Chapter

Brace Treatment for Children and Adolescents with Scoliosis

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Abstract

The aim of brace treatment in patients with scoliosis during growth is (1) to stop curve progression and (2) to improve appearance/cosmesis. There is high quality evidence available supporting brace treatment. According to recent publications, the outcomes of different braces vary to a high extent. Although most of the scoliosis cases will not affect the patient's health, the impact of braces on the cosmetic outcome to date is not well determined. Standardised asymmetric braces (mainly Chêneau derivatives) have better outcomes than symmetric compression braces and may also lead to significant improvements of the deformity. For symmetric braces, no evidence exists that these could significantly change the deformity. Soft braces have no indication and the use of night-time braces should be largely restricted due to poor outcomes when compared to current standards of full-time bracing.

Keywords: scoliosis, deformity, progression, brace treatment

1. Introduction

Scoliosis is a three-dimensional deformity of the trunk and spine which may deteriorate quickly during phases of rapid growth [1–3]. Scoliosis may be caused by neuromuscular disorders and mesenchymal disorders, and it may be congenital and caused by other rare conditions, but for most cases (80–90%), it is referred to as idiopathic because no underlying cause has been identified [1–4]. Idiopathic scoliosis is further distinguished by the age at the onset of the condition. Infantile idiopathic scoliosis (IIS) is defined as starting at the age of 1.6–3 years, juvenile idiopathic scoliosis (JIS) at the age of 4–6 years and adolescent idiopathic scoliosis (AIS) at the age of 10–14 years old [1, 4]. The treatment of scoliosis consists of observation, exercises, brace treatment and spinal fusion surgery [1–3]. When considering surgery versus conservative treatment, high-quality evidence exists for the application of pattern specific exercises (PSE for example, Schroth) [5, 6] and spinal bracing [7–9]. No long-term evidence exists to support spinal fusion surgery [10–14]. Further comparisons are not possible when there is a lack of publicised surgical outcomes. High rates of complication have been reported in the mid and long terms [15–18], whilst no long-term complications have been publicised regarding PSE and brace treatment. AIS is a relatively benign disorder in most cases [19, 20] and therefore the long-term complications of spinal fusion surgery may outweigh the long-term consequences of the deformity [15–18, 21].

Figure 1.
Many different braces as still applied today for the treatment of scoliosis.

Consequently, the indication for spinal fusion surgery in patients with AIS is controversial [22] as is for most of the other scoliosis conditions [12, 23, 24]. When comparing surgery versus bracing and PSE, there is evidence for conservative treatment, but no published evidence for spinal fusion surgery for AIS.

It is well established in literature that pattern-based or pattern-specific exercises do have a positive impact on the course of the disease [5, 6, 25–27]. Obviously, general exercises or sport activities also reduce the incidence of progression in small curvatures [28] or in patients with a low risk for progression [29]. However, there is only one relevant randomised controlled trial (RCT) with an untreated control group [5], whilst other RCTs involving PSE have major flaws (amongst other things not providing an uncontrolled control group) and therefore would not contribute to high quality evidence [30, 31].

Brace treatment is supported by high-quality evidence as well [7–9]; however, the approach to bracing differs significantly in design (**Figure 1**). There are many types such as symmetrical braces [7, 9, 32–35], asymmetrical braces [8, 36–49], night-time braces [50–55] and soft braces [56, 57]. It has been shown that soft braces have no advantage over hard braces [8, 58–60]. The authors and company owners have published a body of literature [61], but independent high-quality papers have concluded that soft braces in patients at risk of progression, will not benefit from such treatment [8, 58–60]. Therefore, only hard braces should be used in patients at risk for progression.

Purpose of this review is to discuss the best possible approach for bracing scoliosis patients with respect to (1) rate of success and (2) impact on the deformity.

2. Materials and methods

A literature review has been undertaken using the Pub Med database on June 27th, 2019 and a hand search identifying outcome papers on the topic of bracing in adolescent idiopathic scoliosis containing data with respect to (1) rate of success and (2) impact on the deformity. Search terms used were (1) scoliosis, brace treatment, rate of success and (2) scoliosis, brace treatment, cosmetic outcome.

3. Results

The results of the search; (1) 31 items have been found of which 14 were found to be relevant reporting a rate of success [7, 9, 47, 52, 55, 62–70]; (2) 14 items were found of which 3 reported upon cosmetic outcomes [71–73]. In the hand search additional papers were revealed for search (1) [32–46, 48–51, 53–55, 74]. Hand search for search (2) revealed a narrative review on the topic [75].

Success rates between less than 50% and more than 90% were found [7–9, 32–55, 74]. In one study, there was a success rate of 100%; however, only small curves and only single curve patterns were included [42]. The latter study therefore cannot be regarded as being comparable to the content of the other studies found in literature.

More symmetrical braces (Boston style) have consistent success rates of just over 70% [7, 9, 32–35], whilst asymmetrical full-time braces show success rates between 50 and 95% [8, 36–49]. Night-time braces when compared to full-time braces seem to have poor results (57.1%) [55]. Standardised asymmetrical braces may have success rates exceeding 80% [8, 41, 46] even in curves of 40° and above [47, 74].

Most of the brace studies did not include any measures regarding the impact of the brace on the deformity of the trunk. Only in a few papers, the measurement of trunk deformity was reported [71–73] and in very few papers clinical and cosmetic improvements after brace treatment were documented [75].

4. Discussion

Symmetrical braces (Boston style with dorsal or ventral closures) provide success rates of 70% or little over [7, 9, 32–35] (**Figure 2**). Asymmetrical three-dimensional braces (mainly Chêneau style) may have success rates between less than 50 and more than 90% [8, 36–49]. There is a wide variety of outcomes used in research, which may be related to the differing qualities of asymmetrical brace adjustments and designs (**Figures 3–5**).

With a more or less symmetrical tube shape (**Figure 2**) brace construction is more simple, whilst asymmetrical braces can only be constructed and adjusted well

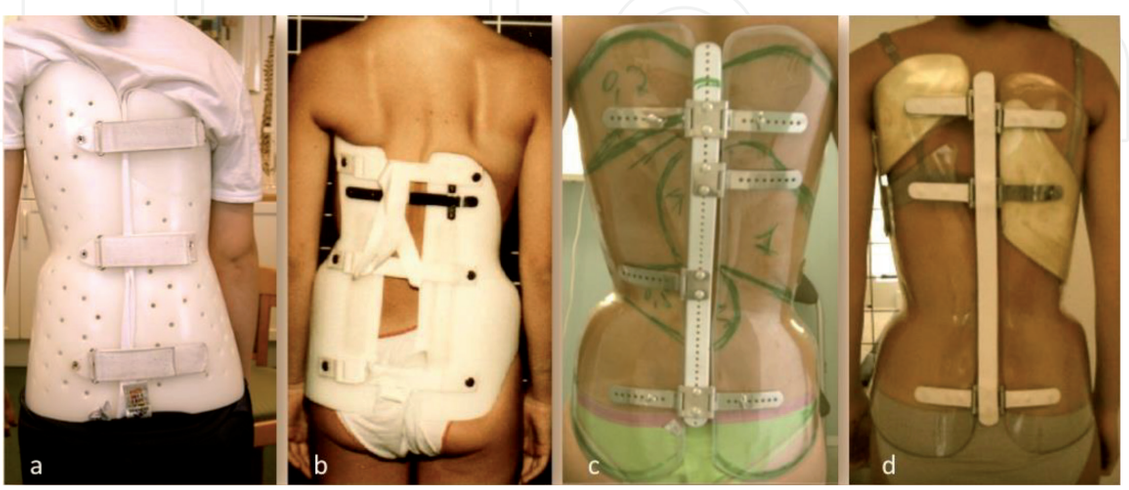

Figure 2.
Visually almost symmetrical braces mainly correcting via trunk compression. (a) Boston brace made with a little shift towards the thoracic concavity, (b) Boston brace from Denmark pushing the trunk into the main thoracic curve and (c and d) symmetrical compression braces from Italy [34, 35].

Figure 3.
Different Chêneau style braces all for a main thoracic curve to the right. (a) Rigo brace and (b) Gensingen (GBW) brace clearly mirroring the deformity shifting the thoracic part of the trunk to the left. (c and d) Hand-made Chêneau derivatives without obvious impact on the trunk deformity still decompensated to the right in the brace. In a good asymmetrical high correction brace mirroring of the deformity will always be visible (a and b).

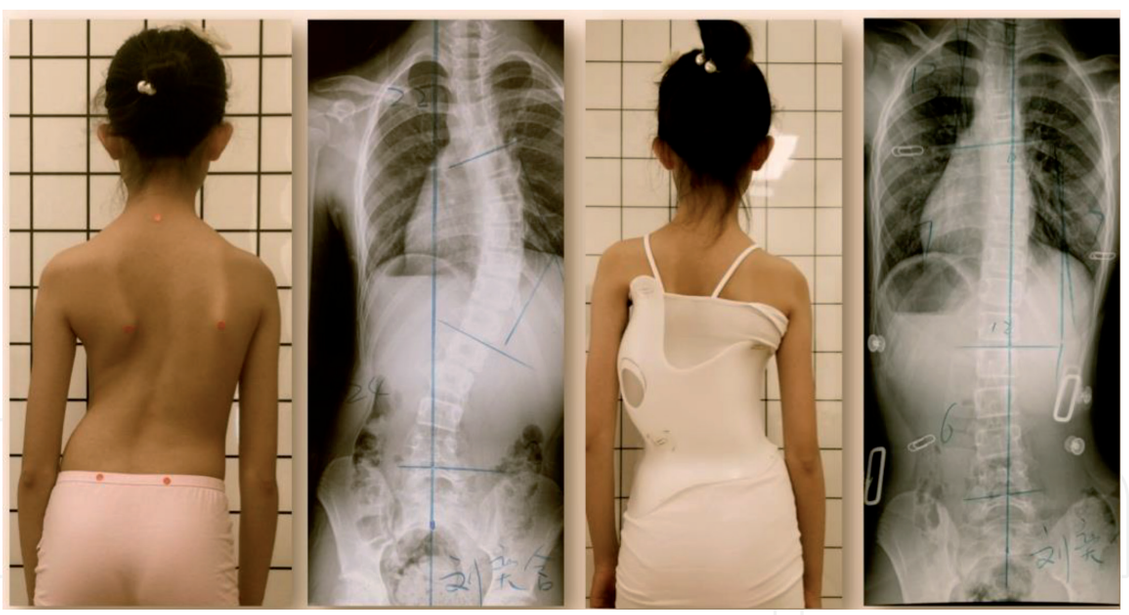

Figure 4.
Asymmetrical high correction brace (GBW) with a clear mirroring of the deformity in the brace and a reasonably successful cosmetic improvement along with the in-brace correction as shown on the right. GBW brace produced in May, 2019 with a thoracic curvature of 45°, lumbar curvature of 24°. In-brace X-ray, thoracic 7°, lumbar 7° Cobb (courtesy of Xiaofeng Nan, Xi'an, China).

with a very experienced and highly skilled technician/orthotist or by using well calibrated and reliable CAD (computer-aided design, see **Figures 3–5**) series based on certain classifications and proven reliable methods [76, 77].

It is not the name of the brace that ensures a good outcome; it is the brace manufacture and adjustments based on standardised algorithms [76, 77]. It is concerning that in many studies on brace treatment, an example of the brace design is not presented in a picture [55, 78]; sometimes the brace design is not even named [78].

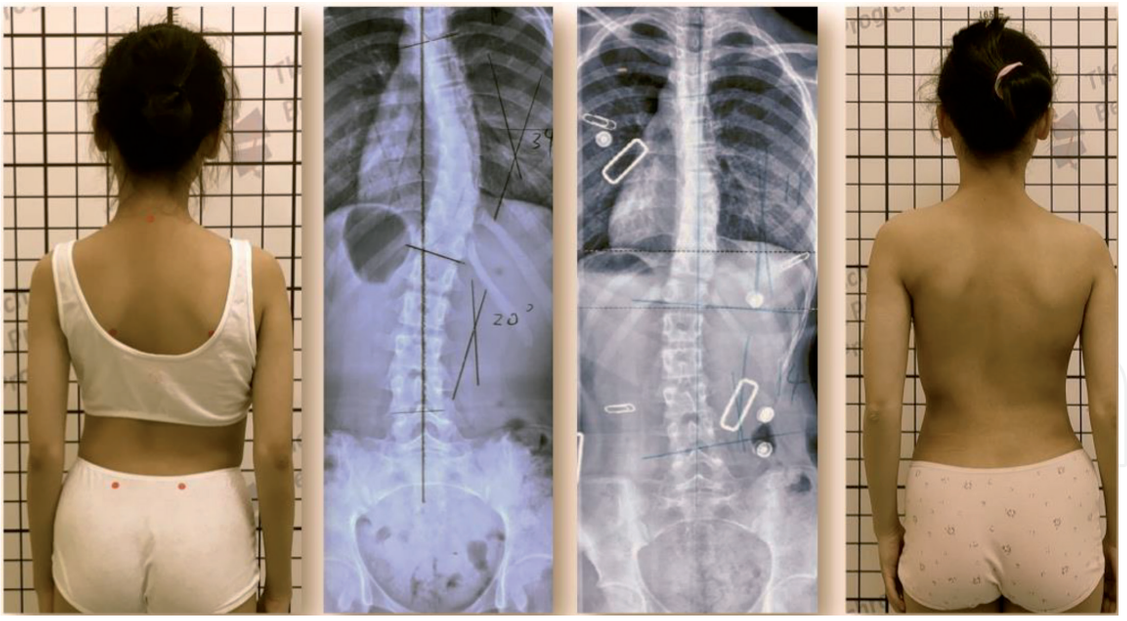

Figure 5.
Girl with a Risser stage of IV. The thoracic curve initially was 34° and the lumbar 20°. After wearing the GBW brace in-brace X-ray of the thoracic curve was 11° and lumbar 14°. Half a year later X-ray without the brace (for over 24 hours) is 24° and lumbar 20° with a reasonable clinical correction as seen on the right. This case shows that also in the more mature patient significant cosmetic improvements can be gained (courtesy of Xiaofeng Nan, Xi'an, China).

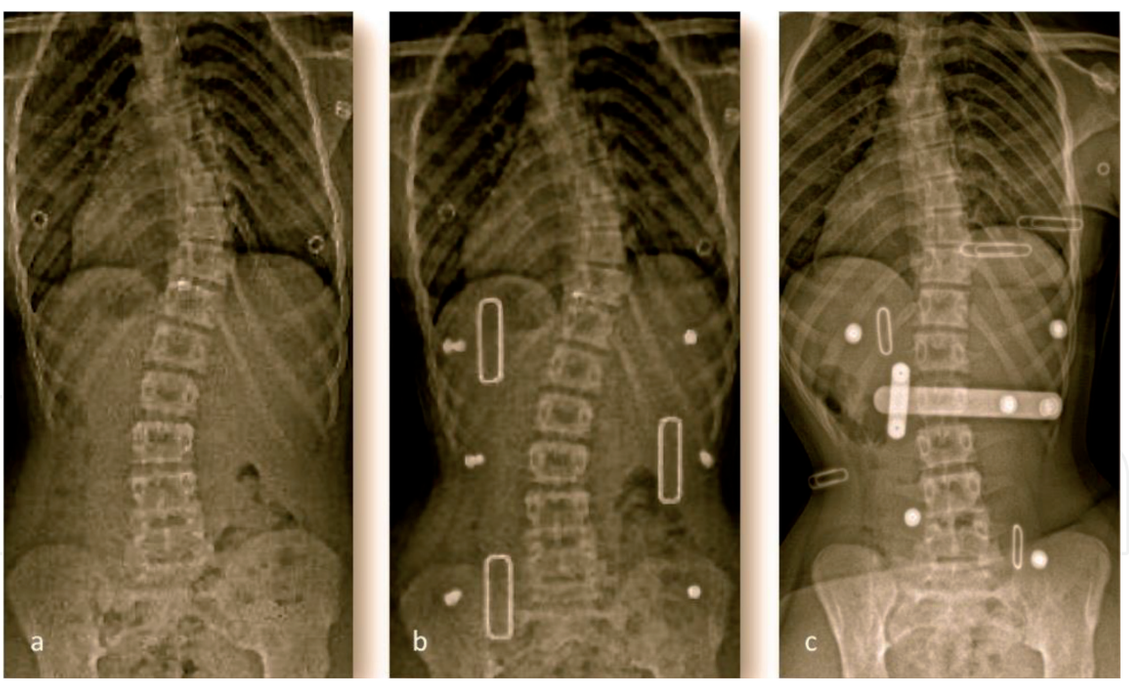

Figure 6.
X-ray of a patient with a main thoracic curve to the right (a). (b) No correction in a Boston style brace and (c) reasonable correction of the curve in a GBW, after the patient changed her brace due to discomfort in the Boston brace (courtesy of Dr Marc Moramarco, Scoliosis 3DC, Woburn, MA, US).

Outcomes with respect to Cobb angle: Landauer et al. in their retrospective study [37] examined 62 adolescent female patients with right thoracic scoliosis (20–40 Cobb degrees) treated with a Chêneau style brace. Initial correction improvements of >40% ($p < 0.002$) and satisfactory compliance ($p < 0.004$) gained a significantly successful outcome (**Figure 6**). There was an average improvement of 7° in Cobb angle, with patients with good compliance and with a significant initial correction.

The authors concluded that compliant patients with a high initial correction can expect a final correction of around 7°, whilst compliant patients with low initial correction may maintain the curve to some extent. Bad compliance was associated with curve progression.

Bullmann and colleagues in their study [38] had 52 patients with a Cobb angle of between 25 and 40°. Prior to starting brace treatment with the Chêneau-Toulouse-Muenster orthosis, skeletal age and flexibility of the curve (bending films) were evaluated. The average follow-up after weaning of the brace was 42 months (36–78 months). Three years after weaning there was an overall increase of the Cobb angle to 37° on average. The authors concluded that curve progression was prevented in 58%. Prognostic risk factors were a young age at the start of brace treatment, a thoracic curve, unsatisfactory curve correction in the brace and a male gender.

Zaborowska-Sapeta et al. presented a prospective study using SRS and SOSORT guidelines [40], including 79 progressive idiopathic patients (58 girls and 21 boys). The treatment included a Chêneau brace and physiotherapy. And the patient group included an initial Cobb angle between 20 and 45°, Risser 4 maturity at final assessment and no other or previous brace treatment. The follow up results were outlined that 25.3% improved, 22.8% were stable with no change in progression, 39.2% worsened and progressed but below the surgical indicated level of 50° Cobb angle and 12.7% worsened and progressed beyond 50°. Two patients out of the initial 79 patients progressed >60° Cobb angles. Progression concerned the younger and less skeletally mature patients. The results of this study may indicate that this Chêneau style and design of the brace used is more effective in reducing the incidence of surgery, even when it is compared to the natural history (without treatment) of this condition.

These are two studies with low quality Chêneau style braces. Both studies indicate that less skeletally mature patients had worse outcomes than the more mature patients. This seems the typical finding in low quality braces that patients more at risk for progression have worse outcomes than the more mature lower-risk patients [55, 70].

In studies with more high quality brace designs, the more immature patients seem easier to correct and preserve better outcomes than the more mature patients [45, 47, 74, 75, 79, 82].

Aulisa and colleagues reviewed 93 patients with adolescent idiopathic scoliosis (AIS) that implemented the PASB (Progressive Action Short Brace) and the Lyon method [46]. The age range was wide, ages from 10 to 35 years old. Two groups were separated according to their Cobb, less than 30° and more than 30°. The follow-up was long, at a mean age of 184.1 months (±72.60) after treatment was stopped. The pre-treatment mean Cobb angle was 32.28° (±9.4°), the post treatment mean was 19.35° and then increased to 22.12° in the 10 years after the end of treatment. No significant change was noted in the mean Cobb angle between the end of weaning and the later follow up ($p = 0.105$). Patients prescribed a brace from the beginning had reduced Cobb angles by 13° within the treatment period, which then worsened by 3° after treatment ended. The group with Cobb angles >30° showed a pre-brace mean curve of 41.15°; then at the end of treatment, the mean angle was 25.85° and had worsened with a mean of 29.73° at later follow-up. The group with ≤30° Cobb angle initially presented with a mean Cobb angle of 25.58° which then reduced to a mean of 14.24°, but then worsened after treatment to 16.38°. There was no significant change in the mean progression of Cobb angles between the two groups. This paper concluded that scoliosis did not progress in 15 years after treatment. The natural history of this pathology, at these levels of moderate severity, deems that normally a progressive but small increment will continue to worsen

until skeletal maturity. High-quality bracing is a valuable and effective alternative treatment method, demonstrated by successful long-term follow-up outcomes, even with patients that initially present with moderate AIS.

In another paper with curves initially presenting at 40° and which included over fifty-five participants [47]. Just under half of the participants had a minimum follow-up of 18 months and an average of 30.4 months (SD 9.2).

The 25 patients had the following characteristics at their initial presentation: Cobb angle of 49° (SD 8.4; 40–71°); 12.4 years old (SD 0.82); Risser: 0.84 (SD 0.94; 0–2). A statistical z-test was used to compare the success rate in this cohort to the success rate in the prospective braced cohort from BrAIST (Bracing in Adolescent Idiopathic Scoliosis Trial).

At follow-up, the average Cobb angle was 44.2° (SD 12.9). Two patients progressed, 12 patients were able to halt progression, and 11 patients improved. Angle of trunk rotation (ATR), demonstrating cosmetic improvements, decreased from over 12° to just over 10° in the thoracic spine ($p = 0.11$) and from 4.7 to 3.6° ATR improvements noted in the lumbar spine ($p = 0.0074$). When comparing the success rate to the BrAIST cohort with the success rate of patients in this cohort, the difference was statistically significant ($z = -3.041$; $p = 0.01$). The Gensingen brace was successful in 92% of cases of patients with AIS, whose patient group initially presented with large curvatures and the improvements were significantly more effective when compared to the BrAIST study results of 72%, whose patient group initially had smaller curves comparatively.

Recently, a paper was published with the SRS inclusion criteria for studies on bracing (Girls only, Age 10–14 years, Risser 0–2, Cobb angle 25–40°), the range of Cobb angles was extended to curvatures of up to 45° in order to increase the amount of participants in the study [79]. Twenty-eight patients from their prospective cohort (12.5 years; Risser 0.8; Cobb 32.6°) were weaned off their CAD Chêneau style brace (Gensingen brace). The results of this cohort were compared with the BrAIST study by Weinstein et al. with the help of the z-test. Failure in both studies was defined as a Cobb angle reaching or exceeding 50° Cobb.

The in-brace correction was 51.4%. Two out of the 28 patients (7.1%) from this group reached or exceeded 50° Cobb angle at final follow-up making a success rate 92.9%. Comparative to the results of 72% in the BrAIST study, the improvement was highly significant in the z-test ($z = 2.58$, $t = -3{,}42$, $p = 0.01$).

The authors concluded that the results as achieved with the Gensingen brace were significantly better than the results as achieved with the Boston brace. Therefore, the standards should be adapted from symmetrical compression braces to asymmetrical high correction braces, maintaining improved standards by use of a classification-based corrective system for most of the possible curve patterns.

These results show the high variability of outcomes with different asymmetrical braces with very different qualities. Low quality asymmetrical braces seem to have outcomes with insignificant effects to natural history, and high-quality asymmetrical braces offer the advantage of improving Cobb angle and the cosmetic and postural issues of the deformity [45–47, 74, 75, 79–82].

4.1 Clinical outcomes

In patients with AIS (80–90% of all scoliosis patients) rarely suffer severe health problems [3, 19, 20]. The cosmetic outcome of brace treatment might be important rather than the Cobb angle which is visible on the X-ray only. However, there is only a small body of literature on brace treatment with a focus on cosmetic outcomes [75]. For more symmetrical braces mainly correcting the curve via trunk compression (**Figure 2**) no clinical evidence exists, that these would significantly influence

the trunk deformity. In one paper on a modified Boston brace changes of lumbar ATR were detected, but in the thoracic region obviously no improvements were obtained [72]. For asymmetrical high-quality full-time braces, there is evidence that cosmetic improvements can be gained [46, 47, 73–75, 79–82].

Trunk deformity can be improved when using asymmetrical CAD libraries [46, 47, 73–75]. This has recently been confirmed in another end-result study [79]. It has also been shown that improvements of the trunk deformity may stay stable years after brace weaning [46, 82] (**Figure 7**).

In a study with more mature patients, cosmetic improvements have been reported [71]. The treatment indication for these patients was to improve aesthetic/cosmetic reasons and/or for curve reduction. Their Risser sign was 4–5 initially and by the end of treatment 34 females and 2 males, age 16.2 ± 1.6 years had a Cobb angle of 27.6° ± 8.9°. The Lyon or SPoRT (so called Symmetric, Patient oriented, Rigid, Three-dimensional, active) braces were used as treatment. A brace wearing prescription is of 18–24 hours daily, SEAS (Scientific Exercises Approach to Scoliosis) exercises, rapid weaning (2–3 hours every 6 months). 39% of this cohort improved and 46% of the group initially presented with curves over 30° cobb angle. Only one patient progressed 6°. Results were successful; statistically significant reductions of Cobb angle maximal (−4.4°), thoracic cobb angles (−6.0°), thoracolumbar cobb angles (−6.6°), and further statistically significant improvements for the Aesthetic Index outcome. The authors concluded that before 20 years of age, even in skeletally mature patients, it is possible to reach radiographic and aesthetic improvements, although it was not as significant as when during growth spurts. In a recent review, a case series is documented with obvious clinical corrections in patients treated with the Gensingen brace [75]. All patients from this case series had curvatures of 45° and over at the start of the treatment, whilst the patients were immature and were clearly recompensated after brace weaning (**Figures 8** and **9**).

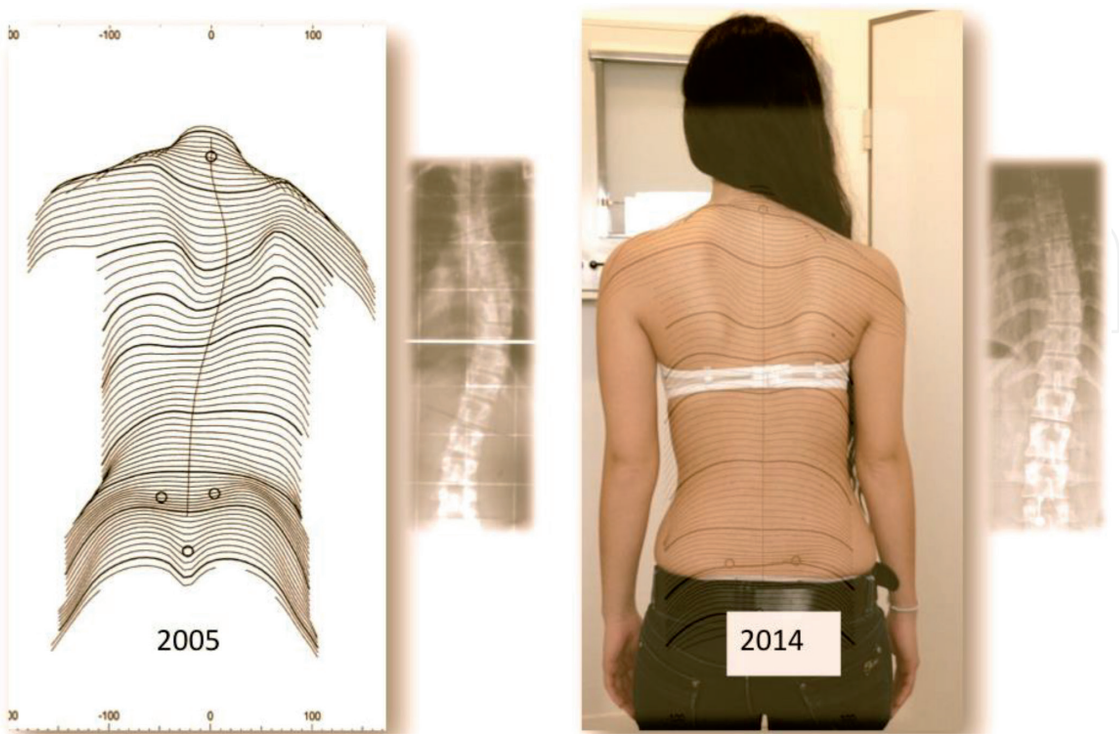

Figure 7.
Clinical and radiological improvement 5 years after weaning off a Chêneau light brace. Initially the patient had 38° and a significant decompensation of the trunk. Five years without the brace the patients' trunk seems recompensated and the residual curve is 19° [80].

Figure 8.
Male patients with a decompensated thoracic curve of 56° to the right. Slightly recompensated 2010 as the intermediate result during the treatment with a GBW. Six months after brace weaning (2012), the posture and X-ray are clearly compensated. The patients' residual deformity is hardly visible although the Cobb angle is still 43° as shown on the right. This case shows that significant cosmetic improvements can be achieved with modern asymmetric high-quality braces [75].

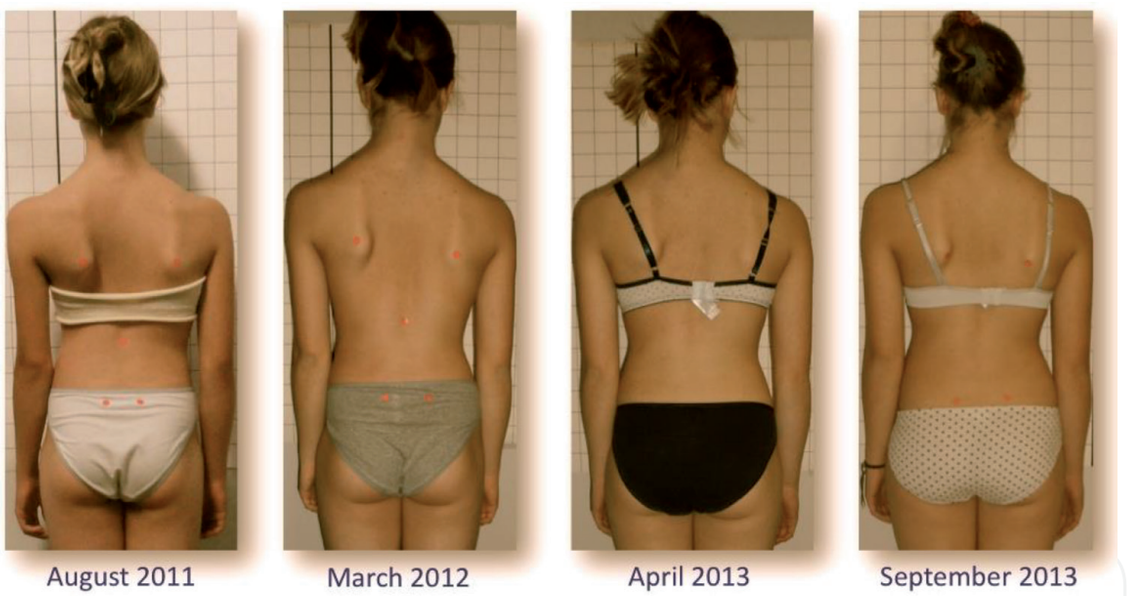

Figure 9.
Clinical changes from the start of treatment with a GBW (left) to 3 months after brace weaning (right). Initially, the patient is decompensated to the right and at the end a mature woman is visible with a well-compensated trunk [75].

In rare cases, it is possible that these braces can improve the trunk deformity significantly, whilst the Cobb angle stays unchanged [75] or even shows a progression [83]. Therefore, for patients with AIS, using CAD libraries and specialists should be preferred [46, 47, 73–75, 79–82].

4.2 Outcomes of part-time bracing

As early as in 1997 in a meta-analysis, it has been shown that part-time bracing is clearly inferior to full-time bracing [84]. Later, these findings have been confirmed [37, 85]. But night-time braces are still widely marketed [54, 55] despite of the fact that brace wearing time, along with in-brace correction determines the outcome of

brace treatment [37, 84]. The low success rate of night-time bracing would not make this a beneficial option. In the contrary, when the curve gets worse with night-time bracing, the patient will lose trust in bracing and the compliance with full-time bracing will probably be reduced. Furthermore, the bigger the curve and the more mature the patient, the longer the treatment might last with less possibility of a cosmetic improvement.

On the other hand, when brace treatment in the immature adolescent with a moderate degree of curvature starts with a high-quality brace full-time in the most important phase of growth drastic improvements can be achieved (see **Figure 7**) and part-time brace wearing can be offered to the patients when the intermediate curve is below 20°. It is logical to start with full-time treatment with an asymmetrical high-quality brace in the immature patient at risk for curve progression as this will usually lead to a final improvement of cosmetics and to the shortest possible treatment duration.

With respect to patient compliance, the bracing service besides reliable in-brace corrections should also offer braces with the best possible comfort. This means the brace should be made as small as possible without compromising its corrective effect. Compression effects in the brace should be minimised, whilst the corrective movement (shift) should be maximised (**Figures 3–5**).

In patients at risk of progression and curvatures between 15 and 25°, however, night-time bracing may be of benefit. In a paper by Seifert and Selle [69], 22 children ranging from 5 to 12 years old were provided with a Chêneau derivate brace. Patients with a Cobb angle of 20–25° and 15–19° in cases of progression, bracing was indicated and provided in this study. Follow-up was 25 months and in the main curves, a successful correction of 82.2% was attained. The mean Cobb angle prior to brace treatment was 20.2°. At the end of brace treatment, it was 15.8° Cobb angle. Three cases experienced Cobb angle progression measuring over the 25° limit and then part-time bracing had to be re-adjusted to full-time bracing. In 86.4% patients, either improved Cobb angle measurements or their halted progression and spinal fusion operations were avoided.

4.3 The sagittal profile

AIS is a 3D deformity usually also compromising the sagittal profile of the spine and trunk. Structural thoracic curves lead to a flatback or even a hollow back in the thoracic region, whilst structural lumbar curves usually lead to loss of lumbar lordosis or to a lumbar kyphosis [1–3]. Whilst the long-term consequences of a thoracic flatback are yet to be determined, loss of lumbar lordosis is clearly correlated to non-specific chronic low back pain [86, 87]. Improvement of lumbar lordosis can also improve the frontal plane deformity (Cobb angle) [88–90]. A feature of a brace should also address the sagittal profile of the deformity [45, 47, 79, 91, 92]. It is concerning that braces are provided which reduce lumbar lordosis and increase thoracic flatback [32–35] (**Figure 10**).

4.4 Bracing in curves of 40° and over

There is some evidence that asymmetrical high-quality braces may stop curve progression in patients with Cobb angles exceeding 40° [47, 74]. In addition, significant clinical and radiological improvements have been documented [47, 75, 79, 82]. Considering that in patients with AIS, there is no long-term evidence supporting spinal fusion surgery [10–14], and in view of its significant long-term complications [15–18], brace treatment for curves exceeding 40° should be of importance. According to literature, asymmetrical high-quality braces offer success rates of about

Figure 10.
Patient with a thoracolumbar curve pattern treated with a Boston brace (upper line of pictures) and later with a Gensingen brace (GBW, see lower line of pictures). For this curve pattern, the GBW is smaller compared to the Boston brace. It is also observed that the Boston brace reduces lumbar lordosis, whilst the GBW preserves lumbar lordosis (courtesy of Dr Marc Moramarco, Scoliosis 3DC, Woburn, MA, US).

90% in this group of patients and can be regarded as the safest bracing approach for curves exceeding 40° when worn full-time at the start of treatment (**Figure 11**).

4.5 Comparing outcomes symmetrical versus asymmetrical braces

There is a small body of literature comparing asymmetrical high-quality Chêneau style braces to symmetric Boston style braces [45, 47, 76, 79]. It has been shown that the outcome of Chêneau derivatives is significantly better with respect to the success rate [45, 47, 79]. Whilst in-brace corrections in the Rigo brace (RCO) were comparable to the in-brace corrections of the Boston brace [45], in-brace corrections in the Gensingen brace (GBW) at average have been significantly higher [47, 76, 79].

In research that implements the Rigo brace (RCO) and compares the outcome with a basic Boston-style TLSO brace (Thoraco-lumbar-orthosis) [45], a retrospective study was published over 15 years, up until 2014. The initial major curves included only those between 25 and 40° and included 108 patients (93 girls) with a mean (±standard deviation) age at brace initiation of 12.5 ± 1.3 years. Thirteen participants wore an RCO, and 95 participants wore a TLSO brace. Mean pre-bracing major curves were 32.7 ± 4.8° in the RCO group and 31.4 ± 4.4°, slightly lower in the TLSO patient group ($p = 0.387$). No RCO patient and 34% of TLSO patients progressed to spinal

Figure 11.
Immature patient with a thoracic curve exceeding 70° treated with a GBW with an additional shoulder retraction strap. Clinically mirroring of the deformity is clearly visible whilst the patient is decompensated to the right without the brace on and an overcompensation to the left in the brace. After 9 months of full-time treatment, a clear improvement (re-compensation) has been achieved [47].

surgery (p = 0.019). After treatment ended, the main curves of patients improved by 6° or more in 31% of the RCO group and only 13% of the TLSO group (p = 0.100). Patients were comparatively similar at baseline and had similar compliance of in-brace time, but there was a significantly lower rate of spinal surgery in the RCO group [45].

5. Conclusions

Asymmetric high-quality braces provide the highest rate of success and the best documented cosmetic outcomes. Symmetric braces correcting via compression should be abandoned and their worldwide provision reconsidered.

There is no indication for soft braces.

There is no indication for night-time braces in the normal range of brace indications (curves of 25° and over).

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Conflict of interest

HRW is receiving financial support for attending symposia and has received royalties from Koob GmbH & Co KG. The company is held by the spouse of HR Weiss. DT is employed by an orthotic company that supplies a wide range of orthotics, including spinal braces.

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