Stud Health Technol Inform. 2008;135:274-90.

Biomechanical and clinical perspectives on nighttime bracing for adolescent idiopathic scoliosis.

Grivas TB, Rodopoulos GI, Bardakos NV.

Biomechanical and Clinical Perspectives on Nighttime Bracing for Adolescent Idiopathic Scoliosis

Theodors B. Grivas[*], MD, Georgios I. Rodopoulos[**], MD,
Nikolaos V. Bardakos[§], MD
[*]*Orthopaedic Surgeon; Head, Orthopaedic Surgery Dept., 'Thriassio' General Hospital, Magoula, Attica, Greece;* [**]*Orthopaedic Surgeon, Orthopaedic Surgery Dept., 'Thriassio' General Hospital, Magoula, Attica, Greece;* [§]*Orthopaedic Surgeon, Private Practice, Athens, Greece*

Abstract. The present review article aims at providing an update on the basic science and clinical information underlying the use of nocturnal braces for adolescent idiopathic scoliosis. The use of nocturnal braces has been dictated by the encouraging results recorded by some studies on part-time bracing, combined with increasing concerns on poor patient compliance noted with the use of full-time bracing. The cardinal feature of nighttime braces lays in their ability to hypercorrect the scoliotic curvature, thereby eliminating the asymmetric water accumulation that occurs in the apical and adjacent intervertebral discs, thus restoring a close-to-normal force application through the Hueter-Volkmann principle and preventing curve progression. The two nighttime braces mostly used hypercorrect the spine through different mechanisms, one acting by bending the spine and the other by the application of opposing forces. Based on the clinical results available, nighttime braces constitute an attractive option for single-major lumbar/thoracolumbar curves not exceeding 35º in magnitude. Multi-center, randomized studies using strict criteria set forth by the Scoliosis Research Society and the Study group On Scoliosis Orthopaedic and Rehabilitation Treatment are needed to better define the role of nocturnal bracing in the conservative treatment of adolescent idiopathic scoliosis.

Keywords. Adolescent idiopathic scoliosis, conservative treatment, nighttime braces, nocturnal braces

1. Introduction

With regard to treatment of adolescent idiopathic scoliosis (AIS), the only potentially effective alternative to operative correction and fusion is orthotic management alone[1], or coupled with exercises[2-4]. The cervicothoracolumbosacral orthosis (CTLSO) was the first to be used in a full-time mode to treat scoliosis conservatively, albeit with modest success[5].

Problems with patient compliance and poor self-image[6] and the questionable results of the Milwaukee brace prompted the need for the development of underarm braces (thoracic-lumbar-sacral orthoses, TLSO) in curves with an apex at T8 or below. The prototype TLSO, the Boston brace, developed by Hall and Miller in the mid

1970s[7,8], remains a popular choice today. Although results have been encouraging[7, 9], the need to decrease the psychological burden of the young patients still remained. Thus, further refinements in the conservative management of AIS entailed the reduction in the amount of time the brace is worn on a daily basis. Part-time bracing has been reported to have contradictory results in the literature[7, 10, 11].

The newest strategies today employ the concept of part-time orthotic use during nighttime. Conceivably, this type of treatment is likely to have the least negative psychosocial impact on patients. The purpose of this article is to provide an overview of the theory and clinical results of nighttime bracing used for treatment of AIS.

2. Indications for Use

Current indications for use of a nighttime brace in AIS appear to include patients aged >10 years old with single-major curves ranging between 25-35º with an apex below T8. Double curves should be considered an advanced indication, especially with the Charleston brace. Skeletally immature patients (Risser 0-2) are the best candidates for nocturnal bracing, as they have more time for treatment and their endplates are more amenable to repair.

3. The Rationale behind Nighttime Bracing

It is generally agreed upon that the critical question in the decision-making process for treatment of AIS is: where is the child in his or her growth spurt[12]? The answer to this question, together with additional information derived from clinical and radiographic examination, will determine the type of treatment required, if at all.

One must remember that natural history data refer to 'estimates' and 'likelihoods' derived from findings in large population samples. They do not tell us what will happen to an individual child. Therefore, each patient should be carefully managed on a strict case-by-case basis, in the context of a multidimensional approach, taking into consideration every piece of clinical, radiographic and social information available and defining the goals of treatment very clearly right at the outset.

In defining those goals, the physician plays a key role. Apart from correcting or delaying the progression of the deformity, other aspects of treatment, including, but not being limited to, balance, aesthetics, psychological well-being and disability, have been gradually incorporated to the list of outcome measures.

As one would expect, these goals are not prioritized similarly amongst treating physicians. Recently, the consensus paper of the Scientific Society On Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) on the reasons scoliosis is treated for cited aesthetics, quality of life and psychological well-being as the first three primary outcome criteria in the conservative treatment of AIS; the same factor is only minimally taken into account in the literature (about 3%). Interestingly, back pain, Cobb angle and Perdriolle angle ranked 5th, 12th and 15th respectively in that study[13].

This finding corroborates other reports[14, 15] concerned with the psychosocial well-being during orthotic treatment and highlights the current trend of physicians treating scoliosis toward an holistic therapeutic approach[16], in which technical factors, such as the Cobb angle, are only a secondary outcome. It is also in accordance with an important element of brace treatment, namely poor patient compliance, which has been frequently cited in the literature as a factor leading to inferior results[17-20] .

Adolescence is a sensitive phase in the development of a young person. Patients diagnosed with AIS must commit to a lengthy, confining and uncomfortable course of treatment. In light of this, the use of nighttime bracing seems, at least in theory, justified.

4. Function of Nighttime Braces

4.1. Biomechanics

The rationale for conservative management of scoliosis during skeletal growth assumes a biomechanical mode of deformity progression, based on the Hueter-Volkmann principle[21], whereby extra axial compression decelerates growth and reduced axial compression accelerates it[22]. In treating scoliosis conservatively, bracing does nothing more than exploiting this principle, by applying appropriately directed forces through the skin, soft tissues and ribs to the vertebral growth plates.

The biomechanical function of nocturnal braces is discussed below. Four different perspectives are presented which, although seemingly different, are at the same time complementary to each other, as will be demonstrated.

4.1.1. The Vicious Circle Model

This theory, first described by Roaf[23] in 1960, claims that, asymmetric loading of the spinal axis is the primary force for the development and progression of pathologic spinal curves, with increasing deformity causing more asymmetric loading, which in turn will worsen deformity. Roaf attributed the asymmetric damage on the vertebral endplates to the application of this unequal load upon them. On the premises of this theory, Roaf described the action of hyperextension jackets for patients with Scheuermann's kyphosis. In an earlier report of his[24], Roaf cited gravity and muscle imbalance as the primary deforming forces in scoliosis; thus, prolonged recumbency, by eliminating gravity and, to some extent, muscle action, would, in theory, cease the vicious circle of scoliosis – despite its obvious disadvantages precluding its use[23].

This model was most recently revisited by Hawes and O'Brien[25] who, in their literature review, describe experimental and clinical evidence supporting the contention that a functional scoliotic curve may evolve to a fixed structural curve, if the spine is not relieved of the offending agents[25-27]. Differences in progression amongst individuals are due to differential muscle activation strategies, rather than other inherent differences[28]. Interestingly, the authors present evidence for the reverse: because vertebral growth is not permanently affected by applied loading, a structural curve may correct, if postural asymmetry is corrected, provided adequate growth potential exists[25, 27, 29, 30].

Macroscopically, the model is confirmed by the presence of wedged intervertebral discs and vertebrae in scoliosis [22, 25, 31, 32]. Vertebral wedging has consistently been found to reach its maximum at the apex of thoracic curves[25, 33, 34]. At the cellular level, increased apoptotic cell death has been found[35], secondarily leading to inhibition of matrix turnover in involved discs[36]. Again, cell apoptosis has been observed to be highest in the apical discs, irrespective of the aetiology of scoliosis[37].

Hawes and O'Brien predict that "the activation of programmed cell death in response to mechanical loading comprises the molecular mechanism by which a reversible spinal curvature is converted into an irreversible spinal deformity"[25].

In summary, according to the vicious cycle model, whatever the cause of the original deformity, a sustained imbalance of forces acting along the spine will eventually lead to structural disc and vertebral changes that clinically manifest as scoliosis. However, if the asymmetric biomechanical environment is reversed, these changes are reversible, provided significant growth potential remains[25].

4.1.2. The Recumbent Position

The scoliotic deformity is hereby described as consisting of two components, namely the elastic and the plastic components of the deformity. The former is the one that is readily correctable by merely changing body position or lying down, while the latter is what is targeted with any form of treatment[38].

The influence of gravity on scoliosis is long known[23, 39] and a diurnal variation in the magnitude of Cobb angle has been described[40, 41]. Elimination of gravity and muscle tone minimisation during recumbency have been already referred to in Roaf's work[23, 24]. The novel element introduced by this theory is the fact that, during recumbency, self-induced corrective forces are exerted through the rib cage upon the spine.

This is accomplished by the patient's own weight, which is transferred through the ribs, in the form of pressure to the costovertebral joints, changing the spinal curvature accordingly. Of course, the magnitude and direction of the force vector and its final influence on the curve are highly dependent on the patient's position in bed. In essence, there is an alteration of the direction of gravity relative to the body axis (along the body axis in the erect position, perpendicular to it in recumbency); stated otherwise, in the recumbent position gravity acts to the patient's benefit[38].

During sleep, not only is there this beneficial effect of gravity, but muscle tone is minimised as well. Therefore, it appears as if this is the optimal time for the application of an additional corrective force, which will fully restore the elastic element and possibly continue to correcting part of the plastic deformity. Nachemson and Elfstrom[42] have demonstrated the tremendous increase in the magnitude of side forces applied by a brace in the recumbent position. Additional data have been provided by Mulcahy et al[43], showing that side forces almost double in magnitude, especially in larger (>40°) curves. Although longitudinal distraction forces are also exerted by braces, side forces constitute their key aspect of action[42].

In summary, this hypothesis points to the utility of using a brace in the recumbent position as a result of the following sequence:

1. The vector of gravity is used to the patient's benefit, creating corrective forces through the ribs to the spine.
2. Muscle tone is minimal. This, combined with point 1, renders elastic deformity almost fully self-correctable.
3. The plastic component of scoliosis is now amenable to side corrective forces from braces; these forces, in any case, are significantly increased in the recumbent position.

4.1.3. The Role of the Intervertebral Discs

The theory of the intervertebral disc (IVD) being the primary offending agent in scoliosis is proposed by one of the authors (TBG). It has been reported that in mild scoliotic curves, when the deformity is initiating, the IVD is found wedged, but the vertebral body is not. The spine is deformed first at the level of the IVD, due to the increased plasticity of the IVD, in the way of either torsion or wedging as an expression of other initiating factors that may result in idiopathic scoliosis (IS) [44]. The IVD contains the aggrecans of glycosaminoglycans (GAGs) which imbibe water through the so called Gibbs-Donnan mechanism. The highest concentration of aggrecans is in the nucleus pulposus (NP) where they are entrapped in a type II collagen network[45].

There is an increased collagen content in the NP of AIS IVD, which is maximal at the apex of the curvature. Furthermore, in the scoliotic spine the NP in the IVD is displaced towards the convex side of the wedged interspaces[46]. Differences also exist in the collagen distribution between the concave and convex sides of the scoliotic annulus fibrosus in AIS, with depleted levels in the former compared to the latter[47].

Composing all the above findings, it has been suggested[44] that the imbibed water, mainly in the apical IVD but also in the adjacent discs above and below it, must be in a greater amount in the convex side that in the concave. This asymmetrical pattern of the water distribution in the scoliotic IVD, in association with the diurnal variation in the water content of lumbar IVD[48], imposes asymmetrical, convex-wise, concentrated cyclical loads to the IVD and the adjacent immature vertebrae of the child during the 24 hours period. The convex side of the wedged IVD sustains greater amount of expansion than the concave side, leading to the sequelae of asymmetrical growth of adjacent vertebrae (Hueter-Volkmann law).

The strong correlation between lumbar **L**ower **I**nter**V**ertebral **D**isc **W**edging (LIVDW) and thoracic Cobb Angle (CA)[44] implicates the important role of the lumbar spine and particularly that of the lumbar LIVDW to the progression of the scoliotic curve, as the lumbar IVDs are significantly higher. The correlations found[44] imply that the apical intervertebral disc wedging through the proposed mechanism seems to be an important contributory factor in the progression of IS curves, emphasizing the role of the apical intervertebral disc in IS pathogenesis.

The nighttime brace corrects or overcorrects the mild or moderate scoliotic curve, acting also on the apical and adjacent wedged IVDs, thereby reducing the previously described asymmetrically imbibed water (greater amount in the convex side rather that in the concave). Hence, the diurnal variation in the water content of IVD occurs under more normal conditions. Under the action of the nighttime brace, the convex side sustains no greater amount of expansion than the concave side, (ceasing the asymmetrical application of Hueter-Volkmann law), reversing the deleterious hypothesis of progression of IS curves; consequently, the growth of the apical and adjacent immature vertebrae turns more normal, within a close-to-normal biomechanical environment.

A pertinent observation on changes in body height and scoliosis angle under the influence of gravity was also reported by Zetterberg et al [40, 49], namely a decrease in the scoliosis angle occurring during the day in younger and more skeletally immature individuals.

4.1.4. The Effect of Moment Arms

An explanation on the efficacy of nighttime braces based on the action of moment arms has also been proposed: in a full-time brace worn in the upright position, a vector is created to displace the curve toward the patient's midline; at the same time, an opposing vector maintains the patient upright, with the head over the pelvis. The limiting factors in the placement of the vectors are the axilla proximally and the iliac crest distally. When applying a three-point vector for curve correction, the vector moments must remain constant for the patient to remain balanced, meaning that the magnitude of the vectors increases as the distance (moment arm) between the vectors decreases. This often involves a significant amount of pressure to be applied to correct a curve by 50%[50].

Nighttime brace design eliminates two factors associated with vector placement in full-time braces: (a) the iliac crest being the most distal level for vector placement, and (b) the need to maintain the head in line with the pelvis, as in the upright position. In this way, it is possible to increase the distance between vectors, thus decreasing the applied force. Ultimately, a nocturnal brace is able to obtain much greater in-brace curve corrections[50].

4.1.5. Summation of Biomechanical Theories

In an effort to best explain the action of nighttime braces, four theories/models have been presented. These may be best regarded in conjunction with each other, rather than in isolation. Hence, a nighttime brace disrupts the crucial state of asymmetric loading of the spine (vicious circle model), mainly by taking advantage of the unique transformation of gravity direction relative to the body during recumbency (recumbent position theory); in this condition, the shape of the apical and adjacent intervertebral discs is restored and symmetrical growth stimuli are now transmitted to the endplates (role of intervertebral discs). Increased moment arms used by those braces facilitate this scenario (effect of moment arms).

4.2. Biology

In addition to their biomechanical mode of action, nocturnal braces have been demonstrated to take advantage of the daily peak of growth hormone, which occurs between midnight and 2a.m. as part of the normal circadian rhythm of adolescents [51]. It is theorized that corrective action taken during that time stands the best chance of having the desired effect.

This might also be related to the neuroendocrine or 'melatonin-deficiency' hypothesis[52], as a possible cause for AIS. Bagnall et al [53] have suggested that activity of melatonin may be mediated through growth hormone. Decreased melatonin levels have been correlated with scoliosis in both chickens and humans [54-56], although other studies have failed to confirm this [53, 57-61]. Two recent studies by Moreau et al[62] and Azeddine et al[63] strongly suggest that the problem with melatonin may be qualitative, rather than quantitative, and may lie in the melatonin cell receptors of osteoblasts. Based on these conflicting data, the additive role of melatonin and nighttime bracing (in cases with normal melatonin levels) or the compensatory role of nighttime bracing (in cases with decreased melatonin levels) is currently only conjectural.

5. Types of Nighttime Braces

At present, two braces are mostly used at nighttime. These are the Charleston Bending Brace (Sea Fab, Inc., Orlando, FL, USA), introduced in 1979 by C. Ralph Hooper, Jr., CPO and Frederick E. Reed, Jr., MD and the Providence Nighttime Scoliosis System (Spinal Technology, Inc., West Yarmouth, MA, USA), developed by Barry McCoy, MEd., CPO.

The two nighttime braces available have distinctly different mechanical modes of action. The Charleston brace works by bending the spine, whereas the Providence brace works by the application of opposing forces which push the curve apices to the midline.

The Charleston brace (see Figure 1), is based on the side-bending theory for correction of deformities of the spine, first introduced by Guérin[64, 65] and popularized by Risser, who developed the turnbuckle cast initially and the localizer cast later[65, 66]. Braces of this kind are based on the premise that scoliosis is caused by muscle imbalance, accentuated by asymmetric forces predicted by the Hueter-Volkmann principle; the deformity is accompanied by soft-tissue stretching on the convex side and contracture on the concave side[65]. The Charleston brace is a rigid custom-made orthosis aiming at stretching the contracted concave side at nighttime, when muscle tone is minimal.

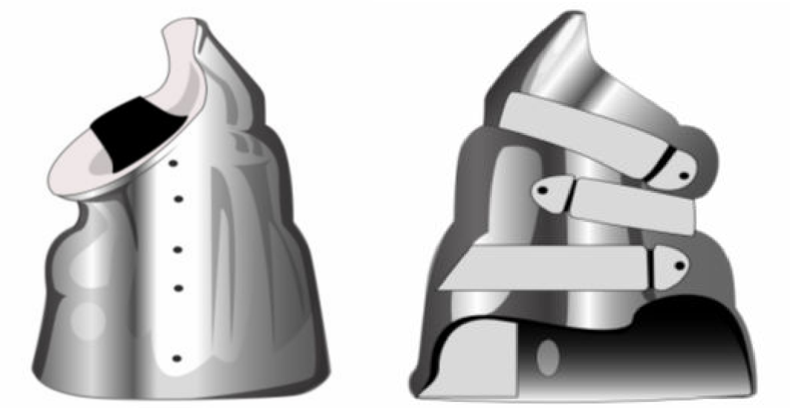

Figure 1 The Charleston Bending Brace [schematic representation]

The computer-fitted Providence Scoliosis System, originally developed to demonstrate spinal flexibility in the supine position for purposes of pre-operative planning, was further marketed as a true scoliosis orthosis when it was observed that significant correction of scoliotic curves could be achieved using an acrylic frame to apply direct corrective forces to the patient. It is fabricated of polypropylene plastic from measurements or a plaster impression, but carbon fibre-reinforced braces are also available. Over the last years, cast molds are scanned into a CAD/CAM computer so that fabrication is done with measurements alone in all cases of AIS (see Figure 2). Patients with other types of scoliosis are still casted[67].

In the Providence brace, the amount of corrective force required is monitored with the use of pressure-sensitive film. When the patient outgrows the brace, this becomes tight circumferentially but the pressure drops at the apex of the curve. During the recommended three-month check-up visits to the orthotist, pressure readings serve to evaluate the ongoing effectiveness of the brace as the patient grows [67].

6. Design and Manufacturing of Nighttime Braces

The Charleston brace is custom-made from a negative impression taken by an orthotist and fabricated of thermoplastic material[68]. The exclusive manufacturing and quality control responsibility has been assigned to SEA FAB, INC.

The Providence brace features a double curve design which provides an overlapping three-point pressure system approach. In addition to the use of a three-point pressure system, this involves the use of void areas that are located opposite the pressure application points. Voids, as opposed to holes, are necessary to maintain the shell in continuity, if pressure application is to remain constant at all times. However,

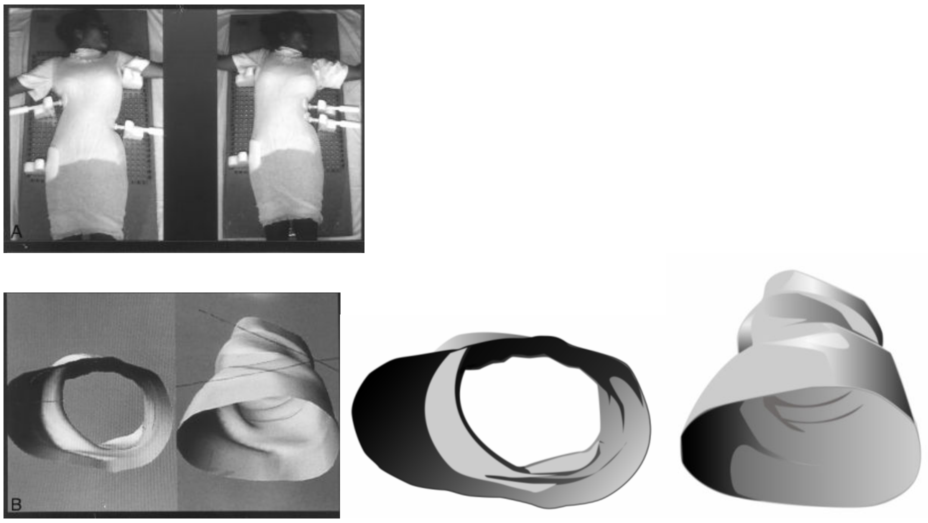

Fig.ure 2 A. Measuring frame for the Providence brace, B. Mold made on CAD/CAM milled bank [reproduced with permission from D'Amato CR, Griggs S, McCoy B. Nighttime bracing with the Providence brace in adolescent girls with idiopathic scoliosis. Spine 2001;26(18):2006-12].

the advent of carbon fibre-reinforced braces, has allowed cutting out the void areas; this has made the brace much more patient-friendly[67].

The three-point system helps control double curves (in those cases the two 3-point systems overlap) and theoretically allows for treatment of curves with apices as high as T6 without the use of a neck extension (though a neck extension may be used for treating higher apices)[67].

Derotation is effected differently, depending on the location of the curve. In the lumbar spine, segmental derotation is accomplished by the lumbar pad itself, placed at the appropriate angle between the iliac crest and the 12^{th} rib. In the thoracic spine, the ribs are used, acting as long lever arms, to derotate the vertebrae. Derotation in the thoracic section of the brace is accomplished on the CAD/CAM model. The thoracic section is separated from the lumbar section. Then the thoracic portion is rotated a specific amount and rejoined to the lumbar section of the model. Obtaining rotational control by rotating the thoracic portion of the orthosis is something that can not be done with full-time or daytime braces; it is only possible in the supine or prone position[67].

7. Results

7.1. Providence Brace

Few studies on the results of the Providence brace have been reported (see Table 1). In a prospective study, D'Amato et al were the first to report on the results of a series of 102 female adolescents with Risser sign between 0-2[69]. The authors found their results (26% progression) comparable to those of the SRS non-randomized controlled multi-center prospective study[70]. In the subgroup of patients with Risser 0-1, 23% progressed; this was noted to be clearly superior to the natural history data published by Lonstein and Carlson (68% progression rate)[71].

Table 1 Summary of studies on Providence brace

Authors	*Year*	*Design*	*Follow-Up (yrs)*#	*No. Patients*	*No. Curves*	*Initial in-brace correction rates*	***Progression Rates***
D'Amato et al	2001	prospective	2.6	102	148	96%	**26%**
Yrjönen et al	2006	comparative*	1.8	72 (36+36)†		50%; 92%†	**22%; 27%**†
Janicki et al	2007	comparative**	not recorded	83 (48+35)†		not recorded	**85%; 69%**†

after cessation of brace wear

* prospective for the Providence group and retrospective for the Boston

** retrospective

† TLSO and Providence groups respectively

Two recent studies have compared the results of the Providence brace with a TLSO orthosis. Yryönen et al[72] studied 36 patients treated with the Providence brace and compared them to a matched group treated with the full-time Boston brace. Progression rates were 27% for the Providence group and 22% for the Boston group. The authors concluded the Providence brace may be recommended in lumbar and thoracolumbar curves of <35°.

Janicki et al[1] published the first study to be conducted using the new SRS Committee on Bracing and Nonoperative Management inclusion and assessment criteria[73]. Although the overall rates of successful treatment were 21% and 40% for the TLSO and Providence groups respectively, the authors were able to demonstrate a statistically significant superiority of the Providence brace in the curves of lesser magnitude (25°-35°) only.

7.2. Charleston Brace

Results on the Charleston brace are summarized in Table 2. In 1990 Price et al[51] published their early report using the Charleston brace and later reported their long-term follow-up results[74]. Despite the very good overall results, the first report raised concerns on the fate of double curves, as approximately 46% (11 of 24) of them showed deterioration of their second component. In the long-term study of the same patients, 20 (13%) compensatory or secondary curves progressed >5° and four patients required surgery because of an increase in their compensatory curves alone.

Table 2 Summary of studies on Charleston brace

Authors	*Year*	*Design*	*Follow-Up (mos)#*	*No. Patients*	*No. Curves*	*Initial in-brace correction rates*	***Progression Rates***
Price et al	1990	prospective, multicentre	not recorded	139	191	73%	**17%**
Price et al	1997	prospective, multicentre	14	98	149	87%	**34%**
Katz et al	1997	comparative*	0	319 (153+166)†	457 (217+240)†	41%; 83%†	**34%; 57%**†
Howard et al	1998	comparative*	20; 16†	140 (45+95)†	198 (63+135)†	40%; 84%†	**29%; 52%**†
Trivedi &Thomson	2001	retrospective	41	42	42	104%	**40%**
Gepstein et al	2002	comparative*	24	122 (37+85)†	122 (37+85)†	mean not recorded	**19%; 20%**†

after cessation of brace wear

* retrospective

† TLSO and Charleston groups respectively

Federico and Renshaw[75] conducted a retrospective review of 32 patients, 11 of which had successful treatment, while two were listed as failures. Nineteen patients had not completed treatment at the time of paper submission (not listed in table 2).

Katz et al[68] compared the efficacy of the Charleston to that of the Boston brace. The Boston brace achieved statistically superior results, both in curves 25-35° (progression rates 29% vs. 47%), as well as in larger (36-45°) curves (progression rates 43% vs. 83%). The Boston brace was more successful in double major and single thoracic curves. These findings were strikingly similar to the ones by Howard et al[76], who also compared the efficacy of TLSO vs. Charleston braces in concurrently treated groups.

Climent and Sanchez[14] have conducted the only study so far on the impact of different types of braces on self-perceived patient health status, using the QLPSD instrument[77]. Of 102 patients included in the study, 75 were diagnosed with idiopathic scoliosis. Charleston brace-treated patients achieved the best scores (42.8, denoting least impact on quality of life), although results were not statistically significant from those of TLSO-treated patients (45.6). Of note, back flexibility subscores were significantly superior in the Charleston group (5.6 vs. 8.9).

Treatment of single-curve AIS with the Charleston brace has been reported by Trivedi and Thomson[78] and Gepstein et al[79]. Progression rates were 40% and 20% respectively (no significant difference to the 19% achieved with the TLSO[79]). The former study only included curves between 25-40º in magnitude, whereas there were 32 curves less than 25º in the latter, possibly accounting for the different results.

8. Discussion

Two important issues merit investigation, when evaluating a brace. Firstly, the brace has to be checked as to its potential to alter the natural history of scoliosis. Secondly, it has to be compared against its counterparts, with regard to the clinical results. The efficacy of a brace is also a function of factors including initial in-brace correction, Risser sign and location of major curve apex. The highest success rates of part-time (16 hours daily) bracing ever reported in the literature have reached 89%[80].

Rowe et al[81] have conducted the only meta-analysis study available on the efficacy of non-operative treatment modalities for idiopathic scoliosis. The authors found bracing to be significantly more successful than electrical stimulation or observation. The Milwaukee brace was the most and the Charleston brace the least successful type of brace, with TLSO braces demonstrating intermediate success. Moreover, 23 hours of daily use of bracing was proven the most successful bracing regimen; no statistical difference was found between the 16- and 8-hour daily bracing duration. However, only two studies[51, 75] on the Charleston brace were included in this analysis, both being preliminary, as many patients in each of them were still undergoing treatment at the time of their publication. For this, as well as for other reasons, this meta-analysis has been criticised as being methodologically flawed[82]. However, other studies[70, 83, 84] have indisputably demonstrated that bracing does have a positive effect on the natural history of scoliosis.

Both the Providence and Charleston orthoses are described as 'hypercorrective' (see Figure 3). Indeed, this was confirmed in the study by d' Amato et al[69]: average initial in-brace correction for thoracolumbar and lumbar curves was 111% and 103%, respectively. Flexible, low (below T8) curves and those associated with higher Risser sign were likely to fare better. Similarly, the study by Yrjönen et al[20] demonstrated a far superior in-brace correction, compared to the Boston group. For the Charleston brace, Trivedi and Thomson[78] recorded a mean correction of 104%. Given the fact that maximum correction while in the brace is a desirable factor in conservative treatment of scoliosis[7], this feature may be a strong indication to their potential to halt progression.

Vasiliadis et al[85] studied the influence of a modified Boston brace on patient quality of life (QoL), using a newly developed, validated disease-specific questionnaire[86]. They found physical functioning and vitality to be the factors most affected. Initial in-brace correction has been shown to have another interesting effect, relating to QoL. Climent and Sanchez[14], in their multiple linear regression analysis model, found a significant correlation between initial correction and QoL for all patients. The authors attribute this finding to the patients' satisfaction with no curve progression. Therefore, the superiority of nocturnal braces on patients' psychosocial functioning may not result as the consequence of nighttime use only and merits further study.

Another advantage of nighttime bracing is the opportunity patients have for a concurrent comprehensive exercise treatment programme during daytime. The role of exercises in the treatment of AIS was until recently not clear-cut[87]. However, increasing evidence now exists[2], pointing to several potential benefits (better pulmonary function, improved proprioception, reduced pain, positive psychological

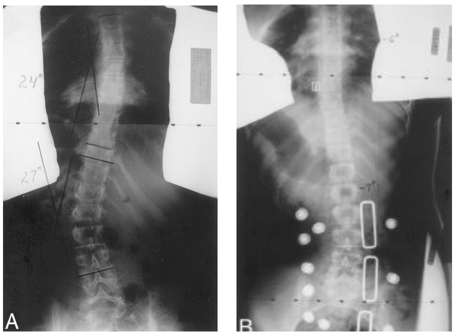

Figure. 3 Case demonstrating in-brace overcorrection of both curves in a double-curve pattern [reproduced with permission from D'Amato CR, Griggs S, McCoy B. Nighttime bracing with the Providence brace in adolescent girls with idiopathic scoliosis. Spine 2001;26(18):2006-12].

impact and less chance of curve progression) from specific physical therapy and intensive rehabilitation[88]. None of the studies on the two nocturnal braces[1, 51, 68, 69, 72, 74-76, 78, 79] have combined bracing therapy with a structured physical exercise programme.

The conclusion that is uniformly drawn from all clinical studies on the Providence brace so far is that it may benefit patients with curves up to 35°. Natural history data from Lonstein and Carlson[71] in patients with Risser 0-1 and curves of 20 to 29° reveal a 68% risk of curve progression. The same curves in patients with Risser 2-4 dropped the risk of progression to 23%. In the Iowa series[89], 68% of 133 curves progressed. We agree with Janicki et al[1] in that to be considered an effective management method, an orthosis must prevent progression in at least 70% of patients.

Based on this figure, two out of three studies[20, 69] on the Providence brace did show results better than the natural history studies. Janicki et al[1] attributed their poor results in a multitude of reasons, including the new SRS criteria, according to which even noncompliant patients are to be included. However, the study by D'Amato et al[69], although it was conducted before the establishment of these criteria, included noncompliant patients as well, albeit with good results.

A technical difficulty in the use of the Charleston brace is the management of compensatory or secondary curves. This is reflected in their significantly lower initial in-brace correction (33%) and the fact that these had the poorest response to treatment in the series of Price et al[74]. Katz et al[68] showed that the Boston and Charleston braces were equally effective in all curve patterns, except for double major and single thoracic curves. There is certainly a concern that there may be a difficulty in 'unbending' two opposite curves[74] or that the forces unbending a curve can worsen the opposite one[69]. In any case, treating a double curve is considered an advanced application of the Charleston brace[90].

Both nocturnal braces appear less effective in larger (>35°) curves. A possible explanation of this observation has been offered by Katz et al[68], based on review of previous biomechanical studies[41, 91, 92]. The authors suggest that patients with larger curves have reduced load-carrying capacity. Despite the fact that the load generated by the upper torso is eliminated in the recumbent position, i.e. when nocturnal braces are used, it may be that larger curves need additional support, with a daytime brace, when the patient is standing.

Comparison of the efficacy of braces across the literature is difficult, due to the disparity of the study groups (patients of mixed aetiologies often included), the variable definition of lack of curve progression among authors (<5° or 10°) and the absence of results according to significant factors, e.g. curve magnitude or maturity. Part-time bracing has been shown to have results equal to full-time bracing, but this may reflect poor compliance of full-time protocols inasmuch as it represents success of part-time bracing[74]. In the authors' view, patients should be included and evaluated in nighttime brace studies according to the criteria seen in Tables 3 and 4.

Table 3 Inclusion criteria proposed by authors for future nighttime brace studies

Criterion	Definition
Diagnosis	AIS
Age	>10 when diagnosis is made
Gender	both
Risser sign	0-3 (4 if curve >35°)
Curve magnitude	>30°
Curve location	lumbar / thoracolumbar
Previous treatment	no
Compliance	any
Menarchal status	pre- or up to 1 year post-menarchal

Table 4 Assessment criteria proposed by authors for future nighttime brace studies

Criterion	Definition
Curve progression	<5° (no progression) or >6° (progression)
Failure endpoint	>45° or recommendation for surgery
Patient subgroups	pattern magnitude rotation Risser sign flexibility menarchal status previous treatment compliance cessation brace use vs. latest follow-up
Follow-up	latest after cessation of brace use
Quality of life	BrQ score

These recommendations are unique in taking into account the SOSORT guidelines[88] for conservative treatment of AIS (e.g. progression risk is used instead of absolute magnitude values for curves <30°) and the modern trend toward a more functional patient evaluation[16, 86] (hence the inclusion of BrQ), combined with the authors' feeling that a detailed stratification in subgroups is essential for results to be comparable.

Nocturnal braces fulfill the two most important factors for successful treatment, namely primary correction and compliance [93, 94], and have shown encouraging results in the literature. Present data render them an attractive alternative for adolescents with single lumbar or thoracolumbar curves. Multi-center, randomized studies using the new SRS inclusion and assessment criteria or the SOSORT guidelines[88] are needed to better define the role of nocturnal bracing in the conservative treatment of AIS.

References

[1] Janicki JA, Poe-Kochert C, Armstrong DG, Thompson GH. A comparison of the thoracolumbosacral orthoses and providence orthosis in the treatment of adolescent idiopathic scoliosis: results using the new SRS inclusion and assessment criteria for bracing studies. *J Pediatr Orthop* **27(4)** (2007) 369-74.

[2] Weiss HR, Negrini S, Hawes MC, et al. Physical exercises in the treatment of idiopathic scoliosis at risk of brace treatment - SOSORT consensus paper 2005. *Scoliosis* **1** (2006) 6.

[3] Kotwicki T, Kinel E, Stryla W, Szulc A. Estimation of the stress related to conservative scoliosis therapy: an analysis based on BSSQ questionnaires. *Scoliosis* **2** (2007) 1.

[4] Hawes MC. The use of exercises in the treatment of scoliosis: an evidence-based critical review of the literature. *Pediatr Rehabil* **6(3-4)** (2003) 171-82.

[5] Noonan KJ, Weinstein SL, Jacobson WC, Dolan LA. Use of the Milwaukee brace for progressive idiopathic scoliosis. *J Bone Joint Surg Am* **78(4)** (1996) 557-67.

[6] Clayson D, Luz-Alterman S, Cataletto MM, Levine DB. Long-term psychological sequelae of surgically versus nonsurgically treated scoliosis. *Spine* **12(10)** (1987) 983-6.

[7] Emans JB, Kaelin A, Bancel P, Hall JE, Miller ME. The Boston bracing system for idiopathic scoliosis. Follow-up results in 295 patients. *Spine* **11(8)** (1986) 792-801.

[8] Moen KY, Nachemson AL. Treatment of scoliosis. An historical perspective. *Spine* **24(24)** (1999) 2570-5.

[9] Montgomery F, Willner S. Prognosis of brace-treated scoliosis. Comparison of the Boston and Milwaukee methods in 244 girls. *Acta Orthop Scand* **60(4)** (1989) 383-5.

[10] Allington NJ, Bowen JR. Adolescent idiopathic scoliosis: treatment with the Wilmington brace. A comparison of full-time and part-time use. *J Bone Joint Surg Am* **78(7)** (1996) 1056-62.

[11] Wiley JW, Thomson JD, Mitchell TM, Smith BG, Banta JV. Effectiveness of the boston brace in treatment of large curves in adolescent idiopathic scoliosis. *Spine* **25(18)** (2000) 2326-32.

[12] Lonstein JE. Scoliosis: surgical versus nonsurgical treatment. *Clin Orthop Relat Res* **443** (2006) 248-59.

[13] Negrini S, Grivas TB, Kotwicki T, Maruyama T, Rigo M, Weiss HR. Why do we treat adolescent idiopathic scoliosis? What we want to obtain and to avoid for our patients. SOSORT 2005 Consensus paper. *Scoliosis* **1** (2006) 4.

[14] Climent JM, Sanchez J. Impact of the type of brace on the quality of life of adolescents with spine deformities. *Spine* **24(18)** (1999) 1903-8.

[15] Korovessis P, Zacharatos S, Koureas G, Megas P. Comparative multifactorial analysis of the effects of idiopathic adolescent scoliosis and Scheuermann kyphosis on the self-perceived health status of adolescents treated with brace. *Eur Spine J* **16(4)** (2007) 537-46.

[16] Sapountzi-Krepia D, Psychogiou M, Peterson D, et al. The experience of brace treatment in children/adolescents with scoliosis. *Scoliosis* **1** (2006) 8.

[17] Rahman T, Bowen JR, Takemitsu M, Scott C. The association between brace compliance and outcome for patients with idiopathic scoliosis. *J Pediatr Orthop* **25(4)** (2005) 420-2.

[18] Parent S, Newton PO, Wenger DR. Adolescent idiopathic scoliosis: etiology, anatomy, natural history, and bracing. *Instr Course Lect* **54** (2005) 529-36.

[19] Lou E, Raso JV, Hill DL, Mahood JK, Moreau MJ. Correlation between quantity and quality of orthosis wear and treatment outcomes in adolescent idiopathic scoliosis. *Prosthet Orthot Int* **28(1)** (2004) 49-54.

[20] Yrjonen T, Ylikoski M, Schlenzka D, Poussa M. Results of brace treatment of adolescent idiopathic scoliosis in boys compared with girls: a retrospective study of 102 patients treated with the Boston brace. *Eur Spine J* **16(3)** (2007) 393-7.

[21] Stokes IA. Analysis and simulation of progressive adolescent scoliosis by biomechanical growth modulation. *Eur Spine J* 2007.

[22] Mente PL, Stokes IA, Spence H, Aronsson DD. Progression of vertebral wedging in an asymmetrically loaded rat tail model. *Spine* **22(12)** (1997) 1292-6.
[23] Roaf R. Vertebral growth and its mechanical control. *J Bone Joint Surg Br* **42-B** (1960) 40-59.
[24] Roaf R. Rotation movements of the spine with special reference to scoliosis. *J Bone Joint Surg Br* **40-B(2)** (1958) 312-32.
[25] Hawes MC, O'Brien J P. The transformation of spinal curvature into spinal deformity: pathological processes and implications for treatment. *Scoliosis* **1(1)** (2006) 3.
[26] Hipps HE. The diagnosis and treatment of incipient and early idiopathic scoliosis. *Am J Orthop* **5** (1963) 76-82.
[27] Harrington PR. Is scoliosis reversible? In vivo observations of reversible morphological changes in the production of scoliosis in mice. *Clin Orthop Relat Res* **(116)** (1976) 103-11.
[28] Stokes IA, Gardner-Morse M. Muscle activation strategies and symmetry of spinal loading in the lumbar spine with scoliosis. *Spine* **29(19)** (2004) 2103-7.
[29] Bradford DS, Bueff HU. Benign and malignant tumors of the spine. In: Lonstein JE, Bradford D, Winter R, Ogilvie JW, eds. Moe's Textbook of Scoliosis and Other Spinal Deformities. Philadelphia: WB Saunders; 1995:483-501.
[30] Mehta MH. Pain provoked scoliosis. Observations on the evolution of the deformity. *Clin Orthop Relat Res* **(135)** (1978) 58-65.
[31] Mente PL, Aronsson DD, Stokes IA, Iatridis JC. Mechanical modulation of growth for the correction of vertebral wedge deformities. *J Orthop Res* **17(4)** (1999) 518-24.
[32] Stokes IA, Spence H, Aronsson DD, Kilmer N. Mechanical modulation of vertebral body growth. Implications for scoliosis progression. *Spine* **21(10)** (1996) 1162-7.
[33] Villemure I, Aubin CE, Grimard G, Dansereau J, Labelle H. Progression of vertebral and spinal three-dimensional deformities in adolescent idiopathic scoliosis: a longitudinal study. *Spine* **26(20)** (2001) 2244-50.
[34] Parent S, Labelle H, Skalli W, Latimer B, de Guise J. Morphometric analysis of anatomic scoliotic specimens. *Spine* **27(21)** (2002) 2305-11.
[35] Ariga K, Yonenobu K, Nakase T, et al. Mechanical stress-induced apoptosis of endplate chondrocytes in organ-cultured mouse intervertebral discs: an ex vivo study. *Spine* **28(14)** (2003) 1528-33.
[36] Antoniou J, Arlet V, Goswami T, Aebi M, Alini M. Elevated synthetic activity in the convex side of scoliotic intervertebral discs and endplates compared with normal tissues. *Spine* **26(10)** (2001) E198-206.
[37] Chen B, Fellenberg J, Wang H, Carstens C, Richter W. Occurrence and regional distribution of apoptosis in scoliotic discs. *Spine* **30(5)** (2005) 519-24.
[38] Valavanis IK. Spine deformities. The conservative treatment. 2nd ed. Athens, Greece: Konstantaras; 1997.
[39] Stokes IA, Gardner-Morse M. Spinal stiffness increases with axial load: another stabilizing consequence of muscle action. *J Electromyogr Kinesiol* **13(4)** (2003) 397-402.
[40] Zetterberg C, Hansson T, Lindstrom J, Irstam L, Andersson GB. Postural and time-dependent effects on body height and scoliosis angle in adolescent idiopathic scoliosis. *Acta Orthop Scand* **54(6)** (1983) 836-40.
[41] Beauchamp M, Labelle H, Grimard G, Stanciu C, Poitras B, Dansereau J. Diurnal variation of Cobb angle measurement in adolescent idiopathic scoliosis. *Spine* **18(12)** (1993) 1581-3.
[42] Nachemson A, Elfstrom G. Intravital wireless telemetry of axial forces in Harrington distraction rods in patients with idiopathic scoliosis. *J Bone Joint Surg Am* **53(3)** (1971) 445-65.
[43] Mulcahy T, Galante J, DeWald R, Schultz A, Hunter JC. A follow-up study of forces acting on the Milwaukee brace on patients undergoing treatment for idiopathic scoliosis. *Clin Orthop Relat Res* **(93)** (1973) 53-68.
[44] Grivas TB, Vasiliadis E, Malakasis M, Mouzakis V, Segos D. Intervertebral disc biomechanics in the pathogenesis of idiopathic scoliosis. *Stud Health Technol Inform* **123** (2006) 80-3.
[45] Melrose J, Gurr KR, Cole TC, Darvodelsky A, Ghosh P, Taylor TK. The influence of scoliosis and ageing on proteoglycan heterogeneity in the human intervertebral disc. *J Orthop Res* **9(1)** (1991) 68-77.
[46] Taylor TKF, Melrose J. The role of the intervertebral disc in adolescent idiopathic scoliosis. In: Burwell G, Dangerfield PH, Lowe TG, Margulies YJ, eds. Etiology of adolescent idiopathic scoliosis: current trends and relevance to new treatment approaches. Philadelphia: Hanley and Belfus Inc.; 2000.
[47] Bushell GR, Ghosh P, Taylor TK, Sutherland JM. The collagen of the intervertebral disc in adolescent idiopathic scoliosis. *J Bone Joint Surg Br* **61-B(4)** (1979) 501-8.
[48] Dangerfield PH, Roberts N. Investigation of the diurnal variation in the water content of the intervertebral disc using MRI and its implication for scoliosis. In: D'Amico M, Santambrogio GC, Merolli A, eds. Three dimensional analysis of spinal deformities: IOS Press; 1995:447-51.

[49] Zettenberg C, Hansson T, Lidstrom J, Irstam L, Andersson GBJ. Postural and time-dependent effects on body height and scoliosis angle in adolescent idiopathic scoliosis. In: Paravertebral muscles in adolescent idiopathic scoliosis An electromyographic and morphologic study. Goeteborg; 1982:59-65.
[50] Hooper Jr. CR. The biomechanics of nocturnal brace design. *Journal of Prosthetics & Orthotics* **15(4S)** (2003) 36-9.
[51] Price CT, Scott DS, Reed FE, Jr., Riddick MF. Nighttime bracing for adolescent idiopathic scoliosis with the Charleston bending brace. Preliminary report. *Spine* **15(12)** (1990) 1294-9.
[52] Grivas TB, Savvidou OD. Melatonin the 'light of night' in human biology and adolescent idiopathic scoliosis. *Scoliosis* **2** (2007) 6.
[53] Bagnall KM, Raso VJ, Hill DL, et al. Melatonin levels in idiopathic scoliosis. Diurnal and nocturnal serum melatonin levels in girls with adolescent idiopathic scoliosis. *Spine* **21(17)** (1996) 1974-8.
[54] Machida M, Dubousset J, Imamura Y, Iwaya T, Yamada T, Kimura J. Role of melatonin deficiency in the development of scoliosis in pinealectomised chickens. *J Bone Joint Surg Br* **77(1)** (1995) 134-8.
[55] Machida M, Dubousset J, Imamura Y, et al. Pathogenesis of idiopathic scoliosis: SEPs in chicken with experimentally induced scoliosis and in patients with idiopathic scoliosis. *J Pediatr Orthop* **14(3)** (1994) 329-35.
[56] Machida M, Dubousset J, Imamura Y, Miyashita Y, Yamada T, Kimura J. Melatonin. A possible role in pathogenesis of adolescent idiopathic scoliosis. *Spine* **21(10)** (1996) 1147-52.
[57] Hilibrand AS, Blakemore LC, Loder RT, et al. The role of melatonin in the pathogenesis of adolescent idiopathic scoliosis. *Spine* **21(10)** (1996) 1140-6.
[58] Fagan AB, Kennaway DJ, Sutherland AD. Total 24-hour melatonin secretion in adolescent idiopathic scoliosis. A case-control study. *Spine* **23(1)** (1998) 41-6.
[59] Brodner W, Krepler P, Nicolakis M, et al. Melatonin and adolescent idiopathic scoliosis. *J Bone Joint Surg Br* **82(3)** (2000) 399-403.
[60] Cheung KM, Wang T, Poon AM, et al. The effect of pinealectomy on scoliosis development in young nonhuman primates. *Spine* **30(18)** (2005) 2009-13.
[61] Suh KT, Lee SS, Kim SJ, Kim YK, Lee JS. Pineal gland metabolism in patients with adolescent idiopathic scoliosis. *J Bone Joint Surg Br* **89(1)** (2007) 66-71.
[62] Moreau A, Wang DS, Forget S, et al. Melatonin signaling dysfunction in adolescent idiopathic scoliosis. *Spine* **29(16)** (2004) 1772-81.
[63] Azeddine B, Letellier K, Wang DS, Moldovan F, Moreau A. Molecular determinants of melatonin signaling dysfunction in adolescent idiopathic scoliosis. *Clin Orthop Relat Res* **462** (2007) 45-52.
[64] Guerin J. Memoire sur l'extension sigmoide et la flexion dans le traitement des deviations laterals de l'epine. 3 ed. Paris; 1842.
[65] Risser JC. Scoliosis: past and present. *J Bone Joint Surg Am* **46** (1964) 167-99.
[66] Hibbs RA, Risser JC, Ferguson AB. Scoliosis treated by the fusion operation. An end result study of three hundred and sixty cases. *J Bone Joint Surg Am* **13** (1931) 91-104.
[67] The Providence scoliosis system manual. Scoliosis Research Society, 2003. (Accessed September 25, 2007). Available at: http://www.srs.org/professionals/bracing_manuals/section8.pdf
[68] Katz DE, Richards BS, Browne RH, Herring JA. A comparison between the Boston brace and the Charleston bending brace in adolescent idiopathic scoliosis. *Spine* **22(12)** (1997) 1302-12.
[69] D'Amato CR, Griggs S, McCoy B. Nighttime bracing with the Providence brace in adolescent girls with idiopathic scoliosis. *Spine* **26(18)** (2001) 2006-12.
[70] Nachemson AL, Peterson LE. Effectiveness of treatment with a brace in girls who have adolescent idiopathic scoliosis. A prospective, controlled study based on data from the Brace Study of the Scoliosis Research Society. *J Bone Joint Surg Am* **77(6)** (1995) 815-22.
[71] Lonstein JE, Carlson JM. The prediction of curve progression in untreated idiopathic scoliosis during growth. *J Bone Joint Surg Am* **66(7)** (1984) 1061-71.
[72] Yrjonen T, Ylikoski M, Schlenzka D, Kinnunen R, Poussa M. Effectiveness of the Providence nighttime bracing in adolescent idiopathic scoliosis: a comparative study of 36 female patients. *Eur Spine J* **15(7)** (2006) 1139-43.
[73] Richards BS, Bernstein RM, D'Amato CR, Thompson GH. Standardization of criteria for adolescent idiopathic scoliosis brace studies: SRS Committee on Bracing and Nonoperative Management. *Spine* **30(18)** (2005) 2068-75; discussion 76-7.
[74] Price CT, Scott DS, Reed FR, Jr., Sproul JT, Riddick MF. Nighttime bracing for adolescent idiopathic scoliosis with the Charleston Bending Brace: long-term follow-up. *J Pediatr Orthop* **17(6)** (1997) 703-7.
[75] Federico DJ, Renshaw TS. Results of treatment of idiopathic scoliosis with the Charleston bending orthosis. *Spine* **15(9)** (1990) 886-7.
[76] Howard A, Wright JG, Hedden D. A comparative study of TLSO, Charleston, and Milwaukee braces for idiopathic scoliosis. *Spine* **23(22)** (1998) 2404-11.

[77] Climent JM, Reig A, Sanchez J, Roda C. Construction and validation of a specific quality of life instrument for adolescents with spine deformities. *Spine* **20(18)** (1995) 2006-11.

[78] Trivedi JM, Thomson JD. Results of Charleston bracing in skeletally immature patients with idiopathic scoliosis. *J Pediatr Orthop* **21(3)** (2001) 277-80.

[79] Gepstein R, Leitner Y, Zohar E, et al. Effectiveness of the Charleston bending brace in the treatment of single-curve idiopathic scoliosis. *J Pediatr Orthop* **22(1)** (2002) 84-7.

[80] Green NE. Part-time bracing of adolescent idiopathic scoliosis. *J Bone Joint Surg Am* **68(5)** (1986) 738-42.

[81] Rowe DE, Bernstein SM, Riddick MF, Adler F, Emans JB, Gardner-Bonneau D. A meta-analysis of the efficacy of non-operative treatments for idiopathic scoliosis. *J Bone Joint Surg Am* **79(5)** (1997) 664-74.

[82] Price CT. A meta-analysis of the efficacy of non-operative treatments for idiopathic scoliosis. *J Bone Joint Surg Am* **80(6)** (1998) 923-5.

[83] Fernandez-Feliberti R, Flynn J, Ramirez N, Trautmann M, Alegria M. Effectiveness of TLSO bracing in the conservative treatment of idiopathic scoliosis. *J Pediatr Orthop* **15(2)** (1995) 176-81.

[84] Lonstein JE, Winter RB. The Milwaukee brace for the treatment of adolescent idiopathic scoliosis. A review of one thousand and twenty patients. *J Bone Joint Surg Am* **76(8)** (1994) 1207-21.

[85] Vasiliadis E, Grivas TB, Savvidou O, Triantafyllopoulos G. The influence of brace on quality of life of adolescents with idiopathic scoliosis. *Stud Health Technol Inform*. **123** (2006) 352-356.

[86] Vasiliadis E, Grivas TB, Gkoltsiou K. Development and preliminary validation of Brace Questionnaire (BrQ): a new instrument for measuring quality of life of brace treated scoliotics. *Scoliosis* **1** (2006) 7.

[87] Lenssinck ML, Frijlink AC, Berger MY, Bierman-Zeinstra SM, Verkerk K, Verhagen AP. Effect of bracing and other conservative interventions in the treatment of idiopathic scoliosis in adolescents: a systematic review of clinical trials. *Phys Ther* **85(12)** (2005) 1329-39.

[88] Weiss HR, Negrini S, Rigo M, et al. Indications for conservative management of scoliosis (guidelines). *Scoliosis* **1** 2006;:5.

[89] Weinstein SL, Ponseti IV. Curve progression in idiopathic scoliosis. *J Bone Joint Surg Am* **65(4)** (1983) 447-55.

[90] The Charleston bending brace - An orthotist's guide to scoliosis management. Scoliosis Research Society,2003.(Accessed September 25, 2007). Available at: http://www.srs.org/professionals/bracing_manuals/section7.pdf

[91] Patwardhan AG, Bunch WH, Meade KP, Vanderby R, Jr., Knight GW. A biomechanical analog of curve progression and orthotic stabilization in idiopathic scoliosis. *J Biomech* **19(2)** (1986) 103-17.

[92] Andriacchi TP, Schultz AB, Belytschko TB, Dewald R. Milwaukee brace correction of idiopathic scoliosis. A biomechanical analysis and a restrospective study. *J Bone Joint Surg Am* **58(6) (**1976) 806-15.

[93] Landauer F, Wimmer C, Behensky H. Estimating the final outcome of brace treatment for idiopathic thoracic scoliosis at 6-month follow-up. *Pediatr Rehabil* **6(3-4)** (2003) 201-7.

[94] Rigo M, Negrini S, Weiss HR, Grivas TB, Maruyama T, Kotwicki T. 'SOSORT consensus paper on brace action: TLSO biomechanics of correction (investigating the rationale for force vector selection)'. *Scoliosis* **1** (2006) 11.