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Methodology

Management

Standardising the treatment with Chêneau braces via CAD: Prospects and risks

HR Weiss[1]

Abstract

Introduction

The use of a brace has become accepted as an effective way to treat idiopathic scoliosis. However, the effectiveness of today's Chêneau treatment goes way beyond just controlling an increase in curvature during adolescence. In the meantime, it has been demonstrated that significant cosmetic corrections to torso asymmetry are possible even with curvatures above the 50° limit. According to the latest findings, the development in making Chêneau braces, from plaster models to CAD/CAM-based production, can help improve the standard of treatment. In particular, universal availability makes it possible for scoliosis sufferers to receive high-quality braces where they live even when there is no specialist in the vicinity.

Methodology

This is a selective review of the literature with respect to the outcome of Chêneau brace treatment. Additionally the different CAD approaches as available today are presented and reviewed critically on the basis of current evidence.

Conclusion

With the CAD/CAM technique, it is possible to receive a brace of highest quality and best possible comfort within just a few days. Medical supply stores that are not very specialised will still have access to models that are standardised and tested in practice. However, individual CAD/CAM-based treatment without a time-tested brace library and without supervision by a specialist will not result in any advantages for the patients.

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Introduction

The use of a brace has become accepted as an effective way to treat idiopathic scoliosis. A Cochrane review[12] successfully confirmed its effectiveness already in 2010. The latest development is a randomised controlled trial (RCT) in North America[30]. This study was based on the inclusion criteria recommended by the Scoliosis Research Society (SRS)[13]. The success rate (no increase in curvature exceeding 5° Cobb) in this trial was approx. 72% for more-or-less symmetrical braces in the USA and Canada (TLSO). In two retrospective trials in Germany[25] and Italy[4] (both of them using the SRS inclusion criteria as well) with braces of asymmetrical design, the success rate was over 95%. These last two trials were based on the corrective principles according to Chêneau. While the studies cited are not entirely comparable, since they do not have the same study design, the difference in the success rate despite the same inclusion criteria nevertheless must be regarded as significant. Asymmetrical[4,25] (pattern-optimised) braces are obviously superior to symmetrical[8,30] (or non-specific) braces with respect to results. The question is therefore how to ensure the best possible treatment success for those suffering from scoliosis, since they have to sacrifice their quality of life to a considerable degree when undergoing brace treatment. The Chêneau brace may be regarded as the prototype for asymmetrical models. It can be individually modelled from a plaster cast and then vacuumed, or the model can be shaped with CAD/CAM (computer-aided design / computer-aided manufacturing) from individual measurements / scan data and vacuumed. At present, there are several CAD models that hearken back to the corrective principles used by Dr. Chêneau. Before we turn our attention to the prospects and risks inherent in CAD-based Chêneau braces, it behoves us to briefly summarise the history of the Chêneau brace first.

History of the Chêneau Brace

The history of treatment with Chêneau braces dates back to the 1970s in Münster / Westphalia. At the university clinic there, the Chêneau-Toulouse-Münster (CTM) using polyethylene developed out of Chêneau's cast resin treatments[18]. However, the history of the Chêneau brace is also closely interwoven with three-dimensional scoliosis treatment according to Katharina Schroth. Dr. Chêneau already visited Katharina Schroth in Sobernheim (renamed Bad Sobernheim in 1995) back in the 1970s. More visits followed, and Dr. Chêneau had intensive conversations with Christa Lehnert-Schroth as well, the head of the sanitorium that existed then and the daughter of Katharina Schroth. It was during this time that Chêneau learned a lot about the scoliotic breathing pattern and how to correct it (rotational angular breathing). He also became acquainted with the pattern classification according to Lehnert-Schroth, which he embraced[9, 10]. At the same time, Elena Salvá – one of Christa Lehnert-Schroth's first students – opened up her own specialised physiotherapy practice (Institut Elena Salvá) in Barcelona. In the late 1980s, her son-in-law Dr. Manuel Rigo studied physiotherapeutic scoliosis treatment in Sobernheim, just like his mother-in-law before him. He later succeeded her as the head of the Institut Elena Salvá. In the 1990s, on the initiative of the author and Katharina Schroth's grandson, annual workshops and advanced training courses for physiotherapists and orthopaedic technicians were held in Bad

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Sobernhem. In these courses, Dr. Chêneau demonstrated the technique of producing braces and talked about his constantly on-going developmental work. Dr. Rigo took part in these courses as well. He learned how to produce Chêneau orthoses from a plaster cast. A collaborative effort came about that led to the book 'Praxis der Chêneau-Korsettversorgung in der Skoliosetherapie' (The Practice of Producing Chêneau Braces in Scoliosis Therapy) being published in 2000 by authors Hans-Rudolf Weiss, Manuel Rigo and Jacques Chêneau[18]. In 2002, the author introduced CAD/CAM treatment at the Asklepios Katharina Schroth Clinic, which he was the head of at the time. He initially used the system on which Rigo's plaster models were based[15]. While Rigo contributed more and more self-produced plaster models from Barcelona, the CAD versions of the models were tested in Bad Sobernheim. It had always been the author's desire to make braces smaller and more comfortable for patients. In the course of his own developmental work (Bad Sobernheim deflexion orthosis, see also [15]), he started to consistently leave off one pelvic half of the brace (Figure 1) in 2001, amidst protests by Chêneau. This was later followed by the development of the Chêneau light® model[22]. In 2009, he eventually began to develop his own CAD series (Gensingen Brace according to Dr. Weiss® – GBW) with sagittal correction that was optimised even further[23]. Now with his own brace library, it has been possible for the author to incorporate his experiences in producing more than 30,000 braces and make further developmental steps towards braces that are 'smaller and more comfortable with the best possible correction' (Figure 2). Various people and health centres have played decisive roles in the history and development of producing Chêneau braces. In Germany, besides those in Sobernheim, Prof. Neff in Berlin and Freddy Hoeltzel in Offenburg deserve mentioning. However, the Chêneau principle is used in many countries. For instance, the author met a Chêneau student (Li Xiangdong) at a convention in Beijing in June 2013 and visited his workshop.

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The Scientific Principles of the Chêneau Brace Treatment

In 1985, the first study of the Chêneau brace including end results after patients were weaned off the brace was published by Hopf and Heine[7]. While this study did not have a control group, the corrective effects of the Chêneau brace treatments at the time were described. They can be compared with those achieved today. Later, there was a series of publications on the Chêneau brace with comparable corrective results[3]. Even back then, the corrections from the Chêneau brace were clearly superior to those with the more-or-less symmetrically constructed Boston brace[1]. Recently, it has been possible to improve the corrective results from various Chêneau brace models even further (Table 1 from [28]). The end results of the latest trials published are interesting as well: While the success rate (no evidence of progression) in a prospective study was still at 80% with the 1999/2000 standard[20], we can now assume a success rate of over 95% with modified Chêneau braces according to the current standard based on two

Figure 1: Left: Model 2000 according to Chêneau (constructed in Berlin) with insufficient correction of lumbar curvature in the brace only to 48°. Right: correction to 20° in the Bad Sobernheim deflection orthosis. The Model 2000 protruded quite a lot, and the lumbar corrections were rather weak. This is why the author experimented with new brace designs (right) at the time[15].

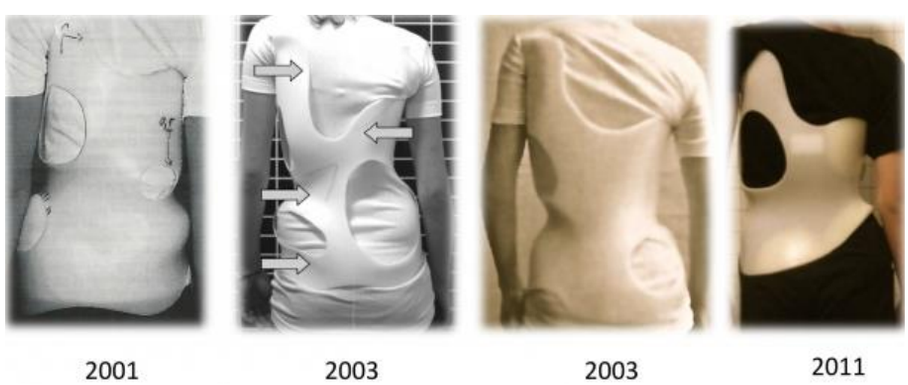

Figure 2: Left: Model 2000 (with markings by the author), made without a shift in the opposite direction at the time. Centre: The first CAD brace with a pronounced shift in 2003 [15]. Right: Model 2011 from the Chêneau Gensingen library with a shift and noticeably smaller design.

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Table 1: Publications on Chêneau brace treatment of adolescent scoliosis in Pub Med and 'Scoliosis'. The average corrective effect (Δ corr) is stated in the studies and was statistically compared to the current CAD standard (Gensingen Brace according to Dr. Weiss®). This statistical analysis reveals significant differences compared to several former treatment methods[7, 11, 14].

Authors	Year	n	Δ Corr	Δ Cobb	Sign
Hopf & Heine[7]	1985	52	41%	36°	0.05
Rigo et al.[14]	2002	105	31%	37°	0.01
Rigo[16]	2007	32	42%	33°	ns
Weiss et al.[22]	2007	81	51%	36°	ns
Maruyama et al.[11]	2012	54	36%	37°	0.05
Weiss & Werkmann[25]	2012	34	59%	31°	ns
Borysov et al.[2]	2013	92	56%	29°	ns
Compared with:					
Weiss et al.[28]	2013	21	66%	31°	

independent trials[4, 25]. While the last two studies referred to are retrospective, they are nevertheless based on the inclusion criteria recommended by the Scoliosis Research Society (SRS)[13]. What is more, the end results are much better than the 72% success rate of the randomised study done in North America, which was celebrated there as proof of the effectiveness of scoliosis orthoses[30]. However, the effectiveness of state-of-the art Chêneau treatment goes way beyond just controlling an increase in curvature or potentially correcting curvatures during adolescence (Figure3)[26]. In the meantime, it has been demonstrated that significant cosmetic corrections to torso asymmetry are possible even with curvatures above the 50° limit (Figure 4)[27].

Prospects of CAD-Based Chêneau Brace Production

Producing braces from a plaster cast is a practice that is still quite widespread today. Standardisation is practically impossible with this method, since every brace is newly modelled and constructed. As a result, there is considerable variability, with the results ranging from 'satisfactory' to 'very good' with experienced technicians, while braces made by technicians without suitable experience rarely earn a 'satisfactory' mark. And yet it is important for patients that an ideal corrective effect be achieved and, along with maximum comfort. As is well-known, the best possible treatment results can only be expected from a combination of good corrective results with optimum wearing time[26]. In contrast, producing Chêneau orthoses from individual measurements / scan data with CAD/CAM can be a highly reliable way to make braces under certain circumstances. The requirements for this are: 1) a fine-tuned brace library, 2) supervision by a specialist and 3) a distortion-free brace sizing programme. The corrective effect from the orthosis and patient compliance are the primary factors that determine the end result[26]. A pattern-optimised orthosis processed according to the latest findings determines the (three-dimensional) corrective effect. Together with adept psychological patient management, the degree of comfort and inconspicuousness of an orthosis paves the way for optimum levels of compliance. An orthosis can only be comfortable when compression effects are precluded. Due to constant product development of CAD-based orthoses, this can be guaranteed thanks to improvements to the CAD library. Minimising the orthosis size – reducing it to what is absolutely necessary – can be accomplished during the developmental phase as well. The pattern library of the Gensingen brace according to Dr. WeissÒ (GBW) consists of 7 basic patterns (Figure 5). These were derived from the Augmented Lehnert-Schroth Classification[23]. Special forms that recur less frequently have also been added. This covers the majority of possible curvature patterns (approx. 90%). For the approx. 10% that remain, pattern selection and sizing can be followed by subsequent adjustments and optimisation using a

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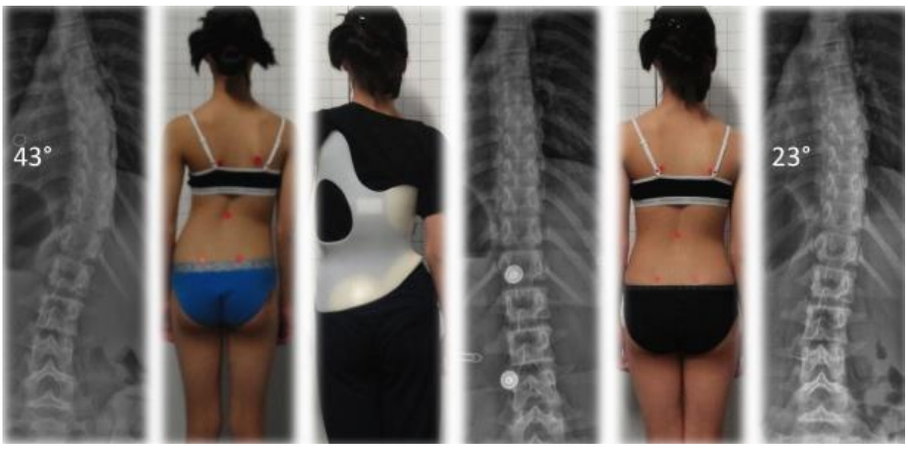

Figure 3: Left: immature patient from New Zealand in the author's practice in 2011 with 43° at the beginning of treatment. Centre: Gensingen Brace® (GBW) with good correction. Right: intermediate result of 23° after 6 months of consistently wearing a brace before receiving a new one. The torso is recompensated. Since then, there have only been slight improvements with little growth. The end result after being weaned from the brace is expected in the summer of 2014[27].

Figure 4: Cosmetically favourable course of treatment in a boy, originally with a Cobb angle of 56°, by recompensating the left-leaning torso in a 3BH Gensingen Brace® (GBW)[27].

special programme. In this way, highly individualised brace treatment is possible even with so few basic patterns. By basing orthosis production on CAD and through the use of a suitable brace library, cumulative and time-tested know-how is available anytime and anywhere. This kind of brace production is not dependent on the daily form or learning curve of the technician. Medical supply stores that are not very specialised will have access to models that are standardised and tested in practice. Another advantage of the state-of-the-art CAD/CAM technique has to do with how quickly braces can be provided. Foreign patients (from Italy, England, the Netherlands, Russia, Malaysia, China, South Korea, USA, New Zealand) are regularly treated at the author's practice. Using the CAD/CAM technique, we can offer 'overnight' service. The patients are fitted with the brace on the day following the examination. In the practice of Dr. Moramarco in the USA (Scoliosis 3DC), the GBW is also fitted the next day, and sometimes even on the same day. Patients come to him from all 50 states.

Discussion

Risks of CAD-Based Chêneau Brace Production

Despite all of its advantages, even the CAD/CAM method of producing braces has a few remaining sources of errors, usually attributable to an improper design (e.g. flat back design), to faulty modelling or simply to selecting the wrong pattern.

The significance of the sagittal profile when producing braces for idiopathic scoliosis – what factors speak against a 'flat back design'?

There are CAD models in Germany that neglect sagittal profile correction or even increase the tendency of flat back syndrome and lumbar kyphosis (flat back design). For this reason, such orthoses are only truly recommendable for thoracic kyphoscoliosis (Figure 6). The majority of scoliosis cases are idiopathic (80-90%) and are identified as such when thoracic curvatures develop into flat back syndrome. Lumbar curvatures lead to a reduction of lumbar lordosis and even to lumbar kyphosis. The flattening of the sagittal profile therefore needs to be counteracted in the orthosis by accentuating the sagittal profile if the deformity is to be consistently corrected in all three planes. Several studies have demonstrated that forced lordosis of the upper lumbar region alone contributes towards correcting lateral curvature. A case study[19] and a small series study[21] successfully documented the fact that it is possible to improve scoliosis simply by means of forced lordosis of the upper lumbar region. Recently, van Loon and associates[17] have confirmed these findings with a more comprehensive radiographic study. This is reason enough to rule out the treatment of idiopathic scoliosis with orthoses that counteract lumbar lordosis. An aggravating factor is the fact that reducing lumbar lordosis correlates closely with the incidence of chronic back pain in adulthood[5,6].

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Faulty Modelling

The modelling of a brace has to do with how pronounced a brace model's individual zones are. The prospects of success of a brace library also harbour risks with respect to modelling: Systematic errors that go unrecognised are passed on from brace to brace. The author has come across one example of a systematic error again and again: poor rotational stability of a CAD-series brace. Horizontal rotational instability (brace twist) is usually due to a stop point that is incorrect or even non-pronounced (point 37 according to Chêneau) or because of an improper balance between other pressure zones. In such cases, the brace usually twists towards the back on the side of the rib hump. The rib hump is then inside the free space that was originally in ventral position and is now in lateral position (see also Figure 5 lower right), thus losing the corrective effect that was good at the outset. This problem occurs regularly in some treatment series and is attributable to a systematic modelling defect (Figure 7). Side shift that is insufficient or completely lacking or forms with not enough curve or 'mirroring' will result in a poor corrective effect. Even if all pressure zones are at the proper height, it will be necessary to replace such an orthosis – or at least alter it considerably. At times, the opinion of a medical specialist may be required to optimise an existing brace (Figure 8).

Curvature Pattern and Brace Selection

Chêneau braces were originally produced taking the simple classification according to Lehnert-Schroth[9, 10] as a basis. Chêneau initially publicised a brace type for curvatures with a main thoracic curve (triple-curve or functional 3-curve pattern) and one for double-curve curvatures or lumbar-dominant curvatures (quadruple-curve or or functional 4-curve pattern). This simple classification according to Lehnert-Schroth is still sufficient today for findings-oriented

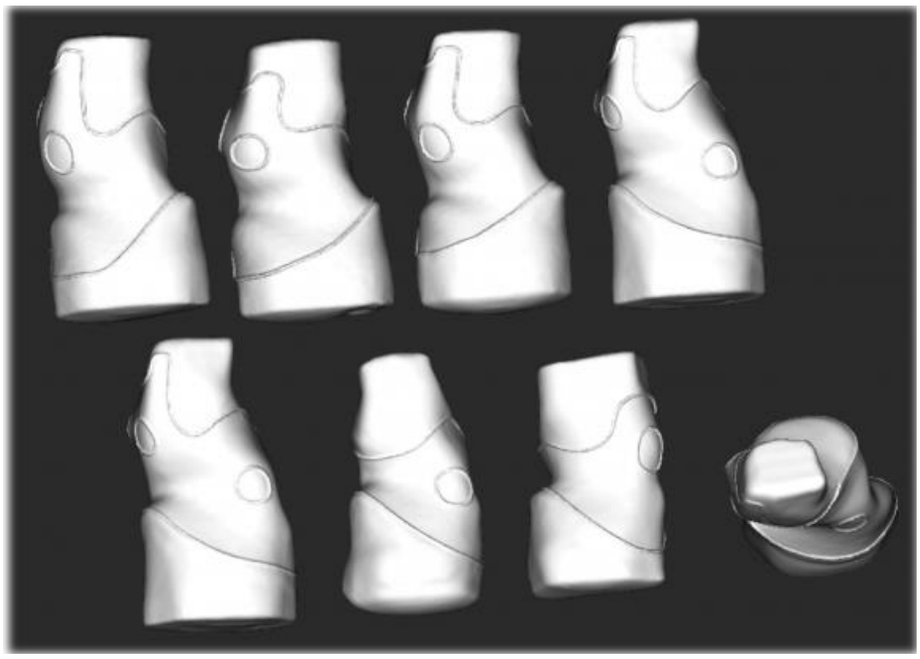

Figure 5: The seven basic models of the Gensingen library. First row from the left: Model 3BH, Model 3BTL, Model 3BN, Model 3BL. Second row from the left: Model 4B, Model 4BL, Model 4BTL. Far right: a view of Model 4B from above, showing the extensively protruding ventral free space. (3B = functional 3 curve pattern / 4B = functional 4 curve pattern).

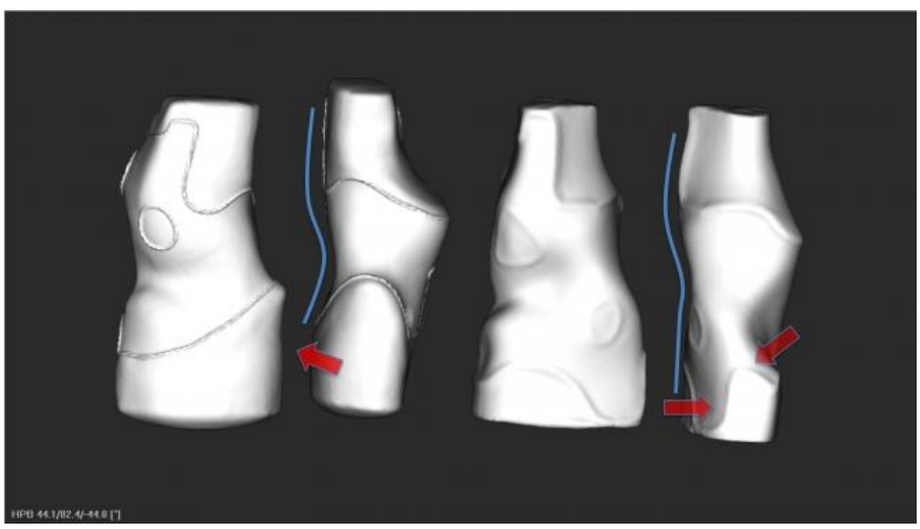

Figure 6: Comparison of two CAD models. Left: on the side panel, harmonic sagittal profile with lumbar lordosis and mildly accentuated thoracic kyphosis, a profile that is also perceived as comfortable by patients. The pelvis can extend out the back (arrow). Right: on the side projection, the obsolete flat back form promoting lumbar kyphosis can be recognised (flat back design). As early as 2003, it was indicated that promoting lumbar lordosis should invariably be a corrective component for treating idiopathic scoliosis[15]. Moreover, there is a pronounced compression effect between the pelvic section blocking lordosis and the heavily accentuating point 37 (arrows). Abdominal problems (increased pains during monthly periods) have been described (source: Scoliosis Info Forum).

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physiotherapy. For the pattern optimised production of corrective trunk orthoses, however, it is necessary to further differentiate this system of classification. The more growth that is anticipated for a patient, the more optimised the brace pattern has to be in order not to cause the progression of secondary curvatures. The brace model needs to perfectly mirror the curvature pattern during times when intense growth is anticipated in order to reliably prevent the progression also of secondary curvatures (Figure 9). In Figure 10, we see a course of treatment that was originally good, but which was nullified by improper treatment later on. The more mature a patient is, the more important it is to focus on correcting the main curvature as much as possible. In some cases, the secondary curvature is intentionally neglected. Such treatment control presupposes a wealth of treatment experience, and only an experienced specialist can guarantee its success. Towards the end of the growth period, it is essential to mirror the static misalignment of the torso (decompensation). Only in this way will a balanced end result be achieved. Such a result 1) is the most cosmetically pleasing, 2) has the least risk of curvature increasing after adolescence, and, in the author's experience, 3) has a lower probability of pain in adulthood[24,29]. If the CAD method is individually applied when no fully developed library is available, it provides no advantages over providing a brace produced from a plaster cast – other than that the patient does not have to endure the unpleasant plaster cast procedure. Neither the design nor the modelling nor the pattern selections are standardised. Each brace constructed this way is like a game of chance. The learning curve to produce braces of above-average quality takes years to master. Any individual brace of average or below-average quality cheats patients of the best possible treatment currently available, usually

Figure 7: CAD brace with rotational instability. The thoracic pressure zone (point 1) twists in the dorsal direction and loses its lateral positioning. The rib hump is inside the free space that was originally in ventral position and is now in lateral position.

DM2 pattern treated with a Rigo brace (No. 17). No real correction effect has been achieved. After readjustment with pelvic hypercompensation the lower curve corrects satisfactory and the thoracic curve has furtherly been improved.
For proper brace adjustment besides a skilled technician a physician with great experience is necessary to achieve the best possible result for the patient.

Figure 8: Brace produced in 2005 using CAD/CAM with poor correction. At the author's direction, the left pelvic half was trimmed, and the right pelvic section was moved in closer. This made it possible to achieve noticeably better correction.

with unpleasant results for the patients. Reports of such experiences are reproduced in the author's scoliosis guidebook[24, 29]. Nowadays, the regular occurrence of below-average results, pain from the orthosis, unnecessary prolongation of the wearing time, reduced comfort, and needless limitations in day-to-day life can easily be avoided.

Conclusion

According to the latest findings, the development in making Chêneau braces, from plaster models to CAD/CAM-based production, can help improve the standard of treatment. In particular, universal availability makes it possible for scoliosis sufferers to receive a high-quality brace where they live even when there is no specialist in the vicinity. Nowadays, the regular occurrence of below-average results, pain from the orthosis, unnecessary prolongation of the wearing time, reduced comfort, and needless limitations in day-to-day life can easily be avoided.

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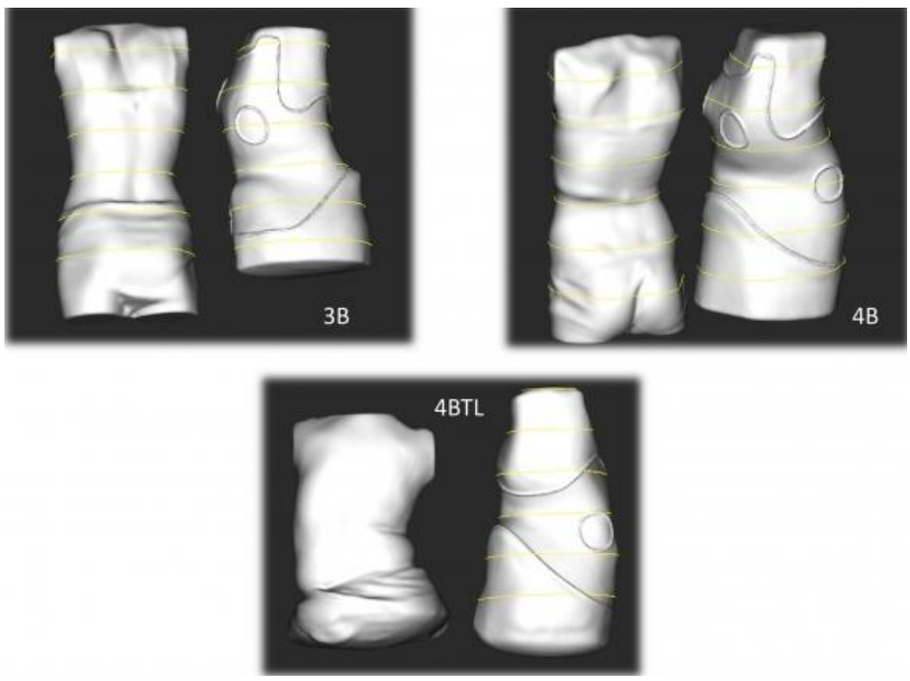

Figure 9: Depiction of mirroring various curvature patterns in the brace. Brace 4BTL was fitted for a physically handicapped boy. Of note is the feature for restoring lumbar lordosis, which gave the patient good stability when sitting.

Figure 10: Left: immature patient with 51° at the beginning of her treatment. Centre: After 9 months, slight curvature correction with noticeable recompensation after treatment with a 3BH brace. A new brace was produced according to the same principles. In 2009, the patient was then had outgrown the second brace and received the centre right brace from a different technician. The heavily protruding lumbar pad continued to cause decompensation of the thoracic curvature by press against the 11th rib. Right: The author saw the patient again with 75°. The experience report is reproduced in the author's guidebook, I Have Scoliosis[24].

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Conflict of interests

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Competing interests

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