Middle East J Rehabil Health. 2016 April; 3(2): e35377. doi: 10.17795/mejrh-35377

Published online 2016 April 23. **Review Article**

Treatment of Scoliosis-Evidence and Management (Review of the Literature)

Hans-Rudolf Weiss,[1,*] Deborah Turnbull,[2] Nicos Tournavitis,[3] and Maksym Borysov[4]

[1]Gesundheitsforum Nahetal, Gensingen, Germany
[2]Maple Leaf Pharmacy and Clinic, Twickenham, United Kingdom
[3]Scoliosis Best Practice Rehabilitation Services, Conservative Treatment Center for Spinal Deformities, Thessaloniki, Greece
[4]Orttech-Plus Rehabilitation Service, Kharkiv, Ukraine

*Corresponding author: Hans-Rudolf Weiss, Gesundheitsforum Nahetal, Gensingen, Germany. Tel: +49-06727894040, E-mail: hr.weiss@koob-skoliose.com

Received 2015 December 9; **Revised** 2015 December 28; **Accepted** 2015 December 28.

Abstract

Context: Scoliosis is a three-dimensional deformity of the spine and trunk which includes lateral deviation, rotation, and a disturbance of the sagittal profile. Treatment is indicated for scoliosis because it may lead to negative consequences with regard to the quality of life and other health issues for some patients. The purpose of this review was to gather current, up-to-date information, and to search the recent articles on scoliosis for evidence of the different modes of treatment.

Evidence Acquisition: A PubMed search for review articles, prospective controlled trials (PCT), and randomized controlled trials (RCT) was performed. The search terms were: 1) scoliosis, treatment (12,045 items found); 2) scoliosis, physiotherapy (776 items found); 3) scoliosis, brace treatment (1,447 items found); and 4) scoliosis, surgery (10,485 items found).

Results: When looking at the current literature, high quality evidence (level I) was found to support physical rehabilitation and brace treatments, while no evidence was found to support spinal fusion surgery. The numerous long-term complications that patients may face post-operation, and the lack of evidence for spinal fusion surgery indicate that there is no clear medical indication for this kind of treatment.

Conclusions: There is a high level of evidence for the conservative treatment of scoliosis, but there are varying levels of success in the different approaches. The better the correction of the curve, the better the end result and outcome for the patient. This is supported by the current evidence reviewed in this paper. Physiotherapy and bracing should be used and, specifically, those approaches using high corrective methods. Spinal fusion surgery is not supported by the current evidence. According to the literature, the long-term complications of surgery for scoliosis far outweigh the consequences of untreated scoliosis.

Keywords: Scoliosis, Physiotherapy, Brace Treatment, Surgery, Evidence, Management

1. Context

Scoliosis is a three-dimensional deformity of the spine and trunk which includes lateral deviation, rotation, and a disturbance of the sagittal profile (1-4). Scoliosis treatment is indicated because scoliosis may lead to negative consequences with regard to the quality of life and other health issues for some patients (1, 5, 6). Scoliosis may be caused by disturbances of the neuromuscular system (neuromuscular scoliosis), alterations of the soft tissue (e.g. Marfan's syndrome and Ehlers Danlos syndrome), alterations of the nervous system (neurofibromatosis), failures in the formation/segmentation of the vertebrae and ribs (congenital scoliosis), and many others (7). The majority of patients with scoliosis have idiopathic scoliosis (8, 9), and rarely, early onset scoliosis (EOS) (6, 7). Late onset idiopathic scoliosis, also called adolescent idiopathic scoliosis (AIS) is diagnosed in 80% - 90 % of the total population with scoliosis (10, 11).

Untreated symptomatic or syndromic scoliosis, as well as EOS, can sometimes cause severe health problems and higher mortality. However, AIS, the most common form of scoliosis, is relatively benign, and does not generally lead to severe health problems or early death (4, 5, 12).

A 50-year follow-up of untreated patients with AIS has shown that this population functions well. There were no more health problems in this group when compared to patients without scoliosis, other than a slight increase in back pain and cosmetic concerns (5). The indications for treatment rely largely on the Cobb angle (13), the angle of curvature as measured on an X-ray of the spine in the frontal plane. Historically the treatment of scoliosis consists of:

- Physical rehabilitation (15 - 25° Cobb)
- Brace treatment (20 - 40° Cobb)
- Spinal fusion surgery (> 40 - 50° Cobb) (1).

Two recent Cochrane reviews have shown that evidence

for surgery is limited (14, 15), and currently, there is no proof that surgery would change the signs and symptoms of scoliosis over the long-term. Some authors have even concluded that in patients with AIS there is no actual indication for spinal fusion surgery (16, 17). The established medical indications and the evidence supporting surgery should be under as much scrutiny as those supporting conservative treatments. Therefore, the purpose of this review was to gather current and available information, and to search the recent articles on scoliosis for the evidence they provide for the different modes of treatment.

2. Evidence Acquisition

For this study, a PubMed search for review articles, prospective controlled trials (PCT) with an untreated control group, and randomized controlled trials (RCT) was performed. Retrospective papers were only included when long-term results were published with a follow-up time exceeding 10 years. The literature cited in the reviews has also been checked with respect to the available abstracts. When the abstract seemed to include the topic, a full paper review was performed, and in a few cases when these were not available on PubMed, a hand search was completed. The search terms included:

- Scoliosis, treatment (12,045 items found)
- Scoliosis, physiotherapy (776 items found)
- Scoliosis, brace treatment (1,447 items found)
- Scoliosis, surgery (10,485 items found)

3. Results

The results of our search have been summarized in Table 1.

With regard to evidence for physical rehabilitation (physiotherapy, Figure 1), one meta-analysis (18), four RCTs (19-22), and one PCT (23) with an untreated control group were found supporting physiotherapy. Previously, a Cochrane review was published showing that there was little evidence for physiotherapy/physical rehabilitation at the time the review was performed (24).

Furthermore, no studies have been included that lack treatment indications as discussed in a critical review (25). Long-term retrospective studies have not been found supporting physiotherapy.

Some evidence has been found for general exercises (22); however, specific correction exercises (Schroth, Side Shift, and Monticone) have been shown to be superior to exercises without a curve pattern specific exercise routine (e.g., Yoga, SEAS, Dobomed, and Clear) (19-21).

With regard to evidence for bracing (Figures 2 - 5), one meta-analysis (26), one RCT (27), and one multi-center PCT (28) were found supporting brace treatment. There are long-term cohorts published in the literature supporting the Boston and Cheneau brace treatment (29-31). In addition, Landauer and colleagues have concluded that compliance (brace wearing time) and in brace correction determine the outcomes of brace treatment (32, 33).

The success rate with the Boston brace was about 70% (27, 28), and with the actual Cheneau standard it was > 90% (Figures 2 and 3) (30, 34). However, the same definition of success has not been applied in all of the studies. Usually, the standard definition of success is "no progression of 6° or more, or an improvement of 6° or more" (28, 34). In the RCT (27) by Weinstein et al. the rate of success was defined as the prevention of curve progression to more than 50°, while in the Italian paper on the Cheneau brace (30), the rate of success was defined as an improvement to 5° or more, or no change within the limits of ± 4°.

No evidence has been found to support spinal fusion surgery (Figure 6), not in four systematic reviews (17, 35-37), nor in two Cochrane reviews (14, 15). While the complication rate of spinal fusion directly after an operation may be small, the long-term rate of complications seems to exceed 50% of the population operated on (35, 38, 39). In addition, there is no evidence that spinal fusion surgery improves signs and symptoms of scoliosis and some literature state that the deformity may well increase again as a later effect even when the instrumentation remains stable (35). Long-term retrospective studies on the effects of surgery are rare, and most of them contain patient samples operated on using the Harrington instrumentation (40-43).

The first modern dorsal double rod instrumentation (CD instrumentation) showed a re-operation rate of 48% within the follow-up period of 20 years (44); but for the instrumentations currently used, no long-term studies exist. With the stapling operation, within only two years, a re-surgery rate of more than 50% was found (45).

Additionally, other side effects have been found; as one study points out, spinal fusion surgery may lead to post-traumatic stress disorder (46). Another study has shown that bone morphogenetic protein 2 (BMP-2), a protein applied during spinal fusion surgery, has a long list of side effects, including carcinogenesis (47, 48).

Table 1. RCTs, Cochrane Reviews, and PCTs (Level I and II) Supporting Physical Rehabilitation and Brace Treatment[a]

	RCT/Meta-Analysis	Cochrane Review	PCT
Physical rehabilitation	5	1	1
Brace treatment	1	1	1
Scoliosis surgery	NA	NA	NA

Abbreviation: NA, not available.

[a]No high level evidence (Level I and II) has been found supporting spinal fusion surgery. The numbers indicate the quantity of papers found in the various columns of the table.

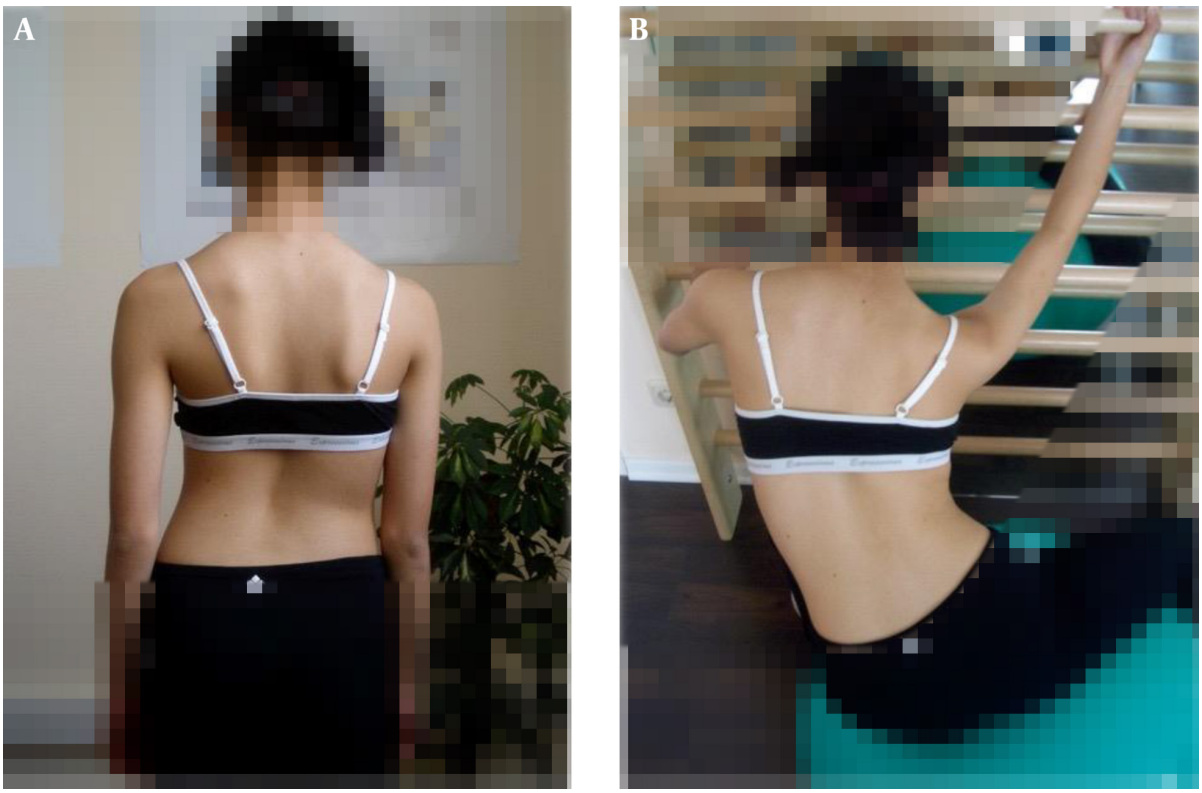
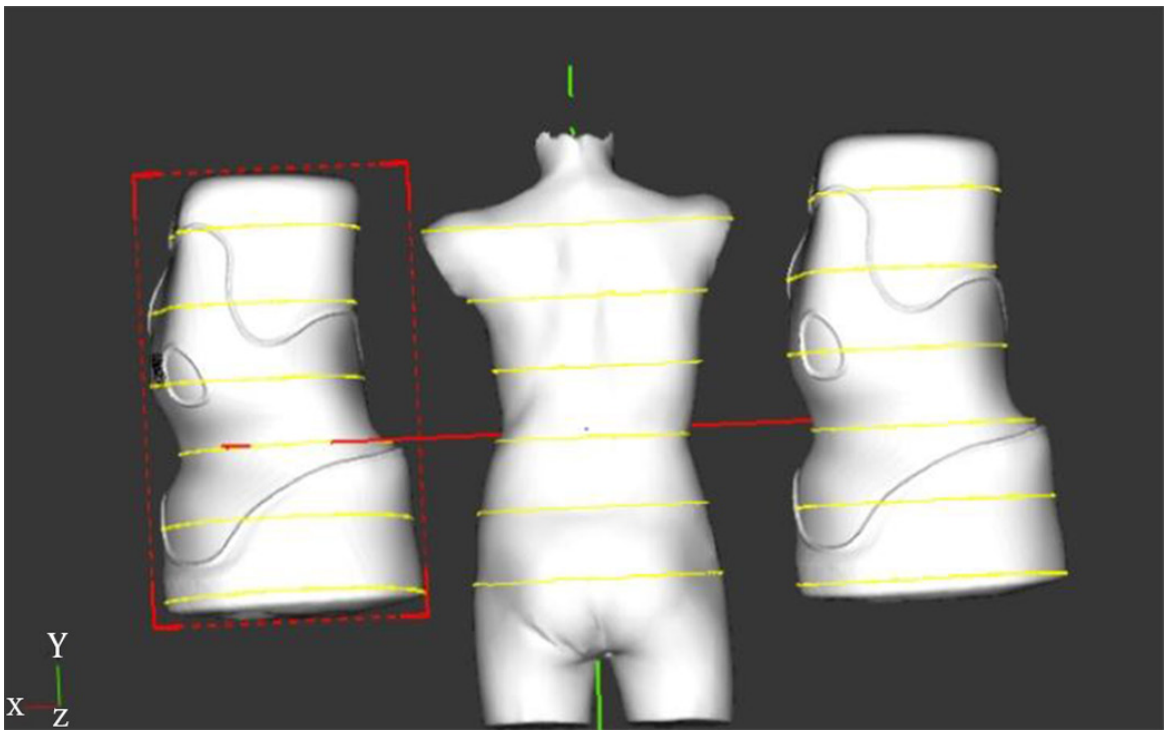


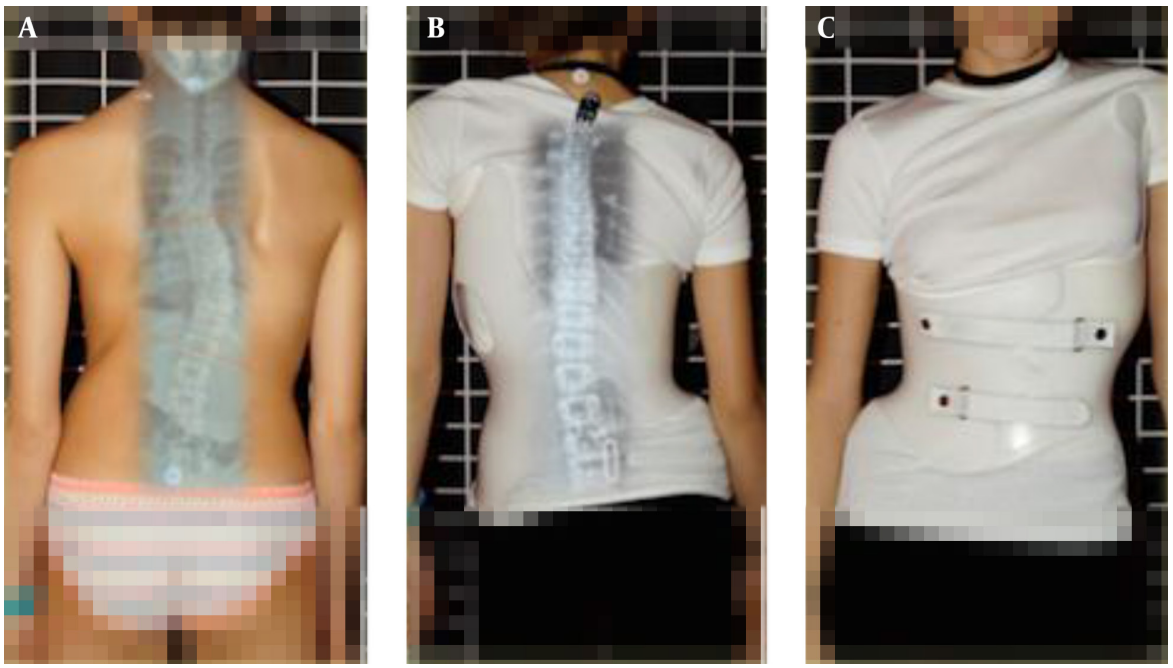
Figure 1. High Correction Exercise (Schroth Best Practice) as Supported by Current Evidence (6)

Figure 2. Standardized CAD / CAM Bracing as Available Today (Gensingen Brace According to Dr. Weiss / GBW)



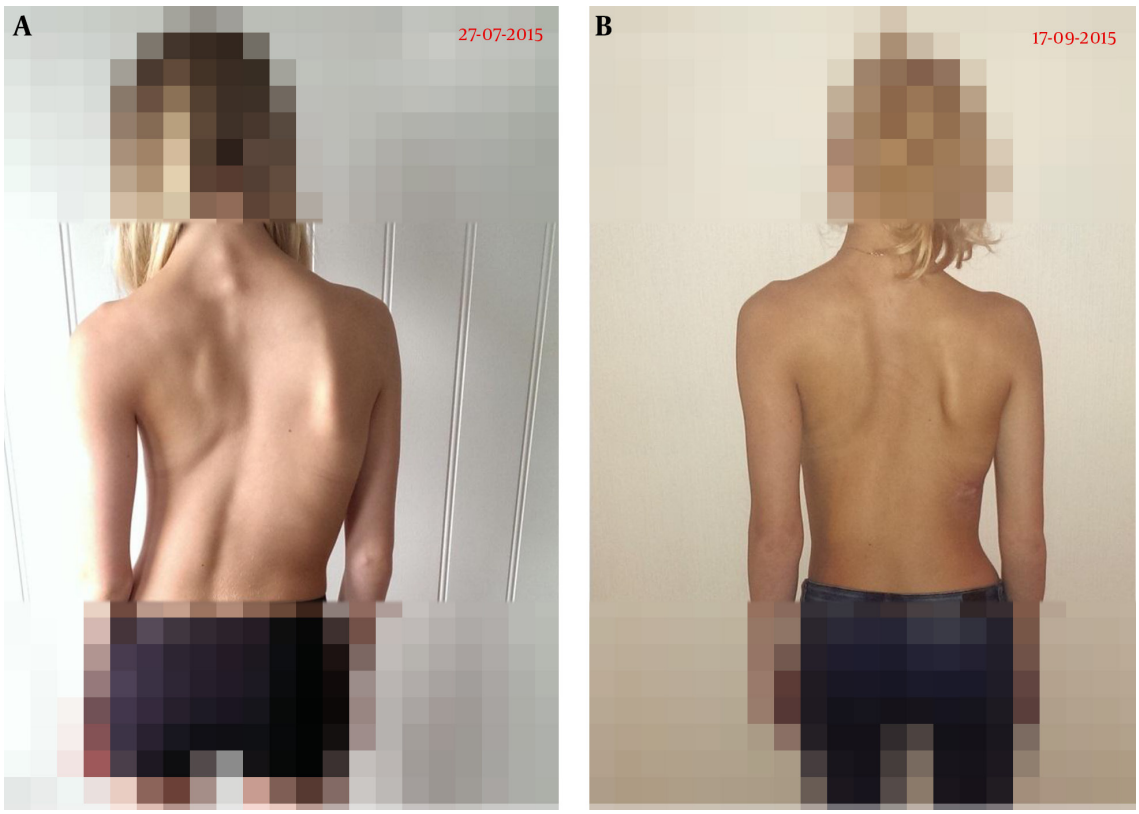
Right, basic brace model for this pattern of curvature; left, final model as individualized (see also https://bestpracticebracing.wordpress.com/bracing-scoliosis/).

Figure 3. Standardized CAD/CAM Bracing (Gensingen Brace According to Weiss/GBW)



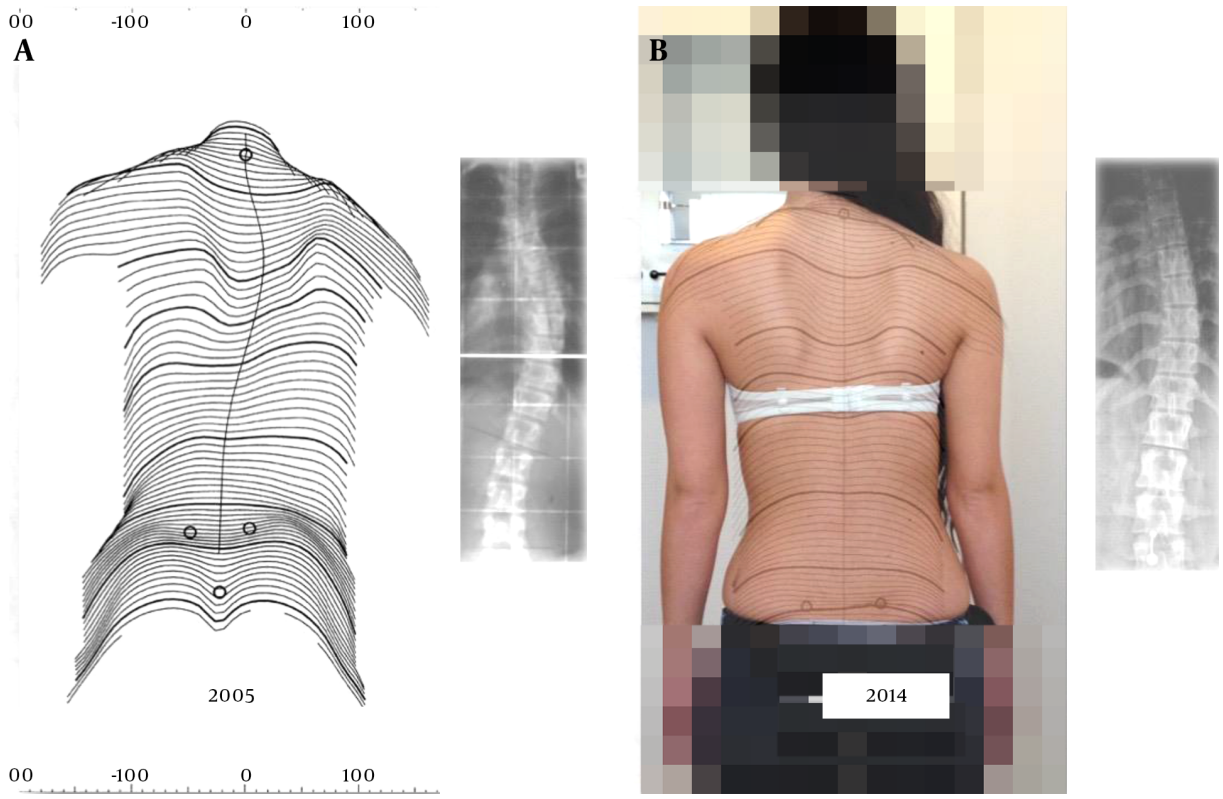
This is the patient from the CAD adjustment visible in Figure 2. This patient from Turkey has been braced in Thessaloniki with a very good in-brace correction (see also https://bestpracticebracing.wordpress.com/bracing-scoliosis/).

Figure 4. These Photos Show a Patient From Norway, Who Was Progressive in Her Previous Brace



A, Before starting treatment with a GBW; B, Six weeks after starting treatment (see also https://bestpracticebracing.wordpress.com/bracing-scoliosis/).

Figure 5. Patient With 38°Initially at the Age of 11 With Final Result of 19° 5.6 Years After Brace Weaning



This shows that stable corrections can be achieved when treatment starts early enough, and if there is enough growth for correction. This case is described more deeply in a case report (33).

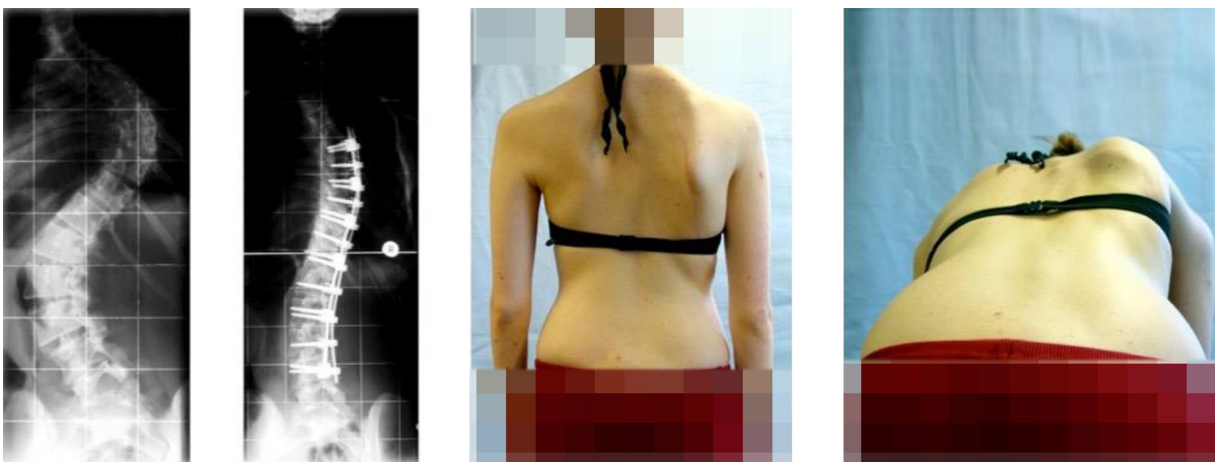


Figure 6. These images show a combined curve, which was surgically corrected. However, the rib hump reappeared later on and the patient was not happy with the surgical outcome (39)

4. Discussion

Based on the current literature, high quality evidence (Level I) has been found to support physical rehabilitation and brace treatment in scoliosis (19, 21, 27), while no evidence has been found to support spinal fusion surgery in the long-term (14, 15, 17). The meta analyses (18, 26) and RCTs (19-21, 27) seem to support conservative management, while only the retrospective studies support the use of outdated surgical approaches like the Harrington

rod (40-43). Long-term studies on recent surgical approaches do not exist, with the exception of one long-term study on the first modern dorsal double rod instrumentation (44). This study shows a re-surgery rate of 48% within a follow-up of 20 years (44). Moreover, one recent development shows a re-surgery rate of > 50% within two years (45). Therefore, the long-term effects of other recent instrumentations are simply not known (49). The many possible adverse effects patients may face in the long-term after the operation, and the lack of evidence for spinal fusion surgery indicate that there is no clear medical indication for surgery in AIS (17).

This study does indicate the necessity to focus on conservative treatment. Many different approaches are offered today, most of them without evidence. Therefore, it is necessary to compare the conservative approaches to ensure the most effective approaches are used. Especially when considering that during the pubertal growth spurt there is no time to waste, from the patients' perspective, with unproven methods of treatment.

Yoga, SEAS, Dobomed, and Clear cannot claim to be the best approaches to treatment since, according to the current evidence, the new high correction approaches provide better results (19-21). The Schroth best practice approach shows the widest range of corrections and improvements of the signs and symptoms of scoliosis (37, 50-53).

With respect to highly corrective bracing, correction can be maintained even two years after wearing these braces (Figure 5) (32). Although the Boston braces have been supported by a high level of evidence, the final results of the asymmetric Cheneau standard seem to lead to a better outcome, which has also been described in a recent paper on CAD/CAM braces (54). CAD/CAM braces, when constructed appropriately, can be standardized, and these standards can be constantly improved. The smallest brace with the best possible correction available today is the Gensingen brace (GBW) (54). Therefore, a high standard of bracing can be provided in all parts of the world for the benefit and comfort of the patients (50).

Since there is no evidence for spinal fusion surgery in the treatment of scoliosis, the quality of conservative treatment should be a matter of further research. According to the literature, pain is more frequent in the population with scoliosis (55). This has been found for untreated patients, braced patients, and operated patients in the long-term as well. Indeed, pain increases post-operation over time (56); therefore, pain is not a valid indication for spinal fusion, because pain can be treated successfully with conservative measures (20, 57).

The papers on surgery, as found in PubMed, total more than 10,000, while the papers on conservative treatment are more rare. This disproportion reflects the interest and the influence of surgeons within the spinal literature. Moreover, the conflict of interest in this field has been described by Hawes (58).

4.1. Conclusions

There is a high level of evidence for the conservative treatment of scoliosis, but there are varying levels of success in the different approaches. The better the correction the better the end result. This is supported by current evidence. Therefore, in physiotherapy and in bracing only high corrective procedures should be applied.

However, spinal fusion surgery is not supported by the current evidence. According to the literature, the long-term complications of surgery for AIS far outweigh the consequences of untreated AIS.

Footnotes

Authors' Contribution: Hans-Rudolf Weiss provided the first draft. Hans-Rudolf Weiss, Deborah Turnbull, Nicos Tournavitis, and Maksym Borysov conducted the literature research and wrote the second draft. All of the authors developed the final manuscript in a 3-step Delphi procedure. In addition, all of the authors have read and approved the final manuscript.

Conflicts of Interests: Hans-Rudolf Weiss is receiving financial support for attending symposia, and receives royalties from Koob GmbH and Co KG. The company is held by the spouse of Hans-Rudolf Weiss. None of the other authors report any competing interests or potential conflicts of interest. Deborah Turnbull provides rehabilitation services for Blatchford, Sheffield, UK and refers patients for bracing.

References

1. Asher MA, Burton DC. Adolescent idiopathic scoliosis: natural history and long term treatment effects. *Scoliosis.* 2006;**1**(1):2. doi: 10.1186/1748-7161-1-2. [PubMed: 16759428]
2. Goldberg CJ, Moore DP, Fogarty EE, Dowling FE. Adolescent idiopathic scoliosis: natural history and prognosis. *Stud Health Technol Inform.* 2002;**91**:59–63. [PubMed: 15457694]
3. Newton PO. *Moe's Textbook of Scoliosis and Other Spinal Deformities*. LWW; 1996.
4. Weinstein SL. Natural history. *Spine (Phila Pa 1976).* 1999;**24**(24):2592–600. [PubMed: 10635522]
5. Weinstein SL, Dolan LA, Spratt KF, Peterson KK, Spoonamore MJ, Ponseti IV. Health and function of patients with untreated idiopathic scoliosis: a 50-year natural history study. *JAMA.* 2003;**289**(5):559–67. [PubMed: 12578488]
6. Weiss H, Lehnert-Schroth C, Moramarco M, Moramarco K. *Schroth Therapy: Advancements in Conservative Scoliosis Treatment.* LAP LAMBERT Academic Publishing; 2015.
7. Winter R. Classification and Terminology. In: Lonstein JEBD, Winter RB, Ogilvie JW editors. *Moe's Textbook of Scoliosis and other Spinal Deformities.* Philadelphia: WB Saunders; 1995.
8. Lonstein D. Adolescent idiopathic scoliosis. *Lancet.* 1994;**344**(8934):1407–12. doi: 10.1016/s0140-6736(94)90572-x [PubMed: 7968079].
9. Weinstein SL. Adolescent idiopathic scoliosis: prevalence and natural history. *Instr Course Lect.* 1989;**38**:115–28. [PubMed: 2649564]
10. Lonstein JE, Carlson JM. The prediction of curve progression in untreated idiopathic scoliosis during growth. *J Bone Joint Surg Am.* 1984;**66**(7):1061–71. [PubMed: 6480635]
11. Weinstein SL, Dolan LA, Cheng JCY, Danielsson A, Morcuende JA. Adolescent idiopathic scoliosis. *Lancet.* 2008;**371**(9623):1527–37. [PubMed: 18456103]
12. Collis DK, Ponseti IV. Long-term follow-up of patients with id-

iopathic scoliosis not treated surgically. *J Bone Joint Surg Am.* 1969;**51**(3):425–45. [PubMed: 4238082]
13. Cobb JR. Outline for the study of scoliosis. *Instr Course Lect.* 1948;**5**:261–75.
14. Bettany-Saltikov J, Weiss HR, Chockalingam N, Taranu R, Srinivas S, Hogg J, et al. Surgical versus non-surgical interventions in people with adolescent idiopathic scoliosis. *Cochrane Database Syst Rev.* 2015;**4**:CD010663. doi: 10.1002/14651858.CD010663.pub2. [PubMed: 25908428]
15. Cheuk DK, Wong V, Wraige E, Baxter P, Cole A. Surgery for scoliosis in Duchenne muscular dystrophy. *Cochrane Database Syst Rev.* 2015;**10**:CD005375. doi: 10.1002/14651858.CD005375.pub4. [PubMed: 26423318]
16. Ward WTRJ, Friel N, Kenkre TS, Brooks MM. SRS 22r Scores in Non-Operated AIS Patients with Curves ≥ 40°.; *Proceedings of the 50th Annual Meeting Minneapolis.*; Minnesota. 2015..
17. Westrick ER, Ward WT. Adolescent idiopathic scoliosis: 5-year to 20-year evidence-based surgical results. *J Pediatr Orthop.* 2011;**31**(1 Suppl):S61–8. doi: 10.1097/BPO.0b013e3181fd87d5. [PubMed: 21173621]
18. Anwer S, Alghadir A, Abu Shaphe M, Anwar D. Effects of Exercise on Spinal Deformities and Quality of Life in Patients with Adolescent Idiopathic Scoliosis. *Biomed Res Int.* 2015;**2015**:123848. doi: 10.1155/2015/123848. [PubMed: 26583083]
19. Monticone M, Ambrosini E, Cazzaniga D, Rocca B, Ferrante S. Active self-correction and task-oriented exercises reduce spinal deformity and improve quality of life in subjects with mild adolescent idiopathic scoliosis. Results of a randomised controlled trial. *Eur Spine J.* 2014;**23**(6):1204–14. doi: 10.1007/s00586-014-3241-y. [PubMed: 24682356]
20. Schreiber S, Parent EC, Moez EK, Hedden DM, Hill D, Moreau MJ, et al. The effect of Schroth exercises added to the standard of care on the quality of life and muscle endurance in adolescents with idiopathic scoliosis-an assessor and statistician blinded randomized controlled trial: "SOSORT 2015 Award Winner". *Scoliosis.* 2015;**10**:24. doi: 10.1186/s13013-015-0048-5. [PubMed: 26413145]
21. Kuru T, Yeldan I, Dereli EE, Ozdincler AR, Dikici F, Colak I. The efficacy of three-dimensional Schroth exercises in adolescent idiopathic scoliosis: a randomised controlled clinical trial. *Clin Rehabil.* 2016;**30**(2):181–90. doi: 10.1177/0269215515575745. [PubMed: 25780260]
22. Wan L, Wang GX, Bian R. Exercise therapy in treatment of essential S-shaped scoliosis: evaluation of Cobb angle in breast and lumbar segment through a follow-up of half a year. *Chinese J Clin Rehabil.* 2005;**9**(34):82–4.
23. Weiss HR, Weiss G, Petermann F. Incidence of curvature progression in idiopathic scoliosis patients treated with scoliosis in-patient rehabilitation (SIR): an age- and sex-matched controlled study. *Pediatr Rehabil.* 2003;**6**(1):23–30. doi: 10.1080/1363849031000095288. [PubMed: 12745892]
24. Romano M, Minozzi S, Bettany-Saltikov J, Zaina F, Chockalingam N, Kotwicki T, et al. Exercises for adolescent idiopathic scoliosis. *Cochrane Database Syst Rev.* 2012;**8** doi: 10.1002/14651858.CD007837.pub2.
25. Weiss HR. Physical therapy intervention studies on idiopathic scoliosis-review with the focus on inclusion criteria1. *Scoliosis.* 2012;**7**(1):4. doi: 10.1186/1748-7161-7-4. [PubMed: 22277541]
26. 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.* 1997;**79**(5):664–74. [PubMed: 9160938]
27. Weinstein SL, Dolan LA, Wright JG, Dobbs MB. Effects of bracing in adolescents with idiopathic scoliosis. *N Engl J Med.* 2013;**369**(16):1512–21. doi: 10.1056/NEJMoa1307337. [PubMed: 24047455]
28. 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.* 1995;**77**(6):815–22. [PubMed: 7782353]
29. Danielsson AJ, Hasserius R, Ohlin A, Nachemson AL. A prospective study of brace treatment versus observation alone in adolescent idiopathic scoliosis: a follow-up mean of 16 years after maturity. *Spine (Phila Pa 1976).* 2007;**32**(20):2198–207. doi: 10.1097/BRS.0b013e31814b851f. [PubMed: 17873811]
30. De Giorgi S, Piazzolla A, Tafuri S, Borracci C, Martucci A, De Giorgi G. Chêneau brace for adolescent idiopathic scoliosis: long-term results. Can it prevent surgery? *Eur Spine J.* 2013;**22**(6):815–22.
31. Fang MQ, Wang C, Xiang GH, Lou C, Tian NF, Xu HZ. Long-term effects of the Cheneau brace on coronal and sagittal alignment in adolescent idiopathic scoliosis. *J Neurosurg Spine.* 2015;**23**(4):505–9. doi: 10.3171/2015.2.SPINE14970. [PubMed: 26161517]
32. Landauer F, Wimmer C, Behensky H. Estimating the final outcome of brace treatment for idiopathic thoracic scoliosis at 6-month follow-up. *Pediatr Rehabil.* 2003;**6**(3-4):201–7. doi: 10.1080/13638490310001636817. [PubMed: 14713586]
33. Weiss HR. Bracing can lead to a persistent correction in the treatment of Adolescent Idiopathic Scoliosis: A case report. *Hard Tissue.* 2014;**3**(1):8.
34. Weiss HR, Werkmann M. Rate of surgery in a sample of patients fulfilling the SRS inclusion criteria treated with a Cheneau brace of actual standard. *Stud Health Technol Inform.* 2012;**176**:407–10. [PubMed: 22744540]
35. Hawes M. Impact of spine surgery on signs and symptoms of spinal deformity. *Pediatr Rehabil.* 2006;**9**(4):318–39. [PubMed: 17111548]
36. Weiss HR, Goodall D. The treatment of adolescent idiopathic scoliosis (AIS) according to present evidence. A systematic review. *Eur J Phys Rehabil Med.* 2008;**44**(2):177–93. [PubMed: 18418338]
37. Moramarco M, Weiss HR. Congenital Scoliosis. *Curr Pediatr Rev.* 2015 [PubMed: 26573161]
38. Weiss HR, Goodall D. Rate of complications in scoliosis surgery - a systematic review of the Pub Med literature. *Scoliosis.* 2008;**3**:9. doi: 10.1186/1748-7161-3-9. [PubMed: 18681956]
39. Weiss HR, Moramarco M, Moramarco K. Risks and long-term complications of adolescent idiopathic scoliosis surgery versus non-surgical and natural history outcomes. *Hard Tissue.* 2013;**2**(2):27.
40. Danielsson AJ, Nachemson AL. Back pain and function 23 years after fusion for adolescent idiopathic scoliosis: a case-control study-part II. *Spine (Phila Pa 1976).* 2003;**28**(18):E373–83. doi: 10.1097/01.BRS.0000084267.41183.75. [PubMed: 14501939]
41. Danielsson AJ, Nachemson AL. Childbearing, curve progression, and sexual function in women 22 years after treatment for adolescent idiopathic scoliosis: a case-control study. *Spine (Phila Pa 1976).* 2001;**26**(13):1449–56. [PubMed: 11458150]
42. Danielsson AJ, Nachemson AL. Radiologic findings and curve progression 22 years after treatment for adolescent idiopathic scoliosis: comparison of brace and surgical treatment with matching control group of straight individuals. *Spine (Phila Pa 1976).* 2001;**26**(5):516–25. [PubMed: 11242379]
43. Danielsson AJ, Wiklund I, Pehrsson K, Nachemson AL. Health-related quality of life in patients with adolescent idiopathic scoliosis: a matched follow-up at least 20 years after treatment with brace or surgery. *Eur Spine J.* 2001;**10**(4):278–88. [PubMed: 11563612]
44. Mueller FJ, Gluch H. Cotrel-dubousset instrumentation for the correction of adolescent idiopathic scoliosis. Long-term results with an unexpected high revision rate. *Scoliosis.* 2012;**7**(1):13. doi: 10.1186/1748-7161-7-13. [PubMed: 22710010]
45. O'Leary P T, Sturm PF, Hammerberg KW, Lubicky JP, Mardjetko SM. Convex hemiepiphysiodesis: the limits of vertebral stapling. *Spine (Phila Pa 1976).* 2011;**36**(19):1579–83. doi: 10.1097/BRS.0b013e318227df9c. [PubMed: 21681138]
46. Deisseroth K, Hart RA. Symptoms of post-traumatic stress following elective lumbar spinal arthrodesis. *Spine (Phila Pa 1976).* 2012;**37**(18):1628–33. doi: 10.1097/BRS.0b013e318255e214. [PubMed: 22460923]
47. Mesfin A, Buchowski JM, Zebala LP, Bakhsh WR, Aronson AB, Fogelson JL, et al. High-dose rhBMP-2 for adults: major and minor complications: a study of 502 spine cases. *J Bone Joint Surg Am.* 2013;**95**(17):1546–53. doi: 10.2106/JBJS.L.01730. [PubMed: 24005194]
48. Tannoury CA, An HS. Complications with the use of bone morphogenetic protein 2 (BMP-2) in spine surgery. *Spine J.* 2014;**14**(3):552–9. doi: 10.1016/j.spinee.2013.08.060. [PubMed: 24412416]
49. Weiss HR, Moramarco M. Indication for surgical treatment in patients with adolescent Idiopathic Scoliosis - a critical appraisal.

Patient Saf Surg. 2013;**7**(1):17. doi: 10.1186/1754-9493-7-17. [PubMed: 23705983]
50. Borysov M, Mogiliantseva T. Rehabilitation of adolescents with scoliosis during growth - preliminary results using a novel standardized approach in Russia. *Curr Pediatr Rev.* 2015
51. Moramarco M, Fadzan M, Moramarco K, Heller A, Righter S. The Influence of Short-Term Scoliosis-Specific Exercise Rehabilitation on Pulmonary Function in Patients with AIS. *Curr Pediatr Rev.* 2016;**12**(1):17–23. [PubMed: 26573165]
52. Ng SY, Borysov M, Moramarco M, Nan XF, Weiss HR. Observation and Early Intervention in Mild Idiopathic Scoliosis via Corrective Exercises in Growing Children. *Curr Pediatr Rev.* 2016;**12**(1):24–30. [PubMed: 26573164]
53. Ng SY, Borysov M, Moramarco M, Nan XF, Weiss HR. Bracing Scoliosis - State of the Art. *Curr Pediatr Rev.* 2015 [PubMed: 26573162]
54. Weiss HR, Kleban A. Development of CAD/CAM Based Brace Models for the Treatment of Patients with Scoliosis-Classification Based Approach versus Finite Element Modelling. *Asian Spine J.* 2015;**9**(5):661–7. doi: 10.4184/asj.2015.9.5.661. [PubMed: 26435781]
55. Grauers A, Topalis C, Moller H, Normelli H, Karlsson M, Danielsson A, et al. Prevalence of Back Problems in 1069 Adults With Idiopathic Scoliosis and 158 Adults Without Scoliosis. *Spine (Phila Pa 1976).* 2014. doi: 10.1097/BRS.0000000000000312 [PubMed: 24718070]
56. Upasani VV, Caltoum C, Petcharaporn M, Bastrom TP, Pawelek JB, Betz RR, et al. Adolescent idiopathic scoliosis patients report increased pain at five years compared with two years after surgical treatment. *Spine (Phila Pa 1976).* 2008;**33**(10):1107–12. doi: 10.1097/BRS.0b013e31816f2849. [PubMed: 18449045]
57. Zapata KA, Wang-Price SS, Sucato DJ, Thompson M, Trudelle-Jackson E, Lovelace-Chandler V. Spinal Stabilization Exercise Effectiveness for Low Back Pain in Adolescent Idiopathic Scoliosis: A Randomized Trial. *Pediatr Phys Ther.* 2015;**27**(4):396–402. doi: 10.1097/PEP.0000000000000174. [PubMed: 26397085]
58. Hawes M. *Scoliosis and the Human Spine*.Arizona: West Press; 2002.