Spinopelvic alignment with SpineCor brace use in adolescent idiopathic scoliosis: An assessment

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Adolescent idiopathic scoliosis (AIS) affects 2–4% of adolescents, where females are at a 10-fold higher risk of curve progression than males (Home et al, 2014). AIS results in >600 000 physician visits a year (Ogilve, 2010), which creates a socioeconomic burden. AIS is a three-dimensional (3D) deformity of the spine, characterised by primary lordosis, secondary lateral curvature, and vertebral rotation (Schulte et al, 2008; Guo et al, 2012). These abnormal spinal curvatures interfere with normal spinal curvatures' function—keeping the head over the pelvis and acting as a shock-absorber through the spine by distributing mechanical forces during daily activities (Bernhardt, 2011). This in turn requires corrective torques to maintain balance (Eshragi et al, 2012). Although most adolescents with idiopathic scoliosis do not suffer from clinical symptoms, scoliosis progression can cause compromised respiratory functions and major cosmetic and psychological problems in some patients (Horne et al, 2014).

Bracing has been documented to be the most effective conservative treatment for stabilising the spine, preventing curve progression, and preserving spinal growth potentiality in patients with mild to moderate AIS (Wong and Liu, 2003; Weiss et al, 2005). However, the patient's acceptance to bracing—especially rigid bracing—still remains a matter of concern to most patients, which can ultimately affect treatment compliance and outcome (Wong et al, 2008). The main concern is that rigid braces need to be worn for many years until skeletal growth stops. This time is of extreme importance to adolescents as they are concerned with their external appearance; using braces detracts from this appearance. It can generate negative body image and cause poor self-esteem and, as a consequence, affect the psychological status of these patients (Olafsson et al, 1999; Sapountzi-Krepia et al, 2001). In addition, the compromised ventilation that the brace causes reduces one's physical comfort and sense of wellbeing. Finally, the use of rigid plastic bulky braces that encircle one's trunk interfere with one's mobility during daily living activities, and increases functional discomfort (Olafsson et al, 1999; Sapountzi-Krepia et al, 2001; Wong et al, 2008).

In an attempt to reduce the drawbacks of rigid braces, a dynamic flexible brace, called 'SpineCor', was developed by Coillard and Rivard in 1994 (Coillard et al, 2003). SpineCor is a dynamic, non-rigid harness that provides dynamic control of the shoulders, thorax, and pelvic girdles, restricting adverse movements. It corrects the deformity while preserving spinal mobility and growth (Wong et al, 2008; Szwed and Kolban, 2012).

SpineCor depends on the corrective movement principle rather than the three-point principle that is used by rigid braces for managing AIS (Coillard et al, 2007). Spinal correction is achieved through the transmission of de-rotational and correcting forces via a system of corrective bands (Szwed and Kolban, 2012).

An aspect that has not been studied yet is the effect of SpineCor bracing on sagittal plane spinal alignment in AIS. The frontal plane has long been the main plane of concern for assessing scoliosis (Patias et al, 2010), despite the fact that the sagittal plane is involved in both AIS initiation and progression.

AIS is initiated by a sagittal plane deformity, followed by a rotational deformity and finally by a frontal plane deformity (Weiss and Klein, 2006). The initial sagittal plane deformity evolves when there is disproportionate growth between the anterior and posterior columns of the spine during the pubertal growth stage, occurring mainly in AIS with thoracic hypokyphosis. This results in sagittal spinal malalignment, which causes bucking and spinal instability under self-gravity compression, which causes scoliosis development and progression (Ylikoski, 2005; Jiang et al, 2010). Moreover, the rate of curve progression is determined by the degree of the sagittal plane thoracic kyphosis. Curvatures with minor thoracic kyphosis are progressed at a higher rate than ones with major kyphosis (Ylikoski, 2005).

Pelvic alignment is intimately related to sagittal plane spinal alignment and balance (Chanplakorn et al, 2011; Roussouly and Pinheiro-Franco, 2011). With sagittal plane spinal malalignment, abnormal compensatory pelvic tilt is usually adopted to maintain an upright spine with efficient energy (Le Huec, 2011). Pelvic anteversion (reduced pelvic tilt angle) may cause sagittal plane spinal malalignment through bringing the apical region of the thoracic curve anterior to the axis of spinal column rotation and the axis of the hip joint. This may result in adverse biomechanical effects on the apical region, causing increased axial rotational instability and curve progression (Jiang et al, 2010). Both sagittal plane spinal malalignment and the consequent adopted pelvic posture contribute to AIS development and progression (Ylikoski, 2005). Thus, maintaining normal sagittal plane spinal alignment in AIS is important for the preservation of healthy posture (Newton et al, 2010).

With the lack of knowledge regarding the effect of SpineCor brace on sagittal plane spinopelvic alignment, this study was conducted in an attempt to add to the body of knowledge in this regard. The effect of the SpineCor brace on the kyphotic angle, lordotic angle and pelvic inclination in the sagittal plane and trunk imbalance in the frontal plane was assessed before and after a 6-month rehabilitation period.

METHODOLOGY

Participants

Nineteen patients with clinically and radiographically diagnosed thoracic AIS participated in the study. They were referred by an orthopaedist at an outpatient clinic who was informed of patient inclusion and exclusion criteria. They were randomly assigned into two groups; experimental (group 1, n=9) and control (group 2, n=10). Group 1 involved six females and three males, while group 2 involved seven females and three males. Their age ranged from 12–20 years, weight from 48–75 kg and height from 150–175 cm. All patients had a mild or moderate degree of scoliosis with a Cobb's angle of 20–40° and Risser sign >2. The SpineCor brace has been found to be effective in mild and moderate curves of scoliosis (Coillard et al, 2003). Its beneficial effects of preventing curve progression are evident with Cobb angles >20° and Risser sign 0–3.40.

Patients were excluded if they had any previous spinal surgery, any disorder that would interfere with maintaining an erect standing posture, such as cerebellar or inner ear disorders, any lower limb deformity that may interfere with the global posture, or a clinically diagnosed neuromuscular scoliosis.

Instrumentation

A 3D Formetric II system (Diers International GmbH, Schlangenbad, Germany) was used for spinopelvic alignment assessment. The system allows fast, contactless, non-invasive and radiation-free static 3D assessment of the spine, thorax and pelvic girdle (rasterstereography). Surface analysis is conducted using a computer where quantification of linear and angular postural parameters is allowed. The print-out of the system provides the concerned variables directly among others. Rasterstereography was found to be a reliable method of 3D radiation-free back surface analysis and spinal deformity reconstruction (Drerup and Hiergolzer, 1996). It provides reliable data in patients with AIS treated conservatively or surgically and having a Cobb angle of up to 80° (Hackneberg et al, 2003). Rasterstereography shows a good correlation with the Raimondi method (X-ray based method) for vertebral rotation assessment (Mangone et al, 2013). It has been suggested to replace radiographs in AIS long-term follow-ups (Schulte et al, 2008).

Standing anteroposterior and lateral X-ray views of the spine were used for assessing the degree of severity of scoliosis through measuring the Cobb angle. The angle was assessed by measuring the superior angle formed by two intersecting perpendicular lines drawn to the two lines that pass parallel to the superior and inferior surfaces of the most superiorly tilted and most inferiorly tilted vertebrae to the concave side of the curve (Kim et al, 2010).

A SpineCor brace was used by group 1 to test its effect on the spinopelvic alignment. It is a flexible brace that provides progressive correction of idiopathic scoliosis of a Cobb angle of 15° and more (Christine et al, 2008). It preserves normal body movement and growth and allows normal activities of daily living. It is worn comfortably and easily under clothes. It consists of two sections. The first section consists of the pelvic base, crotch bands and thigh bands. This section acts as an anchoring point and support for the actions applied by the corrective elastic bands to the patient's trunk. The second section consists of a bolero and corrective elastic bands. This is the part designed to correct the scoliosis. The fitting of the corrective bands is specific for each patient and depends on the type and direction of curve. Corrective forces were increased gradually over the 6-month period after subsequent re-evaluation to ensure a stretching effect. For hygienic and comfort reasons, patients were advised to keep the brace clean as much as possible and to wear a cotton bodysuit under the brace.

Procedures

Initially, each patient was given an orientation session about the nature of the study and its aims. A written informed consent form was obtained from all patients' parents before starting the study, which was approved by the Ethical Committee of the Faculty of Physical Therapy, Cairo University. All patients were assessed for the dependent variables before and after a 6-month period, during which both groups received a rehabilitation exercise programme in the form of stretching and strengthening exercises, while group 1 also used the SpineCor brace.

To assess the spinal curvatures, the patient's whole back was kept bare and the hair bound up. He/she stood in front of a black background screen at a distance of 2 meters from the Formetric II system projector. His/her position was adjusted so that the trunk region was viewed in the centre of the control monitor.

A mark was drawn on the floor to ensure proper positioning of the patient. After proper positioning, the system was ready for image capture. The patient was asked to breathe normally, then to hold their breath while the image was captured. Three captures were performed and an average measurement was recorded.

At baseline and before the SpineCor brace application for group 1, the patient's posture was evaluated. The patient was asked to stand with bare feet and light clothes on a flat surface. The type and direction of scoliosis were detected. The pelvic base of the SpineCor was applied first as it acts as an anchoring point and a support for the action applied to the patient's trunk by the corrective elastic bands. Then, a corrective detorsion movement was performed between the thorax and shoulder girdle; the thorax was brought counterclockwise and the shoulders clockwise. Then, the bolero was put on, together with the corrective elastic bands that are designed to correct the scoliotic curve. All patients and their parents were taught how to manipulate the brace, how to perform their specific corrective movements and how to correctly fit the brace while maintaining an optimal corrective movement position. They were instructed to wear the SpineCor for 20 hours per day for 6 months so that the free 4 hours are taken in two or more intervals during the least active part of the day. They were instructed to wear the brace while sleeping (Christine et al, 2008).

The rehabilitation exercise programme (Kisner and Colby, 1990) was conducted for both groups. It involved both stretching and strengthening exercises. The tight back muscles on the concave side of scoliosis, together with both hamstrings, were stretched and the elongated back muscles on the convex side were strengthened. This was in addition to strengthening the trunk muscles that are necessary for postural control and trunk stability. Exercises were conducted three times a week for the whole 6-month period.

Data and statistical analysis

A pre-test post-test control group design was used in this study. The tested parameters were assessed before and after the 6-month rehabilitation period in both groups. Three parameters were tested in the sagittal plane and one in the frontal plane. The sagittal plane parameters were thoracic kyphosis, lumbar lordosis and pelvic inclination. The frontal plane parameter was trunk imbalance. The maximum kyphotic angle was recorded in the current study; it was measured as the angle between the upper inflection point near the vertebra prominence (C7 spinous process) and the thoracolumbar inflection point. Similarly, the maximum lordotic angle was recorded and it was defined by the thoracolumbar inflection point and the lumbo-sacral inflection point near the midpoint of the two pelvic dimples. Pelvic inclination was measured as the mean vertical torsion of the two surface normals (or the tangential planes) on the right and left dimples, where a positive pelvic inclination denotes a mean vertical component upwards and a negative inclination, a mean vertical component downwards. Finally, trunk imbalance refers to the lateral deviation of the vertebrae prominence from the midpoint of the two pelvic dimples. It is measured in millimetres and degrees. A positive value means a shift to the right, and a negative value a shift to the left. A printout of the measured variables was provided by the Formetric II system directly.

Data were initially screened for normality and homogeneity of variance assumptions. This exploration was done as a prerequisite for parametric analysis. Normality assumption was tested through examining for the presence of significant normality tests, skewness and kurtosis. Once data were found not to violate both assumptions, parametric analysis was conducted. The statistical package for social sciences (SPSS. Inc, Chicago, IL) version 17 was used for statistical analysis.

Two by two mixed design multivariate analysis of variance (MANOVA) was conducted to compare both groups' 'between-subject effect' at each of the pre-test and post-test conditions and between the pre-test and post-test conditions the 'within-subject effect' for each group for the four tested variables. This is in addition to testing for the interaction effects between both independent variables. The alpha level of significance was set at 0.05.

RESULTS

Descriptive statistics revealed that the mean ± standard deviation (SD) age, weight and height were 16.89 ± 2.15 vs 15.3 ± 2.5 years, 59.78 ± 6.85 vs 62.5 ± 8.33 kg and 162.78 ± 5.76 vs 159 ± 5.72 cm for group 1 vs group 2. The unpaired t-tests revealed that there were no significant differences ($P>0.05$) between both groups for the age, weight, and height. On another regard, the two by two mixed design MANOVA indicated that the mean values for the thoracic kyphotic angle, lumbar lordotic angle, pelvic inclination and trunk imbalance decreased significantly ($P<0.05$) after the 6-month rehabilitation period compared with the values at the start of the study.

Moreover, the mean value for the thoracic kyphotic angle decreased significantly ($P<0.05$) in group 1 compared with group 2 after the 6-month period with no significant differences ($P>0.05$) found for the remaining variables. *Tables 1* to *3* present the descriptive statistics and multiple pairwise comparison tests for the tested variables.

DISCUSSION

Although the SpineCor seems to be more favourable than rigid braces to avoid the consequences of rigid brace use, there still remains a great controversy about its effectiveness (Coillard et al, 2003; Weiss et al, 2005; Coillard et al, 2007; Wong et al, 2008). The SpineCor brace was found to significantly reduce posterior rib hump, pectoral and hamstring muscle contractures and lumbar prominence, leading to clinical posture improvement and curve stabilisation as measured by the Cobb angle (Plewka, et al, 2013). It has the ability of stopping curve progression in about 60% of patients with AIS (Coillard et al, 2007), correcting the curve in 48%, and stabilising the curve in 28% (Szwed and Kolban, 2012). On the other hand, it was found that the SpineCor had a significantly less survival rate than the rigid brace as indicated by a prospective randomised controlled study with a mean follow-up of 45 months at skeletal maturity (Wong et al, 2008). The survival rate refers to the percentage of patients who did not show documented curve progression over the 45 months and completed the use of their initial treatment protocol over this time period.

In addition, SpineCor was found to be less effective than rigid braces (Weiss et al, 2005; Wong et al, 2008). However, it should be noted that although rigid braces, Milwaukee braces specifically, were reported to provide lasting reduction in the degree of curvature (Edmonsson and Morris, 1977), subsequent studies with longer follow-up did not show these findings (Noonan et al, 1996). It was found that after rigid brace removal, the curve that was previously corrected by the end of brace use tended to increase once again towards the pre-treatment degree. This great controversy highlights the need for additional investigations of aspects of SpineCor effectiveness.

In the same context, sagittal plane spinal alignment was not only found to affect scoliosis development and progression, but to affect the correctability of the deformity in the frontal plane as well.

Although the sagittal plane deformity is the stiffest component of the 3D deformity and consequently the least correctable, there is evidence that correction forces applied in the sagittal plane are capable of stabilising and even correcting the deformity in the frontal plane (van Loon et al, 2008). Thus, awareness of sagittal plane spinal balance is necessary to achieve optimum outcomes, avoid future complications (Schmitz et al, 2005) and gain long-term patient satisfaction (Dimar et al, 2008).

The findings of the current study revealed a significant reduction in the mean value of the thoracic kyphotic angle in group 1 compared with group 2 after the 6-month rehabilitation period. The reduced kyphotic angle indicates that the SpineCor brace has a hypokyphotic effect on the sagittal plane spinal alignment in the short term. Based on the corrective movement principle stated by Coillard et al (2002) corrective band adjustment allows transmission of posteriorly directed forces across the trunk which may provide a stretching effect to the anterior chest wall muscles favouring extension and retraction. Extension forces applied on the thoracic cage were previously suggested to correct unhealthy standing and sitting postures as kyphosis and trunk tilt in adolescents (Jiang et al, 2010).

The thoracic hypokyphotic effect of bracing has long been reported as a side effect of brace treatment that may be associated with pulmonary function impairment (Jiang et al, 2010; Courvoisier et al, 2013). Attention should be directed to the fact that the hypokyphotic effect of bracing should not be considered an absolute side effect as the studied samples may differ. For instance, the hypokyphotic

Table 1. Descriptive statistics of the measured spinopelvic alignment parameters in the sagittal and frontal planes

	Tested group	Pre Mean ± SD	Available national data
Trunk imbalance (mm)	Group 1	14.41 ± 9.42	9.89 ± 7.67
	Group 2	9.76 ± 4.77	5.74 ± 2.19
Pelvic inclination (°)	Group 1	19.5 ± 12.46	15 ± 11.05
	Group 2	24.07 ± 8.19	20.04 ± 9.15
Kyphotic angle (°)	Group 1	44.3 ± 4.34	35.64 ± 6.11
	Group 2	48.02 ± 9.18	44.68 ± 8.92
Lordotic angle (°)	Group I	37.24 ± 15.94	30.44 ± 14.45
	Group 2	42.22 ± 11.09	38.72 ± 11.16

Group 1: experimental group (with brace); Group 2: control group (without brace)

Table 2. Descriptive statistics of the measured spinopelvic alignment parameters in the sagittal and frontal planes

						95% Confidence interval for difference	
Measure	Tested group	(I) Time	(J) Time	Mean difference (I - J)	Significance	Lower limit	Upper limit
Trunk imbalance (mm)	Group 1	Pre	Post	4.52	0.001*	2.19	6.86
	Group 2	Pre	Post	4.02	0.001*	1.8	6.24
Pelvic inclination (°)	Group 1	Pre	Post	4.5	0.001*	2.02	6.99
	Group 2	Pre	Post	4.03	0.002*	1.67	6.39
Kyphotic angle (°)	Group 1	Pre	Post	8.66	0.000*	5.18	12.13
	Group 2	Pre	Post	3.34	0.047*	0.04	6.64
Lordotic angle (°)	Group 1	Pre	Post	6.8	0.000*	4.15	9.45
	Group 2	Pre	Post	3.5	0.009*	0.99	6.01

*Group 1: experimental group (with brace); Group 2: control group (without brace); *significant at P<0.05*

Table 3. Comparison between the experimental and control groups for the measured spinopelvic alignment parameters in the pre-test and post-test conditions

						95% Confidence interval for difference	
Measure	Tested group	(I) Time	(J) Time	Mean Difference (I - J)	Significance	Lower limit	Upper limit
Trunk imbalance (mm)	Pre	Group 1	Group 2	4.65	0.185	-2.46	11.76
	Post	Group 1	Group 2	4.15	0.119	-1.18	9.47
Pelvic inclination (°)	Pre	Group 1	Group 2	-4.57	0.353	-14.67	5.53
	Post	Group 1	Group 2	-5.04	0.292	-14.82	4.74
Kyphotic angle (°)	Pre	Group 1	Group 2	-3.72	0.284	-10.81	3.37
	Post	Group 1	Group 2	-9.04	0.021*	-16.52	-1.55
Lordotic angle (°)	Pre	Group 1	Group 2	-4.98	0.437	-18.15	8.2
	Post	Group 1	Group 2	-8.28	0.178	-20.7	4.15

*Group 1: experimental group (with brace); Group 2: control group (without brace); *significant at P<0.05*

effect of the SpineCor brace recorded in our study could be considered as a beneficial effect as our studied patients had initial hyperkyphotic thoracic curve (>40°), and consequently had a straightening beneficial effect. However, Jiang et al (2010) and Courvoisier et al (2013) examined patients with initial hypokyphotic thoracic curve and the use of the brace reduced the kyphosis further. Thoracic kyphosis curvatures of >40° are considered hyperkyphotic according to Lenke's categorisation of idiopathic scoliosis (Lenke et al, 2001). Lenke and colleagies paid significant attention to sagittal plane alignment in this classification as opposed to previous classifications (King et al, 1983). Our finding agrees with the recommendation of using braces in treating hyperkyphosis in skeletally immature patients with kyphotic deformities of 40–45° or greater (Lonestein and Winter, 1995).

SpineCor use could be beneficial in improving right and left lateral reach in patients with hyperkyphosis. Patients with hyperkyphosis have significantly smaller reach distance compared with healthy individuals as assessed using functional reach tests. The rigidity of the spine in lateral bending may account for this difference (Eshraghi et al, 2012). The impairment in functional reach might be associated with the imbalance between the supporting anterior and posterior soft tissues and musculature (Lewis and Valentine, 2010). Reach distance is employed for assessing the ability to control balance and is related to the ability to perform functional tasks and the risk of falling (Lin and Liao, 2011). The effect of bracing in improving hyperkyphosis during scoliosis management was previously reported by Muller et al (2011).

Despite the different tested braces, our reported hypokyphotic effect of SpineCor brace use is additionally consistent with the finding reported by Schmitz et al (2005). They examined the effect of the Chêneau brace on spinal profile in AIS using magnetic resonance examination. They suggested that the correction of the deformity was achieved by the application of postero-lateral force to the spine, leading to flattening of thoracic curves. The hypokyphotic effect was confirmed furthermore by Labelle et al (1996) and Korovessis et al (2000), who used the Boston brace and the thoraco-lumbosacral orthosis respectively.

On the contrary, our findings revealed no significant differences between both groups for the lumbar lordotic angle, pelvic inclination and trunk imbalance. This might be attributed to the construction of the SpineCor brace itself. The pelvic part acted as an anchoring point and support for the corrective actions applied by the corrective elastic bands of the bolero part, which mainly emphasise the thoracic region.

The within-subject effect revealed significant decreases in all tested variables (thoracic kyphotic angle, lumbar lordotic angle, pelvic inclination, and trunk imbalance) after the 6-month rehabilitation period in both groups. The rehabilitation exercise programme conducted for both groups could provide an explanation for the obtained beneficial effects. The conducted stretching and strengthening exercises might have increased neuromuscular control and spinal stability, and assisted in biomechanical reduction of postural collapse, as previously reported (Weiss et al 2003). Additional improvement in spinal stability, antigravity muscle strength, balance and co-ordination were gained following active self-correction exercises, as indicated by Romano et al (2006) and Romano and Zaina (2007).

Improvement might have been added furthermore through the use of the SpineCor brace in group 1. The SpineCor brace was developed to provide active corrective movements rather than passive forces (Zaina et al, 2010). The corrective movements provided by the SpineCor brace provide the opportunity to maintain neuromuscular system integrity as well as re-educate the neuromuscular pattern through active bio-feedback (Coillard et al, 2003). Active mechanical biofeedback therapy is allowed through the adjustment of the four corrective elastic bands of this dynamic harness. Moreover, a counter-rotatory pressure was imposed on the convex side of the curve through the bolero, which may counter curve progression and allow more movement on the concave side.

Limitations

This study is limited by the small sample size that may result in type 2 error. The lack of long-term follow-up, no documentation of the length of time bracing was used, nor how often exercises were completed by each participant, and not assessing for the patients' perceived satisfaction and self-image are also limitations.

CONCLUSIONS

The SpineCor brace with exercise as well as exercise alone comparing pre to post test were beneficial in reducing thoracic hyperkyphosis, lumbar lordosis, pelvic inclination as well as trunk imbalance in the short term, but comparing between groups, only the SpineCor brace with exercise improved thoracic hyperkyposis.

Thus, the SpineCor brace with exercise or exercise alone can be used in treating AIS by reducing spinopelvic alignment deterioration in both the sagittal and frontal planes. **IJTR**

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Bernhardt M (2011) Normal spinal anatomy: normal sagittal plane alignment. In: Bridwell KH, DeWald RL, eds. *The Textbook of Spinal Surgery*.Philadelphia, Lippincott-Raven: 185–90

Chanplakorn P, Wongsak S, Woratanarat P, Wajanavisit W, Laohacharoensombat W (2011) Lumbopelvic alignment on standing lateral radiograph of adult volunteers and the classification in the sagittal alignment of lumbar spine. *Eur Spine J* **20**(5): 706–12. doi: 10.1007/s00586-010-1626-0

Christine C, Alin C, Rivard CH (2008) Treatment of early adolescent idiopathic scoliosis using the SpineCor system. *Stud Health Technol Inform* **135**: 341–55

Coillard C, Leroux MA, Badeaux J, Rivard CH (2002) Spinecor: a new therapeutic approach for idiopathic scoliosis. *Stud Health Technol Inform* **88**: 215–17

Coillard C, Leroux MA, Zabjek KF, Rivard CH (2003) SpineCor—a non-rigid brace for the treatment of idiopathic scoliosis: post-treatment results. *Eur Spine J* **12**(2): 141–48. doi: 10.1007/s00586-002-0467-x

Coillard C, Vachon V, Circo AB, Beausejour M, Rivard CH (2007) Effectiveness of the SpineCor brace based on the new standardized criteria proposed by the Scoliosis Research Society for adolescent idiopathic scoliosis. *J Pediatr Orthop* **27**(4): 375–79. doi: 10.1097/01.bpb.0000271330.64234.db

Courvoisier A, Drevelle X, Vialle R, Dubousset J, Skalli W (2013) 3D analysis of brace treatment in idiopathic scoliosis. *Eur Spine J* **22**(11): 2449–55. doi: 10.1007/s00586-013-2881-7

Dimar JR, Carreon LY, Labelle H et al (2008) Intra- and inter-observer reliability of determining radiographic sagittal parameters of the spine and pelvis using a manual and a computer-assisted methods. *Eur Spine J* **17**(10): 1373–79. doi: 10.1007/s00586-008-0755-1

Drerup B, Hierholzer E (1996) Assessment of scoliotic deformity from back shape asymmetry using an improved mathematical model. *Clin Biomech* **11**(7): 376–83. doi: 10.1016/0268-0033(96)00025-3

Edmonsson AS, Morris JT (1977) Follow-up study of Milwaukee brace treatment in patients with idiopathic scoliosis. *Clin Orthop Relat Res* **126**: 58–61. doi: 10.1097/00003086-197707000-00008

Eshraghi A, Maroufi N, Sanjari M (2012) Effect of Milwakee brace on static and dynamic balance of female hyperkyphotic adolescents. *Prosthet Orthot Int* **37**(1): 76–84. doi: 10.1177/0309364612448805

Guo J, Liu Z, Lv F et al (2012) Pelvic tilt and trunk inclination: new predictive factors in curve progression during the Milwaukee bracing for adolescent idiopathic scoliosis. *Eur Spine J* **21**: 2050–8. doi: 10.1007/s00586-012-2409-6

Hackenberg L, Hierholzer E, Potzl W, Gotze C, Liljenqvist U (2003) Rasterstereographic back shape analysis in idiopathic scoliosis after anterior correction and fusion. *Clin Biomech* **18**(1): 1–8. doi: 10.1097/00003086-197707000-00008

Horne JP, Flannery R, Usman S (2014) Adolescent idiopathic scoliosis: diagnosis and management. *Am Fam Physician* **89**(3): 193–8

Jiang J, Qiu Y, Mao S, Zhao Q, Qian B, Feng Zhu (2010) The influence of elastic orthotic belt on sagittal profile in adolescent idiopathic thoracic scoliosis: a comparative radiographic study with Milwaukee brace. *BMC Musculoskelet Disord* **11**: 219. doi: 10.1186/1471-2474-11-219

Kim H, Kim HS, Moon ES et al (2010) Scoliosis imaging: what radiologists should know. *Radiographics* **30**(7): 1823–42. doi: 10.1148/rg.307105061

King HA, Moe JH, Bradford DS, Winter RB (1983) The selection of fusion levels in thoracic idiopathic scoliosis. *J Bone Joint Surg Am* **65**(9): 1302–13. doi: 10.2106/00004623-198365090-00012

Kisner C, Colby LA (1990) Therapeutic Exercise Foundations and Techniques: Specific Exercises for Treatment of Scoliosis. 2nd edn. F.A. Davis Company, Philadelphia

Korovessis P, Kyrkos C, Piperos G, Soucacos PN (2000) Effects of thoracolumbosacral orthosis on spinal deformities, trunk asymmetry and frontal lower rib cage in adolescent idiopathic scoliosis. *Spine* **25**(16): 2064–71. doi: 10.1097/00007632-200008150-00010

Labelle H, Dansereau J, Bellefleur C,Poitras B (1996) Three-dimensional effect of the Boston brace on the thoracic spine and rib cage. *Spine (Phila Pa 1976)* **21**(1): 59–64. doi: 10.1097/00007632-199601010-00013

Le Huec JC, Aunoble S, Philippe L, Nicolas P (2011) Pelvic parameters: origin and significance. *Eur Spine J* **20**(Suppl 5): 564–71. doi: 10.1007/s00586-011-1940-1

Lenke LG, Betz RR, Harms J et al (2001) Adolescent idiopathic scoliosis. A new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg* **83A**(8): 1169–81

Lewis JS, Valentine RE (2010) Clinical measurement of the thoracic kyphosis. A study of the intra-rater reliability in subjects with and without shoulder pain. *BMC Musculoskelet Disord* **11**: 39. doi: 10.1186/1471-2474-11-39

Lin SI, Liao CF (2011) Age-related changes in the performance of forward reach. *Gait Posture* **33**(1): 18–22. doi: 10.1016/j.gaitpost.2010.09.013

Lonestein JE, Winter RB (1995) *Moe's Textbook of Scoliosis and Other Spinal Deformities*. 3rd edn. Saunders, Philadelphia

Mangone M, Raimondi P, Paoloni M et al (2013) Vertebral rotation in adolescent idiopathic scoliosis calculated by radiograph and back surface analysis-based methods: correlation between the Raimondi method and rasterstereography. *Eur Spine J* **22**(2): 367–71. doi: 10.1007/s00586-012-2564-9

Muller C, Fuchs K, Winter C (2011) Prospective evaluation of physical activity in patients with idiopathic scoliosis or kyphosis receiving brace treatment. *Eur Spine J* **20**(7): 1127–36. doi: 10.1007/s00586-011-1791-9

Newton PO, Yaszay B, Upasani VV (2010) Preservation of thoracic kyphosis is critical to maintain lumbar lordosis in the surgical treatment of adolescent idiopathic scoliosis. *Spine* **35**(14): 1365–70. doi: 10.1097/BRS.0b013e3181dccd63

Noonan KJ, Weinstein SL, Jacobson WC, Dolan LA (1996) Use of the Milwaukee brace for progressive idiopathic scoliosis. *J Bone Joint Surg Am* 78: 557–67. doi: 10.2106/00004623-199604000-00009

Ogilvie J (2010) Adolescent idiopathic scoliosis and genetic testing. *Curr Opin Pediatr* **22**: 67–70. doi: 10.1097/MOP.0b013e32833419ac

Olafsson Y, Saraste H, Ahlgren RM (1999) Does bracing affect self-image? A prospective study on 54 patients with adolescent idiopathic scoliosis. *Eur Spine J* **8**(5): 402–5

Patias P, Grivas TB, Kaspiris A, Aggouris C, Drakoutos E (2010) A review of the trunk surface metrics used as Scoliosis and other deformities evaluation indices. *Scoliosis* **5**: 12. doi: 10.1186/1748-7161-5-12

Plewka B, Sibiński M, Synder M, Witoński D, Kołodziejczyk-Klimek K, Plewka M (2013) Clinical assessment of the efficacy of SpineCor brace in the correction of postural deformities in the course of idiopathic scoliosis. *Pol Orthop Traumatol* **78**: 85–9

Romano M, Tavernaro M, Negrini S, Pilon M (2006)Adolescent Idiopathic Scoliosis and its correlation with balance function. Can we improve them with physical exercises? In: Poznan KT, ed. *3rd International Conference on Conservative Management of Spinal Deformities*. Society on Scoliosis Orthopedic and Rehabilitation Treatment, Barcelona

Romano M, Zaina F (2007) Is there a relationship between the results of Unterberger test and convexity of scoliosis major curve? [abstract]. *Scoliosis* **2**(Suppl 1): S36. doi: 10.1186/1748-7161-2-S1-S36

Roussouly P, Pinheiro-Franco JL (2011) Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. *Eur Spine J* **20**(Suppl 5): 609–18. doi: 10.1007/s00586-011-1928-x

Sapountzi-Krepia DS, Valavanis J, Panteleakis GP, Zangana DT, Vlachojiannis PC, Sapkas GS (2001) Perceptions of body image, happiness and satisfaction in adolescents wearing a Boston brace for scoliosis treatment. *J Adv Nurs* **35**(5): 683–90. 10.1046/j.1365-2648.2001.01900.x

Schmitz A, König R, Kandyba J, Pennekamp P, Schmitt O, Jaeger UE (2005) Visualization of the brace effect on the spinal profile in idiopathic scoliosis. *Eur Spine J* **14**(2): 138–43. doi: 10.1007/s00586-004-0788-z

Schulte TL, Hierholzer E, Boerke A et al (2008) Raster stereography versus radiography in the long-term follow-up of idiopathic scoliosis. *J Spinal Disord Tech* **21**(1): 23–8. doi: 10.1097/BSD.0b013e318057529b

Szwed A, Kołban M (2012) Results of SpineCor dynamic bracing for idiopathic scoliosis. *Stud Health Technol Inform* **176**: 379–82

van Loon PJ, Kuhbauch BA, Thunnissen FB (2008) Forced lordosis on the thoracolumbar junction can correct coronal plane deformity in adolescents with double major curve pattern idiopathic scoliosis. *Spine* **33**(7): 797–801. doi: 10.1097/BRS.0b013e3181694ff5

Weiss HR, Weiss G, Petermann F (2003) Incidence of curvature progression in idiopathic scoliosis patients treated with scoliosis in-patient rehabilitation (SIR): an age- and sex-matched controlled study. *Pediatr Rehabil* **6**(1): 23–30. doi: 10.1080/1363849031000095288

Weiss HR, Weiss GM, Stephen C (2005) Brace treatment during pubertal growth spurt in girls with idiopathic scoliosis (IS): a prospective trial comparing two different concepts. *Pediatr Rehabil* **8**(3): 199–206. doi: 10.1080/13638490400022212

Weiss HR, Klein R (2006) Improving excellence in scoliosis rehabilitation: A controlled study of matched pairs. *Pediatr Rehabil* **9**(3): 190–200. doi: 10.1080/13638490500079583

Wong MS, Cheng JC, Lam TP (2008) The effect of rigid versus flexible spinal orthosis on the clinical efficacy and acceptance of the patients with adolescent idiopathic scoliosis. *Spine* **33**(12): 1360–1365. doi: 10.1097/BRS.0b013e31817329d

Wong MS, Liu WC (2003) Critical review on non-operative management of adolescent idiopathic scoliosis. *Prosthet Orthot Int* **27**(3): 242–53. doi: 10.1080/03093640308726688

Ylikoski M (2005) Growth and progression of adolescent idiopathic scoliosis in girls. *J Pediatr Orthop B* **14**(5): 320–4. doi: 10.1097/01202412-200509000-00002

Zaina F, De Mauroy JC, Grivas T et al (2014) Bracing for scoliosis in 2014: state of the art. *Eur J Phys Rehabil Med* **50**(1): 93–110