2 weeks. She completed the study with one of the unusual gains: Cobb Angles reduced to 20°, a reduction of 13°. Future researchers on AIS should measure ligamentous laxity, and they should observe the ubiquitous over-pronation and flattening of the arches upon weight-bearing. These characteristics of adolescents who develop scoliosis may be important to our understanding of the dynamics of the development of scoliosis (Table 7) (Figure 6a-6d).

Table 7: Measurements of ligamentous laxity in subjects selected to active treatment group.

Beighton Scores	
2 subjects	3/9
3 subjects	4/9
3 subjects	5/9
3 subjects	6/9
1 subject	8/9

Includes 2 subjects who did not complete Active Treatment and 2 subjects who crossed over after serving as Controls, and who completed Active Treatment.

2) Each abnormality in spinal curvature and paraspinal prominence appears to have a correlate in corresponding patterns of muscle tension imbalance and broader but intense patterns of

fascial constriction. The patterns were highly individualized and differed significantly from one subject to another. During the course of active treatment, each subject was re-evaluated on each visit. If there were indications that either the curvature or the paraspinal prominence was worsening rather than improving, the treating clinician examined to look for a direction of abnormal fascial pull that could contribute to the worsening, and the abnormalities found were then treated. Understanding the patterns of myofascial dysfunction was a developing process throughout the treatment of each subject. If treating clinicians are not looking for these complex patterns of myofascial dysfunction, they will not find them, so future researchers are encouraged to seek to develop the skills to find and treat such imbalances.

Figure 6a: Ligamentous laxity Subject 20.

Figure 6b: Subject 15..

Figure 6c: Subject 20 has arches.

Figure 6d: Subject 20's arches totally collapse when weight-bearing.

3) When the clinician comprehends the great tension in the fascial tissues, indicated by the intense but slow and persistent pull that is necessary to induce the fascial constriction to release, it would be surprising if the spine could grow straight. But if we do not look for the fascial constriction, we will have no idea about this force that appears to act on the spine. In future research, it will be important to see if there are ways to image the fascial constriction, and whether there are ways to measure the force required to release the fascia, to extrapolate the tensile strength of the forces acting upon the spine.

4) Treatment of myofascial and articular dysfunction as well as the use of arch supports and ischial lifts, when indicated, was sufficient to bring about balance of hip height seated and standing, in 9 out of the 10 subjects who completed 6 months of care. In the 9/10 cases, the hip height balance was maintained seated and standing even after the heel lifts and ischial lifts were removed. In the past, it had been hypothesized that individuals with a lower iliac crest on one side when seated had a small hemipelvis on that side. Muscle testing while seated and standing was used to monitor the balance of the pelvis and when to use and when to remove the lifts. (If the use of heel lifts and/or ischial lifts is based on trying to shift the tilt of the spine rather than using muscle testing to monitor balance of the iliac crests, there can be worsening because one possibility is that the spine will lean toward the lifted side.) Conclusion: distortion of the pelvis in AIS is likely usually functional, not structural. It would be very helpful if future researchers could employ both myofascial and articular aspects of treatment plus arch support and heel lifts and ischial lifts as necessary, along with strengthening of

any accompanying gluteus maximus weakness to see if they can replicate our findings.

5) There were recurrent and predictable patterns of joint dysfunction and muscle weakness that correlate with spinal curvature and paraspinal prominence. For example, in the typical right-sided rib hump or prominence, there is significant rib/spinal joint dysfunction in the interscapular region accompanied by right-sided weakness of the middle and lower trapezius muscles in many subjects. Intervention to improve joint dysfunction and strengthen these weak muscles can reduce protraction of the right scapula and the rib prominence may also decrease. The clinician can monitor on each visit to see if the improvements are sustained and can decide how to improve treatment or the subject's performance of exercises to restore improvements if they start to ebb during care.

6) Six out of the ten subjects who completed active care showed readily detectable worsening of their conditions after just two weeks of reduced wearing of their arch supports. The factors that worsened included: increased tension in the left medial hamstring muscle, increased twist of the pelvis with increased posterior flare of the sacrum on the left, recurrence of weakness of the left gluteus maximus muscle, recurrence of hip height imbalance: lower left iliac crest seated and/or standing, increased muscle tension and fascial constriction along the left iliolumbar portion of the quadratus lumborum and/or increased muscle tension and fascial constriction in the abdominal obliques, pulling the left rib cage down toward the left iliac crest. When these signs of worsening were observed, subjects were asked to think about what factor or factors had changed in the two-week interval between visits. They each stated that they had been wearing arch supports significantly less time per day during the time since their last visit. This was reversible when arch support use was increased again. Example: One subject had been attending public school, but her circumstances changed, and it was decided that it would be better for her to home school. Previously, she had put on her shoes at 7:30 or 8:00am, and for the first 2 weeks of home schooling, she put on her shoes with arch supports at 1:30 pm. There were clear signs that her condition worsened over the 2-week period. When she put on her shoes early in the morning again, her previous improvements came back. (It may be that the importance of the arch supports is related to the fact that the arches are the end of the fascial chains that extend up each inner calf and thigh to the psoas and diaphragm, and the ligamentous laxity in the feet creates repetitive strain to these fascial chains.)

7) Four of the ten subjects who completed active treatment and who were braced were able to wear their braces significantly more hours per day after fascial constriction was released and myofascial TrPs were also released. Besides addressing myofascial factors to decrease pain in AIS subjects, release of myofascial constriction in the areas most impacted by the spinal bracing resulted in marked increase of subjects' ability to tolerate bracing. (Example: Before her first treatment, one subject was only able to wear her brace for 90 minutes at a time due to pain. Her mother told me that she had heard one of her caregivers call her "non-compliant". Her area of pain correlated with the left side of her lumbar spine where the curvature was convex to the left. The brace was designed to put pressure on this same area. During her first treatment, trigger points and fascial constriction were released in the area of the left iliolumbar portion of the quadratus lumborum, and fascial constriction was released that had been pulling the left rib cage down toward the left iliac crest. When this subject returned for care two weeks later, she bounced into the treatment room. When asked how long she had been able to wear her brace, she stated that she was able to wear it for the full recommended 18 hours per day. Now she only had pain when wearing the brace in a car during a long drive. There are certainly other reasons for intolerance of the brace, but it would be helpful if other researchers would evaluate "non-compliant" subjects to determine whether there is a correlation between the location of the subject's pain, the area that is especially being stretched by the brace, and the area that has myofascial trigger points and fascial constriction. It may well be that compliance with brace use and successful completion of bracing would increase if myofascial dysfunctions were treated when necessary.

8) Rib hump or paraspinal prominence has long been thought to correlate well with degree of curvature. But in this study, we found that once treatment had been underway for several weeks, paraspinal prominence could markedly decrease while the curvature could worsen and vice versa: the curvature might appear to improve but the paraspinal prominence might worsen. A scoliometer was used on each visit to measure paraspinal prominence. While in some subjects, it appeared that the fascial constrictions or dynamics that appear to be involved promoting paraspinal prominence appear to be the same as the fascial dynamics that appear to be involved in promoting increase of Cobb angle, but in other subjects, the clinician had to identify fascial constriction coming from the opposite side of the torso. (Example: One subject had a lumbar curvature to the left and his greatest paraspinal prominence was also on the left. While the myofascial trigger points and fascial constriction in the area of the left iliolumbar portion of the quadratus lumborum were released and more space appeared to develop between the lumbar spine and the left iliac crest, the paraspinal prominence on the left increased from 12° to 17°. The clinician had to find the pull that appeared to be coming from the right front of the torso, that could twist the lumbar vertebrae and contribute to the left paraspinal prominence. When the clinician released the wrap around fascial tension around the right rib cage and anterolateral torso and into the right iliopsoas over the next 3 visits, the left paraspinal prominence reduced to 13°. This subject also was one of those who had unusual improvement of spinal curvature. His initial curvature measured 28° and his ending curvature reduced by 10° and he completed the study with a curvature that measured 18° (Figure 7a, 7b). It is important to recognize that there is often a counterbalancing pull of fascial constriction that may be secondary to a primary web of tension, but we have to discern and release the tensions on opposite sides of the torso in order not to cause worsening of the curvature or the paraspinal prominence, or perhaps both. In other words, we have to find the elements of the tension frame in order to safely treat fascial constriction involved in AIS. If we treat one area of pull or tension and fail to release a countering pull, this can cause worsening because the countering pull can now go to town without as much opposition. This understanding of the dynamics of the tension frame has been termed Biotensegrity.

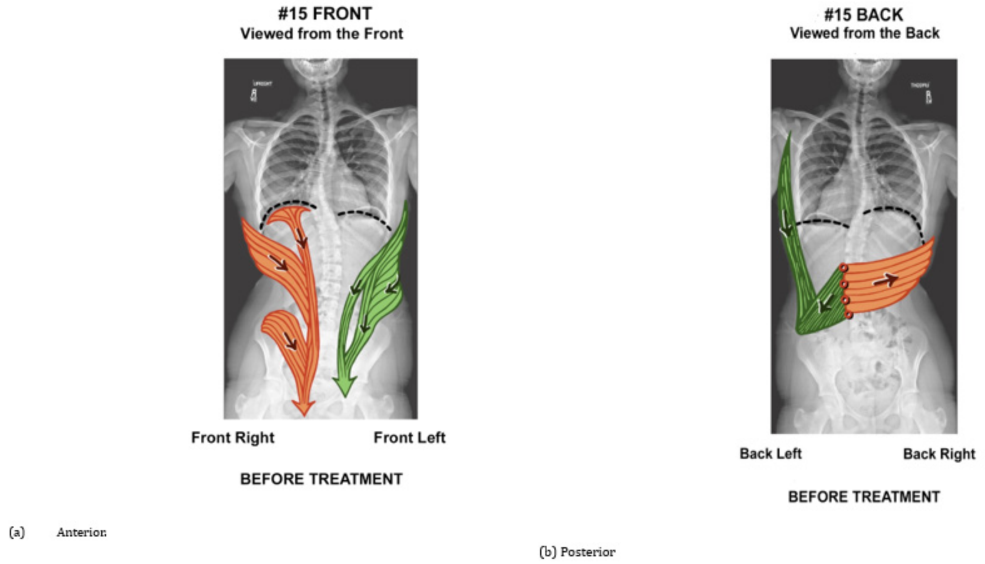


Figure 7: Subject 15: Unique pattern of fascial constriction. As fascial constriction along the left iliolumbar portion of the Quadratus lumborum released, left paraspinal prominence increased 12 degrees to 17 degrees, until release of right anterior fascial constriction wrapping around the rib cage and to the right Psoas muscle and groin area. The left paraspinal prominence then decreased to 13 degrees. Conclusion: Fascial tensions must be kept in balance.
Artwork by Ananda Sundari, Alchemy Arts

9) Fascial constriction in AIS is qualitatively different from fascial constriction in the average individual who has suffered a discrete injury or has constriction after surgery. In other words, the fascial constriction involves distortion that extends in ribbons or webs as opposed to lines or "trains". The original constrictions may have been in lines, but over time (years) these lines coalesce and interconnect and the constriction appears to spread to adjacent tissues. Recall that fibroblasts within the fascia have integrins on the cell wall that monitor strain on the tissues and can initiate transformation of genetic expression in the nucleus of the fibroblast and it becomes a myofibroblast and produces myofibrils that are contractile, and this factor may account for some of the spread of the fascial constriction. The different physics principles involved in biotensegrity may also play a role. The challenge for the clinician is to develop the ability to visualize the tension frame of fascial constriction in 3 dimensions, to be able to release muscle tension and facial constriction in a balanced way. Unless the clinician is alert to the dynamics of the tension frame, these powerful techniques could cause worsening of features of the scoliosis (Figure 8a, 8b).

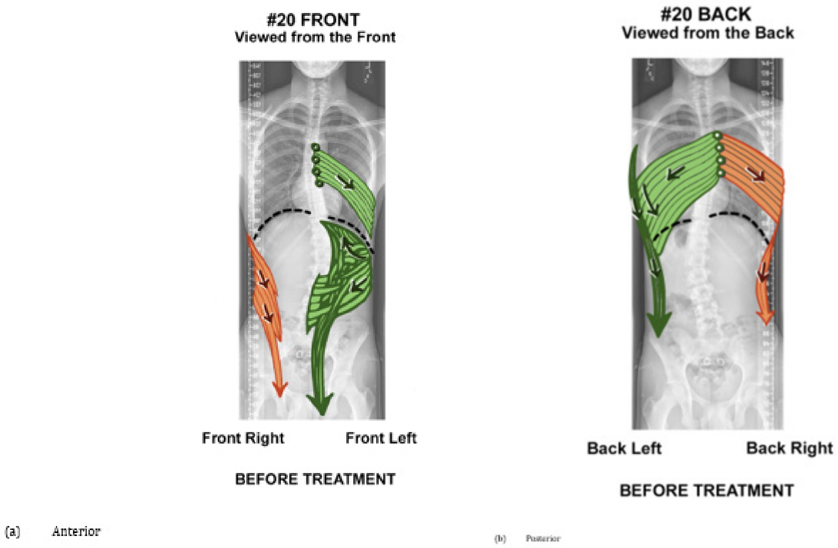


Figure 8: Subject 20: Unique pattern of fascial constriction. Unlike most children with left lumbar scoliotic deviation, there was little fascial constriction along the left iliolumbar portion of the Quadratus lumborum. Instead, the greatest fascial constriction was pulling around the left rib cage and along the left psoas down to the groin. Note the depressed diaphragm on the left. There is a fascial connection from the Psoas muscle to the diaphragm, so the intense left Psoas area fascial constriction tracks to both the left groin and up to the diaphragm, with intense pull on the rib cage and via this pull, tension on the spine that has likely participated in the development of her scoliosis.
Artwork by Ananda Sundari, Alchemy Arts

Discussion

Context and purpose

This study was designed to add an important element to the research regarding etiology and treatment of AIS: fascial constriction and myofascial dysfunction with related joint dysfunction. It is hoped that further research will confirm the importance of these elements and that this will contribute to better clinical improvements that may obviate the need for spinal surgery for some children.

Summary of findings

There were a couple of statistically significant findings from this study, when cross over subjects were included in the analysis. The trends were in a positive direction. The main limitation of the study was the small number of subjects recruited to the study due to the Covid pandemic. There were, however, highly unusual improvements in 40% of subjects receiving active treatment. Also, there were important clinical observations that may help future clinicians and researchers.

Other issues for further research

1) Scoliosis runs in some families and there are genetic findings that correlate with scoliosis. Our findings include a close correlation of ligamentous laxity with scoliosis, we may find that an aspect of the genetics of AIS pertains to connective tissue abnormalities. These genetics may or may not also correlate with decreased bone density. Fascia is an important constituent of bone, and the fascial bags are filled with hydroxyapatite form of calcium and other constituents. Also, the ligamentous laxity in the feet may contribute to repetitive strain at the end of the fascial chain in the feet that spreads up the kinetic chain to the inner thighs, the psoas, and diaphragm. As this strain creates abnormal tension in portions of the fascial system, these forces appear to strongly pull on the spine. The stability of the spine may also be affected by ligamentous laxity. Further research studies could explore the hypothesis that AIS may be a connective tissue disorder.

2) Abnormal proprioception has been identified as a contributor to the development of AIS, yet none of the AIS literature found to date has considered fascia as an organ of proprioception. (And, paradoxically, some AIS subjects are elite athletes.) But since the fascia are full of proprioceptive nerve endings, it may well be that fascial constriction or densification in AIS may account for abnormal proprioception as a factor in AIS. Further research could explore whether fascial constriction correlates with abnormal proprioception and whether fascial release could improve proprioception.

Conclusion

There has long been a prevailing theory that structural changes occurring in the spine are the primary process responsible for AIS and it is acknowledged that AIS is a multifactorial disorder.

Imbalances in muscles and distortions of the pelvis have been considered as compensations to the spinal curvature. Individualized exercise programs to balance strength of torso muscles have more recently been shown to reduce progression of AIS. But, if structural changes of the spine were primarily responsible for progression of AIS, then we would not have been able to achieve the unusual improvements in 40% of the subjects in our study (2 subjects with 13° improvements, 1 with 10° of improvement, and 1 with 9° of improvement, including one cross over subject who received active treatment). We did nothing to change the structure of the spine, and we have strong indications that fascial constriction may be a very influential factor in the development and progression of AIS. The fascial constriction is accompanied by myofascial dysfunction and related articular dysfunction and specific patterns of muscle weakness. We may well have identified major components of the multifactorial nature of the development of AIS. Hopefully, further exploration of myofascial dysfunction and related articular dysfunctions identified above will afford a productive course of future research that will contribute to better quality of life, better success of other existing treatments such as brace use, and reduced need for surgery.

Appendix: Active Intervention Treatment

The treatment of subjects in the active treatment group was designed to achieve certain functional and alignment goals:

GOAL: To balance the pelvis of subjects

This goal is based on the hypothesis that the spine can be straightened more easily or curvature can progress more slowly if the pelvis is balanced under the spine and provides balanced structural support to the spine. A complex set of complementary measures employed was ultimately very successful in achieving this goal: nine out of ten subjects in active treatment achieved balance of the pelvis. The measures employed include the following:

A. Arch supports with substantial support were provided to each subject, to correct over-pronation. They were well tolerated. Six of ten subjects wore the arch supports significantly less time per day than directed during a 2-week periods between visits, and this resulted in significant signs of worsening of balance of the pelvis. In these cases, the treating clinician then encouraged the subject to consistently use the arch supports more hours per day, and this resulted in resumption of clinical progress toward restoration of balance of the pelvis. (Signs monitored in addition to checking the balance of the iliac crests both seated and standing were: increased twist of the pelvis with increased posterior flare of the (usually left) sacrum; increased anterior rotation of the (usually right) ilium, increased tension of the medial hamstring on the same side as the sacral flaring, recurrence of gluteus maximus weakness on the same side as the sacral flaring, and increased muscle and fascial tension pulling the spine and/or rib cage down toward the pelvis on the side of the lower hip/the side of the increased sacral flaring.)

B. When necessary and for only part of the 6 months of active treatment, heel lifts were used to balance the pelvis standing and ischial lifts were used to balance the pelvis seated. (See section below: Use of Heel Lifts and Ischial Lifts)

C. Chiropractic side posture osseous manipulation was performed gently on the subjects to reduce an anteriorly rotated ilium (usually on the right) and to correct the posterior flare of the sacrum (usually on the left). Osteopathic Manipulation or Mobilization Therapy was also performed: Contract/relax (also termed

Muscle Energy) was used to correct an anteriorly misaligned ilium (generally on the right). Contract/relax was also used to reduce the posterior flare of the sacrum (generally on the left). Four subjects who had persistent or recurrent rotation of the pelvis with accompanying misalignments were instructed in daily osteopathic self-correction of their anterior ilium misalignments. (Note: Misalignments of the pelvis can produce apparent leg length differences standing, and an apparent small hemi-pelvis seated. Therefore, correction of joint dysfunction of the pelvis likely contributed to balance of the pelvis standing and seated, and use of the lifts was then discontinued.)

D. Gluteus maximus weakness, usually unilateral (left) and usually correlating with the side of posterior sacral flare, was addressed with one-sided partial bridge exercise. It appears that balanced strength of the gluteus maximus muscles encouraged stability of balance of the pelvis. (See Exercise Regimen below)

E. Other chiropractic and muscle energy manipulations were performed to address subluxations/dysfunctions that could affect balance of the pelvis. All of the subjects had very loose ligaments and some developed extremity subluxations such as functional impingement of the hip, and subtalar subluxation in ankle sprains. Corrections of these subluxations/dysfunctions likely contributed to balancing the pelvis.

GOAL: To reduce the paraspinal or rib prominence or reduce progression of the rib prominence

In some cases, subjects showed a significant reduction of rib prominence, but the results were not consistent. The fact that some subjects experienced such a reduction shows that rib deformity is not necessarily permanent. In some subjects the ribs appear to be like green sticks that deform in a way that correlates with other structural stresses. In these subjects, reduction of such structural stresses apparently reduced rib prominence. The following measures were used to reduce the structural stresses:

A. Anteriority manipulation at the rib/spinal joints was directed to the location of the rib hump or prominence. There was palpable rib/spinal dysfunction that correlated very well with the location of rib hump/prominence, usually involving 3-4 rib/spinal joints. To address the rib/spinal dysfunction, a gentle anteriority osseous maneuver was performed in a standing position with the subject's back against a wall and the treating doctor's contact hand in a vertical fist, behind the subject's back against the rib/spinal restriction, with the spinous processes aligned to fall in the palm of the hand, between the fingertips and the thumb. The doctor's other hand contacts the subject's crossed arms that are held across the chest. The treating doctor presses quickly from anterior to posterior and from inferior to superior (upward), using body weight to create an impulse directed at the location of the hand behind the subject's back.

NOTE: Osseous manipulation of the cervical spine was not performed as part of this study. Cervical joint dysfunction also was not a significant factor among these AIS subjects.

B. Subjects were instructed to lie on a small ball under the locations of rib/spinal dysfunction along the spine, in order to increase mobility at the restricted segments. (See Exercise Regimen below.)

C. Exercise was used to strengthen postural stabilization including scapular retraction. All of the subjects had unilateral weakness of middle and/or lower trapezius muscles that correlated well with the location of paraspinal rib cage prominence. There was also a tendency of the scapula to protract correlating with the location of rib cage prominence. Exercise to strengthen the middle and lower trapezius muscles was used to help stabilize the muscle and joint function in the area of rib cage prominence.

D. Several subjects developed anterior shoulder subluxations. These can affect scapulohumeral function and decrease scapular retraction, and this likely also contributes to rib prominence. Manipulation was performed to address these humerus subluxations and mobilization was used to decrease scapulohumeral protraction.

E. Muscle imbalance and fascial constriction is likely also a factor contributing to paraspinal rib cage prominence. If this constriction follows the line of the right Latissimus dorsi muscle, for example, this force will likely cause the lateral portion of the ribs to be pulled down toward the right ilium, and the ribs would tend to bow in the paraspinal region. In several cases, fascial constriction arose from psoas and anterior rib cage fascial constriction on one side of the torso that apparently caused the spine to rotate in that direction, contributing to contralateral paraspinal prominence. Treatment of fascial and muscle imbalance was therefore performed to release such forces that may contribute to rib cage or paraspinal deformity.

Muscle and fascial release techniques were used to address asymmetrical forces that likely contribute to spinal curvatures

Anyone who has not palpated and explored the degree of tensions playing on the adolescent spine in children who are developing scoliosis would have no idea of the intense strength of the tensile forces at play. A combination of myofascial release techniques was applied to myofascial dysfunctions in a series of body positions to address and relieve these powerful structural stresses. Techniques applied included pressing into the constricted muscles and fascia while stretching and elongating along lines of constriction, gentle percussion of trigger points and densifications of fascia encountered while stretching followed by stretching the tissues released, and Fascial Manipulation ® which involves cross fiber back and forth tissue manipulation. Note: Research has established normal lines of fascial tension including both vertical and spiral lines. Fascial constriction in scoliosis may involve constrictions along these lines. But in scoliosis, several lines in the same region often constrict, so there is a weblike pattern of tissue constriction that needs to be released in a number of different intersecting planes or directions to release the stresses on the spine. The challenge for the clinician is the need to think in 3 dimensions to visualize and work to release intersecting lines of fascial constriction that wrap around one side of the torso and a different pattern of fascial constriction that wraps around the front and back of the opposite side of the torso, creating a collapsing tension frame that acts upon the spine.

In order to decrease the distortion of the spine, it is safest to release these forces in as balanced a fashion as possible. (Artwork is used elsewhere in this article to depict the individual patterns of fascial constriction of these lines in 2 of the active treatment subjects.) The clinician can look at the latest x-rays to identify where the fascial constrictions might be present and pulling in specific directions. Then the clinician explores by palpating for patterns of pull or tension, whether the constrictions are in the expected locations Figure A1.

Figure A1: Notice how the lumbar spine pulls to the left, toward the left iliac crest (before). Using the impression about likely pull on the lumbar spine, you will want to explore whether there is muscle tension and fascial constriction posteriorly, often along the line of the iliolumbar portion of the quadratus lumborum. What will need to release to allow you to lift the mid-lumbar spine away from the iliac crest? And lift the lower rib cage away from the iliac crest? Usually, the muscle imbalance and fascial pull are posterolateral but if you can't find enough constriction there to correlate with the curvature, explore pull coming from the anterior torso, even wrapping from the psoas area and into the abdominal obliques. See how much the lumbar spine has released away from the left iliac crest (after).
Notice how the right rib cage pulls medially toward the lower lumbar spine (before). Using your impression of this pull, you will want to find the muscle tension and fascial constriction that would need to be released, to pull the lower rib cage up and out from the spine and make more space between the ribs on the right. Often you will need to find tensions in both the anterior and posterior torso that will need to be released to move the ribs outward, laterally, and upward. See how much the rib cage has shifted outward and upward in relation to the lumbar spine (after). Having a visual impression of what you are trying to accomplish will help you perform treatment more effectively.

A. Seated release of fascial and muscle imbalance: The subject is seated on a treatment table with legs extended straight in front. The clinician presses the subject's torso forward into flexion, gently but persistently pressing out the lines of greatest muscle and fascial tension. In most cases, the fascial constriction crossed over from the side of lumbar convexity to the opposite side at some point near the thoracic/lumbar spine juncture and the fascia were palpably constricted on that side of the spine at and around the location of thoracic/rib cage prominence. The clinician attempted to lengthen the abnormal tensions to decrease both vertical and rotational constrictions Figure A2(a) & (b).

Figure A2(a): The clinician leans into stretching the left side of the torso cephalad to lengthen the tensions.

Figure A2(b): The clinician feels for the place where the tension (usually) shifts to the right side of the torso, usually near the thoracolumbar juncture.

B. Side lying release of fascial and muscle imbalance: Subjects lie first on one side and then on the other. A pillow is used under the torso at the waist or the pelvis, while stretches and releases are performed. The up-side arm is extended up and forward and up and back, and the upside leg is extended up and forward and up and back, while the clinician presses on the lines of constriction, exploring the tensions pulling the ribs and shoulder down toward the hip and pelvis. The clinician seeks to lengthen the vertical and spiraling lines of tension and constriction. Techniques used to release abnormal tension included manual traction that is focused, slow, and sustained but not too forceful. Areas of tension or densification that do not readily release with the manual traction are addressed with gentle repetitive percussion or Fascial Manipulation ®, followed by additional manual traction. Procedures are repeated with the subject lying on the opposite side Figure A3(a) & (b).

Figure A3(a): With a pillow under the child's waist, the clinician releases anterior and posterior muscle and fascial tensions, to make more space between the right rib cage and the groin, and to increase the space between the ribs.

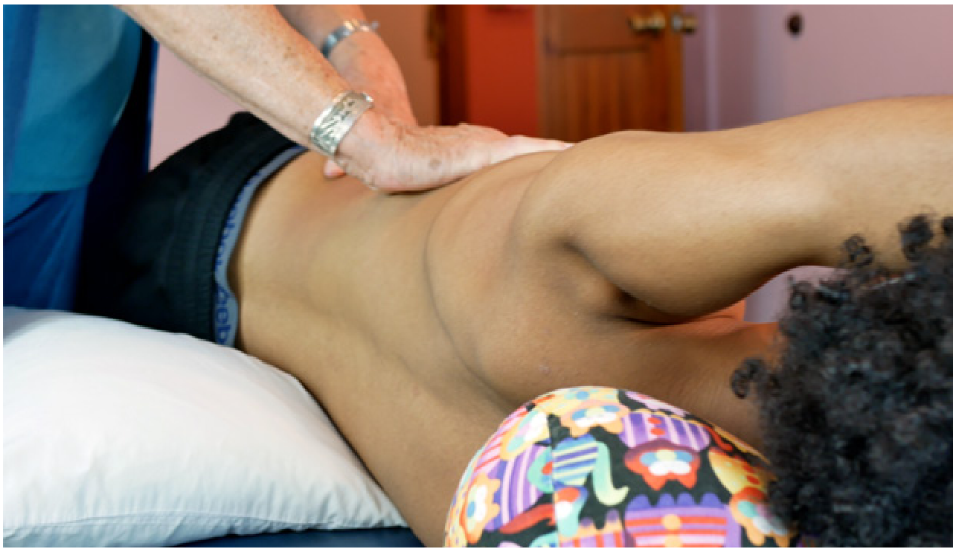


Figure A3(b): To press the lumbar spine away from the left iliac crest, the stretch starts by placing a pillow under the child's pelvis, and then the clinician stretches the lumbar spine down toward the table and away from the hip. Following the side-lying releases, hydrocollators are used to apply moist heat to the anterior and posterior and lateral torso to enhance the final stretch of the muscles and fascia while the child is prone.

C. Moist heat is applied for 10 minutes to the torso, front and back (two square hydrocollators under the back, and 4 cervical hydrocollators used to 1) wrap around from the scapula around the same side rib cage, around to the front including the upper abdomen, 2) same wrap on the opposite side of the torso, 3) wrap from the posterolateral waist around the lateral waist into the lower abdomen and anterior pelvis, 4) same wrap on the opposite side of the torso. The goal of the hydrocollator therapy is to slightly increase the temperature of the fascia based on research and clinical experience showing that this tends to increase fascial viscosity and compliance.

D. Prone release of fascial and muscle imbalance: After the tissues have been heated, the clinician reaches underneath the torso to release psoas tension. One hand is placed under the abdomen with the back of the hand flat on the treating table and the fingers curled up so that they created a fulcrum under tight spots along the psoas line from the diaphragm near the midline and then down toward the groin on each side. The other hand is used to internally rotate the thigh to bring the psoas tension over the fingertips, creating a tenting effect. The same procedure is used on the other side, contacting the psoas and internally rotating the other thigh. Then the clinician stands at the head of the treatment table or to one or the other side of the head of the table while lifting the ribs away from the hips, the scapulae away from the hips, still reaching somewhat around to the anterior torso. While holding the areas of restriction and leaning back, holding was prolonged for at least 10-15 seconds to wait for the fascia to release. The treating clinician consistently leans back, squatting with the knees bent and the buttocks dropped and unsupported by any stool or chair. The holding and pulling is sustained until the fascia start to elongate. Care is taken not to pull too hard, because fascia tends to increase resistance if it is pulled on too hard. A swath of muscle and fascial constriction can generally be identified as it appears to mechanically contribute to each distortion of the spine, and fascial release was focused on reducing these constrictions. Care is also taken to unwind the fascial tension in a balanced fashion, finding areas of constriction on one side of the torso that persist when the similar constrictions on the opposite side have released, until there is no longer significant unbalanced palpable fascial constriction Figure A4(a)- (c).

Figure A4(a): With the child prone, the clinician applies a slow sustained stretch to elongate the left side of the torso and lift the scapula away from the rib cage and hip.

Figure A4(b): With the child prone, the clinician reaches under the lower right torso at the waist and pulls the torso out of a twist while also slowly pulling the scapula away from the pelvis. Compare pull on each side of the torso, and perform further release of any remaining unbalanced tension.

Figure A4(c): Note that the tensile forces wrapping around the torso of the child with scoliosis are intense and it takes a slow sustained stretch for up to 8 to 15 seconds, and this tensile force supports a good portion of the clinician's body weight while she squats and leans back (no stool or chair, just perched in the air!) The tissues will start to elongate gradually.

How heel and ischial lifts are used to help balance the pelvis

When one iliac crest is lower than the other when standing, a 7mm heel lift is provided to each subject, to place in the shoe, under the arch support, on the side of the low hip. When one iliac crest is lower than the other when seated, an ischial lift is provided to be used under the low hip, to balance the pelvis seated. A suitable thick (3/8") magazine is provided to each subject for use when seated for longer periods of time: at home, in a car, and at school, etc. Resistive manual muscle testing is used to corroborate visual inspection and these ischial and heel supports are only prescribed if the muscle testing shows improved muscle function with the lift in place. (Pectoralis major and Latissimus dorsi muscle tests are convenient to use with the subject seated and standing. Muscle testing is performed on both sides.) When the visual inspection shows balanced hips and the muscle strength is good without the supports, use of the supports is discontinued. Occasionally, use of the lifts is re-instituted briefly, until balance is again achieved. Nine out of ten subjects achieved balance of the pelvis within a few months of starting care, and use of the lifts was no longer needed. One of the 10 subjects who completed the active care did not achieve balance. In addition, halfway through the 6 months, the lifts no longer helped muscle balance. The patient's left hip was low standing and seated, but her spine was deviating more and more to the left of midline in both the lumbar and thoracic portions. To continue to support the low hip would risk the circumstance that the spine would lean into the side of the support further, rather than returning more to midline. Muscle strength was better without the lifts than with the lifts, and use of the lifts was discontinued.

An exercise regimen is used to reinforce response to care

A. Each subject was provided with a ball that was a little smaller and softer than a tennis ball (like the ball one might throw for a dog). Each subject was shown how to lie on a mat or a rug on the floor with the small ball under the rib or paraspinal prominence, moving the ball up and down under the locations of most rib/spinal restriction/dysfunction, leaving the ball in place at each spinal level for ½ to 2 minutes until the restriction at each level appeared to ease, 1x/day.

B. Psoas stretches, lunges, on each side were performed on a bench or sofa or bed, 1-2 reps, 2x/day. The subject stood sideways to the bench and lifted the leg next to the bench to place it extending along the bench behind the subject while the subject bent the standing leg to drop the groin toward the bench, The arms were extended with elbows straightened, with the hands flat on the bench. Ending position: torso near vertical with the leg extended horizontally behind. This position is maintained for 8 to 10 seconds.

C. Reverse push-ups were performed in a corner 5-20 reps, 2x/day (with focus on using primarily the weaker side). The subject stood, leaning the back of the torso into the corner with the feet between 18" and 24" out form the corner. The subject was instructed to lift the torso out of the corner by approximating the scapulae. (Subjects were told that this is not an arm exercise.)

D. One-sided partial bridge to strengthen weak gluteus maximus (3-20 reps, 2x/day: Each subject was instructed in how to perform a partial bridge, and then was instructed to take the strong side out of the exercise by bending the leg on the strong side and drawing that bent leg toward the chest, holding it in place with one hand. The lift was performed only on the weak side. They were instructed to hold the lifted position, keeping the pelvis balanced horizontally for 2 seconds/each repetition. Subjects were instructed to discontinue the strengthening exercises as soon as they were not easily able to perform a controlled exercise (wobbling). Better to discontinue than to continue but use the wrong muscles. A couple of subjects who had trouble performing a one-sided exercise were instructed to perform a regular partial bridge to strengthen both sides, and they were subsequently graduated to the one-sided partial bridge after a few weeks of the bilateral form.

E. Partial hanging with feet on the floor was performed by holding onto the doorway hanging bar and allowing the torso to drop some by bending the knees, and then the subject was instructed to bow the body to one side and anterior, then to that same side and posterior, to the other side anterior, and to the other side posterior 2-5 minutes 2x/day. This pattern of stretching was selected to address both vertical and spiraling myofascial tensions and continue the progress made during treatment sessions. One subject was unable to perform the partial hanging because no matter how the exercise was altered, having her use her shoulders in different positions, her shoulders subluxated and were painful. She was given a different torso stretching exercise performed seated, bending forward and then leaning to each side.

F. Monitoring results of exercises: Results of exercises were monitored on each visit, and if muscles were not strengthening as expected, then the subject was observed while exercising and was coached to better perform the exercise to derive the desired improvements. If stretching did not seem to be providing the expected lengthening, subjects were observed and coached in performing the stretching exercises. Joint dysfunction in the interscapular area shifted cephalad or caudad sometimes, and when this occurred, the subject was shown the area of current greatest rib/spinal restriction, so that the lying on the ball exercise could be performed at the appropriate location. Subjects were provided with 2-week check-off tracking sheets, on which they marked their daily compliance with the prescribed exercises. These sheets were collected. Compliance was also readily monitored by seeing if subjects were attaining the desired results. Halfway through participation, one subject started performing sit-ups and dead lifts to get ready for tryouts for a high school sport team, but the muscles did not strengthen in a balanced way, and muscles that were already hypertonic apparently did most of the work, with the result that muscle imbalance increased, and there was apparent increase in paraspinal prominence and likely also in curvature. The subject was asked to discontinue this exercise, but front and back crawl swimming was offered as an alternative activity since swimming often contributes to balanced muscle strengthening rather than causing imbalance. This subject made excellent progress with the last 3 months of care, and this made up for the temporary lack or reversal of progress, and the end result was a 10° decrease in spinal curvature.

Appendix conclusion

The intervention detailed above was used in treating the Active Treatment Group. It is quite complex, and arose out of years of clinical experience, assessing factors that seemed to contribute to worsening of AIS curvatures and factors that seemed to decrease worsening of scoliotic curvatures. Hopefully others can replicate this intervention regimen and can assess its usefulness.

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