Effect of Spinal Bracing on Curve Magnitude in Coronal and Axial Planes in Adolescent Scoliosis Utilising EOS Imaging.

Simon Gatehouse (simon.gatehouse@qcosspine.com.au)
Queensland Children's Hospital
Maree Izatt
Queensland University of Technology
Robert Labrom
Queensland Children's Hospital
Geoffrey Askin
Queensland Children's Hospital
Caroline Grant
Queensland University of Technology
Peter Pivonka
Queensland University of Technology
Paige Little
Queensland University of Technology

Research Article

Keywords: Scoliosis, Adolescent Idiopathic Scoliosis (AIS), Bi-planer imaging = EOSTM imaging = EOS imaging, SterEOSTM = SterEOS, Spinal bracing, Boston Brace, Vertebral rotation, Axial vertebral rotation (AVR), Spine

Posted Date: June 17th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-596556/v1

Abstract

Purpose. This study aimed to investigate the efficacy of spinal bracing in treating progressive scoliosis deformity utilizing EOS (bi-planer) imaging and SterEOS reconstruction software.

Methods. EOS images of scoliosis patients being treated with bracing were obtained both in and out of their brace. These images were processed using SterEOS software to allow 3D representation, which was then compared to traditional coronal 2D parameters. Between January 2019 and January 2020, 29 patients were recruited for participation. Of these participants, 25 had a single episode of EOS imaging out of and in their brace. Additionally, 19 of the 25 participants had further episodes of EOS imaging within the study period, separated by mean 144+/-44 days. This allowed a total of 44 EOS single scan episodes for parameter analysis out of, and in the brace. Longitudinal analysis was also performed on the 19 patients who had sequential scans.

Results. Participants were mean 13.8±1.1 years old at the first scan.

Coronal 2D parameters, specifically Cobb Angle measurement, were accurately reproducible with SterEOS 3D measurements.

Across all EOS scans (n=44) the mean major coronal curve measurement was 42.3±13.3° out of brace and 37.2±13.8° in the brace. This produced a mean correction of 4.6±4.4° ($p<0.05$). The correction achieved in this cohort with bracing appeared more modest than those reported in previous studies using traditional 2D coronal curve measurements[1–3].

The mean axial vertebral rotation (AVR) was 10.6±7.1° out of the brace and 9.6±6.8° in the brace, with a mean correction of 1.4±5.3°($p=0.14$). The current study results suggested no significant change in axial vertebral rotation with brace treatment. Notably, in 17 of the 44 AVR measured, the differences were negative. That is, the AVR worsened in the brace.

There was a significant moderate correlation between 3D coronal Cobb angle measured and AVR measured out of the brace for all curves. However, the change in Cobb and change in AVR with bracing did not correlate.

Over sequential EOS episodes (n=19), there appeared no significant progression of 3D parameters, interpreted as the brace preventing curve progression.

Conclusions. There appeared to be a consistent reduction in the scoliosis Cobb angle of the major curve with brace treatment. AVR demonstrated no significant change with bracing, with instances of worsening of AVR in the brace, which was not reflected by Cobb angle measurement. Despite this, bracing appears to have been effective with limited curve progression in sequential scans, though not in the anticipated manner of immediate in-brace curve correction.

Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional (3D) curvature of the vertebral column, characterized by acquired abnormal development in the sagittal, coronal and axial planes. AIS is the most common spinal deformity of children and adolescents between 10 and 16 years, affecting 2–4% of the population[4,5].

Non-operative measures to control scoliosis during growth are limited. For curve magnitudes between 25–45°, in skeletally immature patients, bracing may be used to control curve progression[5–7]. Though bracing is common, its use is not universal, and the exact mechanisms by which it controls curve progression are not fully understood. Most braces are varied applications of the thoracic-lumbar-sacral orthoses (TLSO), commonly the “Boston brace” (Fig. 1)[8]. Recent braces such as the Rigo-Chenaau [9,10], the PASB [11], and the Sforzesco brace [12,13] are being defined.

Conventionally a standing 2D radiograph is taken to assess the curvature. Understanding scoliosis as a 3D deformity in the axial plane, however, remains of importance, with axial vertebral rotation (AVR) at initial presentation has been identified as a key risk factor in the development of a progressive scoliotic deformity[15,16]. This may occur prior to scoliosis being evident on plane radiographs[17]. The sagittal 2D Cobb angle, though widely used, has been questioned by the SRS[18] as insufficient for complete assessment due to absence of transverse plan assessment[19–21].

Recently EOS™ imaging has been utilized to enable 3D assessment of the spinal deformity, with significantly reduced radiation exposure[3,22] (Fig. 2).

EOS™ allows the acquisition of two images in orthogonal planes simultaneously[24]. Utilizing this feature, with SterEOS™ software, this allows 3-dimensional reconstruction of bony structures [25]. Importantly, this is performed in the standing position in EOS™ with the effect of gravity demonstrated to be in the order of 11° of Cobb angle measurement [26–28].

Methods

This was a prospective study in patients undertaking brace management. The patients typically had a scoliosis of greater than 25°, with growth potential defined by a Risser grading of 0–3.

Ethical approvals were obtained from both the Queensland Hospital and Health Service (*HREC/18/QRCH/26*) and the Queensland University of Technology Human Research Ethics Committee (*QUT 1800000603*).

AIS patients being treated with bracing at the Queensland Children’s Hospital (QCH) were invited to participate using the criteria outlined in Table 1.

Table 1
Inclusion and Exclusion criteria for bracing study

Inclusion criteria:	Exclusion criteria:
Male and female patients aged 10 to 17 years	Patients of congenital, neuromuscular or other types of scoliosis
Diagnosis of idiopathic scoliosis	Patients who had already had corrective surgery
A minimum Cobb Angle required of 10°	The subject's parent/guardian was cognitively impaired or unable to fully understand the study information sheet
Patients eligible for brace treatment as part of their standard clinical care	If consent was not given, participants were not be able to participate in this study

Informed consent was obtained from both the participant and their legal guardian. All research was performed in accordance with the relevant guidelines established with Declaration of Helsinki.

EOS imaging was taken both in and out of the brace at each review appointment during the study period (every 4–6 months). For each review appointment, the brace was removed the evening prior to allow a minimum 12 hours 'out of brace'. The brace was then reapplied after the initial EOS image and a further EOS image taken in the brace to allow comparison. Follow-up continued until the completion of brace treatment.

The EOS images obtained were processed using SterEOS™ software on a Windows Operating System workstation.

Coronal Parameters recorded were 2D and 3D Cobb angle measurements. *Sagittal Parameters* recorded were Pelvic Incidence (PI), Pelvic Tilt (PT), Sacral Slope (SS), Thoracic Kyphosis and Lumbar Lordosis. The single Intervertebral Orientation of *Axial vertebral rotation (AVR)* was recorded in 17 vertebrae from T1 to L5 using SterEOS™. AVR was referenced in both the 'patient plane' (pelvic orientation) and 'radio plane' (device orientation). The apex of the curve and the apical vertebra were used for comparative analysis.

EOS and SterEOS derived curve parameters were interpreted in the context of standard coronal 2D curve angle (Cobb angle[29]) measured from the PA radiograph obtained from EOS.

The Risser sign was recorded from the frontal plane EOS view. The scoliosis curve classification was determined according to Lenke[8].

Statistical analysis was performed using IBM SPSS™ (Version 25) analysis software. Statistical testing was performed using paired sample t-tests and Pearson's correlation.

Results

Between January 2019 and January 2020, 29 patients were recruited. Three patients were prescribed bracing but were non-compliant and one patient did not attend their appointment. This provided a cohort of 25 patients having at least one single episode of EOS imaging out of and in their brace. 19 patients had two episodes of EOS imaging, separated by mean 144+/-44 days, allowing longitudinal analysis of parameters.

There were a total of 44 EOS scan episodes available for immediate parameter analysis, out of and in the brace (Table2).

Table 2

EOS episode demographics including Lenke curve type[30]

	n	Mean Age (yrs +/- SD.)	Mean Risser Grade	Lenke Type[30] (n)
Number of Participants	25	13.8+/-1.1	1.5+/-1.6	1 (15) 2(1) 3(2) 4(0) 5(5) 6(2)
All EOS Scans	44	13.8+/-1.1	1.5+/-1.6	
1st scan	25	13.5+/-1.1	1.3+/-1.6	
2nd scan	19	13.9+/-1.1	1.7+/-1.6	
Average time between 1st and 2nd scan 144+/-44 days				

3D versus 2D coronal Cobb angle measurements on all Scoliosis curves

The coronal 2D Cobb angle measurements, taken from the PA EOS radiographs were compared to the 3D reconstruction Cobb angle measurement from SterEOS (n = 44). The mean 2D coronal Cobb angle out of brace was 42.3+/-13.3°. The mean SterEOS 3D coronal Cobb angle out brace was 41.1+/-12.8°. The mean difference was 1.3+/-3.4°. This produced a significant ($p < 0.05$) strong correlation of values ($r = 0.96$).

3D coronal Cobb angle out of brace versus 3D coronal Cobb angle in brace

Difference in 3D Cobb angle measurements were analyzed for changes between the out of and in brace condition (n = 44). The mean coronal Cobb angle measurement out of the brace was 42.3+/-13.3°. The mean coronal Cobb angle measurement in the brace was 37.7+/-13.8°. This resulted in a mean difference of 4.6+/-4.4° ($p < 0.05$). Curves with a magnitude of less than 40° were separated (n = 18), as to reflect a more common bracing population, with a similar mean difference of 4.3+/-6.9° ($p < 0.05$).

Change in 3D coronal Cobb angle in brace versus 3D Cobb angle out of brace

There was no significant correlation ($p = 0.63$; $r = 0.06$) between the absolute 3D coronal Cobb angle and the change in coronal Cobb angle with bracing in all curve types (Fig. 3). This indicated the magnitude of the reduction in coronal Cobb angle when measured in-brace was independent of curve severity.

AVR out of brace *versus* AVR in brace

Difference in AVR were analyzed for the changes between out of and in brace conditions (n = 44). The mean AVR out of the brace was 10.6+/-7.1°. The mean AVR in the brace was 9.6+/-6.8°. The mean difference in AVR was 1.7 +/- 5.3°, demonstrating no significant difference ($p = 0.14$).

Notably, in 17 of the 44 measurements the AVR were negative. That is, the AVR worsened in brace. These 17 patients were separated for further analysis. For worsening AVR in brace the mean out of brace was 9.7+/-5.45°. The mean AVR in brace was 13.1+/-5.13°. The mean difference in AVR was 3.1+/-3.3° ($p < 0.05$). Out of the 17 patients for whom AVR was recorded to have worsened, only 2 had a worsening of Cobb angle measurement, with 15 still recording an improvement in Cobb angle in brace.

The AVR results were separated out for curve magnitudes less than 40° (n = 18), with mean AVR out of the brace of 7.7+/-3.7° and in the brace of 6.9+/-4.7°. This was a mean difference of 2.6+/-4.9°, demonstrating no significant difference ($p = 0.25$).

AVR out of brace versus 3D Cobb angle out of brace

There was a significant ($p < 0.05$) moderate correlation ($r = 0.47$) between 3D major coronal Cobb angle measured out of brace and AVR measured out of the brace in all curve types (Fig. 4).

Change in AVR in Brace versus 3D Cobb angle out of brace

The change in AVR measurement with bracing was compared to the 3D coronal Cobb angle out of brace (Fig. 5). There was no significant correlation ($p = 0.55$; $r = 0.1$) between the absolute 3D coronal Cobb angle measurement and the change in AVR measurement with bracing.

Results were separated for curve magnitudes of less than 40° (n = 18) (Fig. 6). Although there appeared to be a trend for smaller magnitude changes in in-brace AVR with increasing 3D coronal Cobb angle, there was no significant correlation (p = 0.25; r = 0.29) between these measurements.

Sequential 3D coronal Cobb angle and Axial Vertebral Rotation Measurements

Measurements were analyzed over sequential EOS episodes in the same patient group. This was performed in 19 patients over the study period with a mean time between imaging of 144+/-44 days.

The major coronal Cobb angle out of the Brace were compared over sequential EOS episodes. The mean Initial Cobb angle '*out of brace*' for the first episode was 41.8+/-12.8°. The mean Cobb angle '*out of brace*' for the second episode was 43.2+/-14.6°, demonstrating no significant difference 1.5+/- 6.8° (p = 0.36).

The major coronal Cobb angle measurements '*in brace*' were compared over sequential EOS episodes. The mean Cobb angle in the brace for the first episode was 38.7+/-12.2°. The mean Cobb angle '*in brace*' for the second episode was 38.0+/-15.1°, resulting in a mean difference of 0.7+/- 6.3° (p = 0.65).

This indicated no significant out of, or in brace magnitude progression of the major coronal Cobb angle.

AVR measurements out of the Brace were compared over sequential EOS episodes. The mean AVR '*out of brace*' for the first episode was 10.4+/-6.4°. The mean AVR '*out of brace*' for the second episode was 11.4+/-8.3°, resulting in a mean difference of 1.0+/- 6.8° (p = 0.53).

The mean AVR '*in brace*' for the first episode was 11.1+/-6.7°. The mean AVR '*in brace*' for the second episode was 9.2+/-7.4°, resulting in a mean difference of 1.9+/- 5.4° (p = 0.15).

This indicated no significant out of, or in brace AVR progression.

Discussion

Brace treatment is a common measure used to control scoliosis during growth and is commonly employed at curve magnitudes of 20–40°, with growth remaining[7,31]. The use of EOS imaging for scoliosis surveillance presents an attractive tool to minimize cumulative radiation exposure during this period. Additionally, due to the simultaneous acquisition of frontal and lateral imaging, it has facilitated software, SterEOS™, to allow 3D reconstruction.

In clinical practice, scoliosis is most commonly characterized by 2D curve values as determined by the Cobb method[32]. This method has been shown to exhibit good intra and inter-observer reliability [33–35]. The traditional 2D parameter measurements recorded in our study are reproduced in our SterEOS 3D measurements, with a strong correlation.

The biomechanics of brace correction has the potential to be further defined in 3D planes with SterEOS™ [13]. Measurement beyond the 2D coronal plane is leading to the development of varied brace systems looking to address the rotatory or torsional component of the vertebral deformity[9,11,12,36]. Our study attempted to measure specific parameters of scoliosis correction, including AVR, ultimately to be used to predict the 'in use' effect of the braces rather than relying on the effect of the brace empirically[17].

Across all EOS scans there was a mean 3D Cobb angle correction with bracing of 4.6+/-4.4° ($p < 0.05$). Curves of < 40° (n = 18), reflecting a more common magnitude for bracing, demonstrated a clinically similar mean difference of 4.3+/-4.92°. This would indicate that curve type and magnitude did not appear to influence the degree of correction. This immediate correction appeared more modest than previous studies using 2D Cobb angle measurements[1–3].

Though the exact mechanism of the bracing effect is not known, it has been suggested that a greater immediate curve correction may lead to greater ultimate success[2,5,37]. It is postulated that this may relate to the effect on the bending moment at the apex of the curve. Using finite element modeling, it has been suggested that greater than 20% correction is required to nullify the bending moment[1,38].

Therefore, though 3D Cobb angle measurements in this study demonstrated statistical improvement when imaged in the Brace, from a clinical perspective this appeared more modest. The sample size is relatively small compared to previous multicenter bracing outcome studies and the sample is curve heterogeneous. A larger cohort may have allowed further separations to be made. The time taken for the brace to take effect may also be questioned. The participants were requested to take the brace off the night prior. This appears adequate given previous studies demonstrating loss of correction 2 hours after brace removal.[39] Lastly, spinal flexibility is another factor demonstrated to influence scoliotic curve correction in brace and secondarily, to influence bracing outcome[2,40,41]. Some authors have suggested aiming for 40% or more correction of the initial coronal curvature[37,42,43]. Patient's enrolled in this study did not have flexibility x-rays prior to brace application due to ethical considerations. Flexibility films are, at this point are not accurately attained in the EOS.

The change in the 3D Cobb angle in the brace was also compared to the absolute 3D Cobb angle out of the brace. It was thought that with increasing Cobb angle, there may be less correction of the curve. However, there appeared no significant correlation ($r = 0.06$; $p = 0.63$) between the absolute 3D coronal Cobb angle and the change in Cobb angle with bracing in all curve types. There was a weak, but not significant ($r=-0.18$; $p = 0.48$), negative correlation with curves analyzed of magnitude less than 40^0 (n = 18). From clinical experience, and previous literature, this trend for a negative correlation was expected, but the lack of significance was not. As curve magnitude increases, the curve proportionately becomes stiffer[44]. It was therefore anticipated that there would have been less change in Cobb angle measurement with brace treatment as the curve magnitude increased.

The transverse plane assessment, in the form of AVR, is relevant for complete deformity a assessment[18–21]. When comparing 3D Cobb angle measurement to AVR, there was a significant ($p < 0.05$) moderate ($r = 0.47$) correlation measured out of the brace in all curve types. This would reflect clinical experience with greater rotation observed with increasing curve severity with the deformity related to vertebral rotation within the curvature limits[20,45–48]. This result reinforces other reconstructive methods such as CT and MRI[26,47].

The AVR out of and in the brace were compared. Results for the mean difference in AVR out- vs in-brace suggested no significant change with brace treatment. This is despite a significant change in Cobb angle measurement as seen above. The change in AVR was also not influenced by the severity of the curve, as measured by the out of brace 3D coronal Cobb angle. Notably, in 17 of the 44 AVR measurements, the differences were negative. That is, the AVR was measured greater, or worsened, in brace, with a mean difference of 3.1° +/- 3.3° ($p < 0.05$). Previous literature evaluating change in AVR between the out of and in brace condition is limited. Recently, Courvoisier et al[49] has performed an analysis of biplaner imaging and the effect of bracing in 30 patients. The AVR was improved (> 5°) in only 26% of cases, worsened in 23% and unchanged in 50%. A greater than 5° difference was required in order to state a significant difference, which would be consistent with our confidence interval. In Courvoisier's[49] discussion, "the main finding is the high variability of the effects on bracing on all 3D parameters". It is suggested that given the population is heterogeneous and that the cohort small (n = 30), this may represent a limitation to interpretation of these results.

Given the results of our current study, AVR however does not appear to exhibit significant improvement with orthotic bracing and in some cases worsens.

The fundamental aim of bracing, however, is to prevent curve progression and avoid the curve reaching a magnitude that will continue to progress through skeletal maturity, or require surgical correction. The effectiveness of brace treatment has been established in clinical studies using 2D Cobb angle progression measured from radiographs at the time of bracing to final curve magnitude or progression to surgery as outcomes[17,36,50,51]. Success may be defined as less than 5° major curve progression between episodes, final curve magnitude of less than 50° and/or not requiring surgical intervention[50,51]. Coronal Cobb angle measurements out of the Brace were compared over sequential EOS episodes, and demonstrated no significant change. Clinically, this result may be seen as successful for this cohort, as curve progression had been less than 5° over an interval of 4 months.

Notably this occurred despite what may be considered a modest immediate improvement in coronal Cobb angle measurement when in the brace. The bracing appears to have been universally effective across the study cohort.

Again, though the AVR appears to correlate with absolute Cobb angle measurement, the changes that occurred in bracing do not appear consistent across Cobb angles and AVR. This is not able to be explained form the results obtained. Correlation with more detailed anatomical imaging may be useful in the future.

Conclusions

The present study investigated the function of spinal bracing in treating scoliosis patients utilizing bi-planer imaging, EOS™ imaging and SterEOS™ .

The traditional 2D parameters were accurately reproducible in SterEOS 3D measurements. Across all EOS scans the coronal Cobb angle correction achieved in this cohort with bracing appeared more modest than previous studies [1–3]. This is postulated to be due to curve flexibility and the curve magnitude of the cohort. With respect to the difference in the axial plane that results from bracing, the current study results suggested no significant change in AVR, and in some cases worsening. Notably, in 17 of the 44 AVR measured, the differences were negative. This warrants further investigation.

Over sequential EOS episodes there appeared no significant progression of 3D parameters. This may be interpreted as the brace successfully ‘holding’ the curve. This appears to be occurring through predominantly coronal plane correction.

Bracing AIS therefore appeared universally effective across this cohort, though not in the anticipated manner of significant immediate correction.

Declarations

Data Availability

In accordance with the *Australian Code for the Responsible Conduct of Research* (Part A: 3.1, 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7) the data collected was used strictly for research purposes only. Any data collected continues to be stored safely and securely by the QUT/Biomechanics Spine Research Group. As the research involves adolescents (<18 years), the data will be kept for a minimum of 25 years. Clear and accurate records of the research methods and data sources, including any approvals granted during and after the research process are kept.

Terminology

AIS (Adolescent Idiopathic Scoliosis); EOS™ (Bi-planer collimated beam x-ray); SterEOS™ (Proprietary software used for three-dimensional reconstruction of EOS generated x-rays); Bracing (Spinal orthoses used to control curve progression during growth).

References

1. Clin J, Aubin CÉ, Sangole A, et al. Correlation between immediate in-brace correction and biomechanical effectiveness of brace treatment in adolescent idiopathic scoliosis. *Spine (Phila Pa*

1976) 2010;35:1706–13.

2. Upadhyay SS, Nelson IW, Ho EK, et al. New prognostic factors to predict the final outcome of brace treatment in adolescent idiopathic scoliosis. *Spine* 1995;20:537–45.
3. Melhem E, Assi A, El Rachkidi R, et al. EOS?? biplanar X-ray imaging: concept, developments, benefits, and limitations. *J Child Orthop* 2016;10:1–14.
4. Asher MA, Burton DC. Adolescent idiopathic scoliosis: natural history and long term treatment effects. *Scoliosis* 2006;1:2.
5. Weinstein SL, Dolan LA, Cheng JC, et al. Adolescent idiopathic scoliosis. *Lancet* 2008;371:1527–37.
6. Altaf F, Gibson A, Dannawi Z, et al. Adolescent idiopathic scoliosis. *BMJ* 2013;346:1–8.
7. Weinstein SL, Dolan LA, Wright JG, et al. Effects of Bracing in Adolescents with Idiopathic Scoliosis. *N Engl J Med* 2013;369:1512–21.
8. Laurnen E, Tupper J, Mullen M. The Boston brace in thoracic scoliosis. A preliminary report. *Spine (Phila Pa 1976)* 1983;8:388–95.
9. Ovadia D, Eylon S, Mashiah A, et al. Factors associated with the success of the Rigo System Chêneau brace in treating mild to moderate adolescent idiopathic scoliosis. *J Child Orthop* 2012;6:327–31.
10. Rivett L, Stewart A, Potterton J. The effect of compliance to a Rigo System Cheneau brace and a specific exercise programme on idiopathic scoliosis curvature: a comparative study: SOSORT 2014 award winner. *Scoliosis* 2014;9:5.
11. Aulisa AG, Guzzanti V, Marzetti E, et al. Brace treatment in juvenile idiopathic scoliosis: a prospective study in accordance with the SRS criteria for bracing studies - SOSORT award 2013 winner. *Scoliosis* 2014;9:3.
12. Negrini S, Marchini G, Tessadri F. Brace technology thematic series - The Sforzesco and Sibilla braces, and the SPoRT (Symmetric, Patient oriented, Rigid, Three-dimensional, active) concept. *Scoliosis* 2011;6:8.
13. Donzelli S, Zaina F, Lusini M, et al. The three dimensional analysis of the Sforzesco brace correction. *Scoliosis Spinal Disord* 2016;11:34.
14. Berdishevsky H, Ashley Lebel V, Bettany-Saltikov J, et al. Physiotherapy scoliosis-specific exercises-a comprehensive review of seven major schools. Epub ahead of print 2016. DOI: 10.1186/s13013-016-0076-9.
15. Heidari B, Fitzpatrick D, McCormack D, et al. Correlation of an induced rotation model with the clinical categorisation of scoliotic deformity-a possible platform for prediction of scoliosis progression. In: *Studies in Health Technology and Informatics*. 2006.
16. Lupparelli S, Pola E, Pitta L, et al. Biomechanical factors affecting progression of structural scoliotic curves of the spine. In: *Studies in Health Technology and Informatics*. 2002. Epub ahead of print 2002. DOI: 10.3233/978-1-60750-935-6-81.

17. Courvoisier A, Vialle R, Skalli W. EOS 3D Imaging: assessing the impact of brace treatment in adolescent idiopathic scoliosis. *Expert Rev Med Devices* 2014;11:1–3.

18. Illés T, Tunyogi-Csapó M, Somoskeöy S. Breakthrough in three-dimensional scoliosis diagnosis: Significance of horizontal plane view and vertebra vectors. *Eur Spine J* 2011;20:135–43.

19. Illés TS, Lavaste F, Dubousset JF. The third dimension of scoliosis: The forgotten axial plane. *Orthop Traumatol Surg Res* 2019;105:351–9.

20. Labelle H, Aubin C-E, Jackson R, et al. Seeing the spine in 3D: how will it change what we do? *J Pediatr Orthop* 2011;31:S37–45.

21. Bagheri A, Liu XC, Tassone C, et al. Reliability of Three-Dimensional Spinal Modeling of Patients With Idiopathic Scoliosis Using EOS System. *Spine Deform* 2018;6:207–12.

22. Deschênes S, Charron G, Beaudoin G, et al. Diagnostic imaging of spinal deformities: reducing patients radiation dose with a new slot-scanning X-ray imager. *Spine (Phila Pa 1976)* 2010;35:989–94.

23. The leader in low dose 2D and 3D medical imaging | EOS imaging. Available at https://www.eos-imaging.com/. Accessed January 19, 2019.

24. Illés T, Somoskeöy S. The EOS^{TM} imaging system and its uses in daily orthopaedic practice. *Int Orthop* 2012;36:1325–31.

25. Humbert L, De Guise JA, Aubert B, et al. 3D reconstruction of the spine from biplanar X-rays using parametric models based on transversal and longitudinal inferences. *Med Eng Phys* 2009;31:681–7.

26. Keenan BE, Izatt MT, Askin GN, et al. Supine to standing Cobb angle change in idiopathic scoliosis: the effect of endplate pre-selection. *Scoliosis* 2014;9:16.

27. Wessberg P, Danielson BI, Willén J. Comparison of Cobb angles in idiopathic scoliosis on standing radiographs and supine axially loaded MRI. *Spine (Phila Pa 1976)*. Epub ahead of print 2006. DOI: 10.1097/01.brs.0000249513.91050.80.

28. Torell G, Nachemson A, Haderspeck-Grib K, et al. Standing and supine cobb measures in girls with idiopathic scoliosis. *Spine (Phila Pa 1976)*. Epub ahead of print 1985. DOI: 10.1097/00007632-198506000-00004.

29. Weinstein SL, Ponseti I V. Curve progression in idiopathic scoliosis. *J Bone Jt Surg - Ser A*. Epub ahead of print 1983. DOI: 10.2106/00004623-198365040-00004.

30. Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis. A new classification to determine extent of spinal arthrodesis. *J Bone Jt Surg - Ser A* 2001;83:1169–81.

31. Negrini S, Minozzi S, Bettany-Saltikov J, et al. Braces for idiopathic scoliosis in adolescents. *Cochrane database Syst Rev* 2015;6:CD006850.

32. Cobb J. Outline for the Study of Scoliosis. *Instr Course Lect* 1948;5:261–75.

33. Kuklo TR, Potter BK, Polly DW, et al. Reliability analysis for manual adolescent idiopathic scoliosis measurements. *Spine (Phila Pa 1976)* 2005;30:444–54.

34. Shaw M, Adam CJ, Izatt MT, et al. Use of the iPhone for Cobb angle measurement in scoliosis. *Eur Spine J* 2012;21:1062–8.
35. Keenan BE, Izatt MT, Askin GN, et al. Supine to standing Cobb angle change in idiopathic scoliosis: The effect of endplate pre-selection. *Scoliosis*. Epub ahead of print 2014. DOI: 10.1186/1748-7161-9-16.
36. Negrini S, Minozzi S, Bettany-Saltikov J, et al. Braces for idiopathic scoliosis in adolescents. *Cochrane database Syst Rev* 2015;6:CD006850.
37. He C, To MKT, Cheung JPY, et al. An effective assessment method of spinal flexibility to predict the initial in-orthosis correction on the patients with adolescent idiopathic scoliosis (AIS). *PLoS One*;12. Epub ahead of print 2017. DOI: 10.1371/journal.pone.0190141.
38. Cobetto N, Aubin CÉ, Parent S, et al. 3D correction of AIS in braces designed using CAD/CAM and FEM: A randomized controlled trial. *Scoliosis Spinal Disord* 2017;12:1–8.
39. Zaborowska-Sapeta K, Giżewski T, Binkiewicz-Glińska A, et al. The Duration of the correction loss after removing cheneau brace in patients with adolescent idiopathic scoliosis. *Acta Orthop Traumatol Turc* 2019;53:61–7.
40. Herring JA, Katz DE, Browne RH, et al. Brace Wear Control of Curve Progression in Adolescent Idiopathic Scoliosis. *J Bone Jt Surgery-American Vol* 2010;92:2616–7.
41. Lange JE, Steen H, Gunderson R, et al. Long-term results after Boston brace treatment in late-onset juvenile and adolescent idiopathic scoliosis. *Scoliosis* 2011;6:18.
42. Knott P, Techy F, Cotter T, et al. Retrospective analysis of immediate in-brace correction of scoliosis attainable in patients with AIS: a SOSORT initiative. *Scoliosis* 2013;8:O49.
43. Castro FP. Adolescent idiopathic scoliosis, bracing, and the Hueter-Volkmann principle. *Spine J* 2003;3:180–5.
44. Ameri E, Behtash H, Mobini B. Predictors of Curve Flexibility in Adolescent Idiopathic Scoliosis: a Retrospective Study of 100 Patients.
45. Sangole AP, Aubin CE, Labelle H, et al. Three-dimensional classification of thoracic scoliotic curves. *Spine (Phila Pa 1976)*. Epub ahead of print 2009. DOI: 10.1097/BRS.0b013e3181877bbb.
46. Panjabi MM, Brand RA, White AA. Three-dimensional flexibility and stiffness properties of the human thoracic spine. *J Biomech*. Epub ahead of print 1976. DOI: 10.1016/0021-9290(76)90003-8.
47. Little JP, Izatt MT, Labrom RD, et al. Investigating the change in three dimensional deformity for idiopathic scoliosis using axially loaded MRI. *Clin Biomech*. Epub ahead of print 2012. DOI: 10.1016/j.clinbiomech.2011.12.004.
48. Weinstein S. Idiopathic scoliosis. Natural history. *Spine* 1986;11:780–3.
49. Courvoisier A, Drevelle X, Vialle R, et al. 3D analysis of brace treatment in idiopathic scoliosis. *Eur Spine J* 2013;22:2449–55.
50. Weinstein SL, Dolan LA, Wright JG, et al. Effects of bracing in adolescents with idiopathic scoliosis. *N Engl J Med* 2013;369:1512–21.

51. Danielsson AJ, Hasserius R, Ohlin A, et 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;32:2198–207.

Figures

Figure 1

Clinical example of a Boston brace 8,14.

Figure 2

EOSTM imaging 23 https://www.eos-imaging.com/

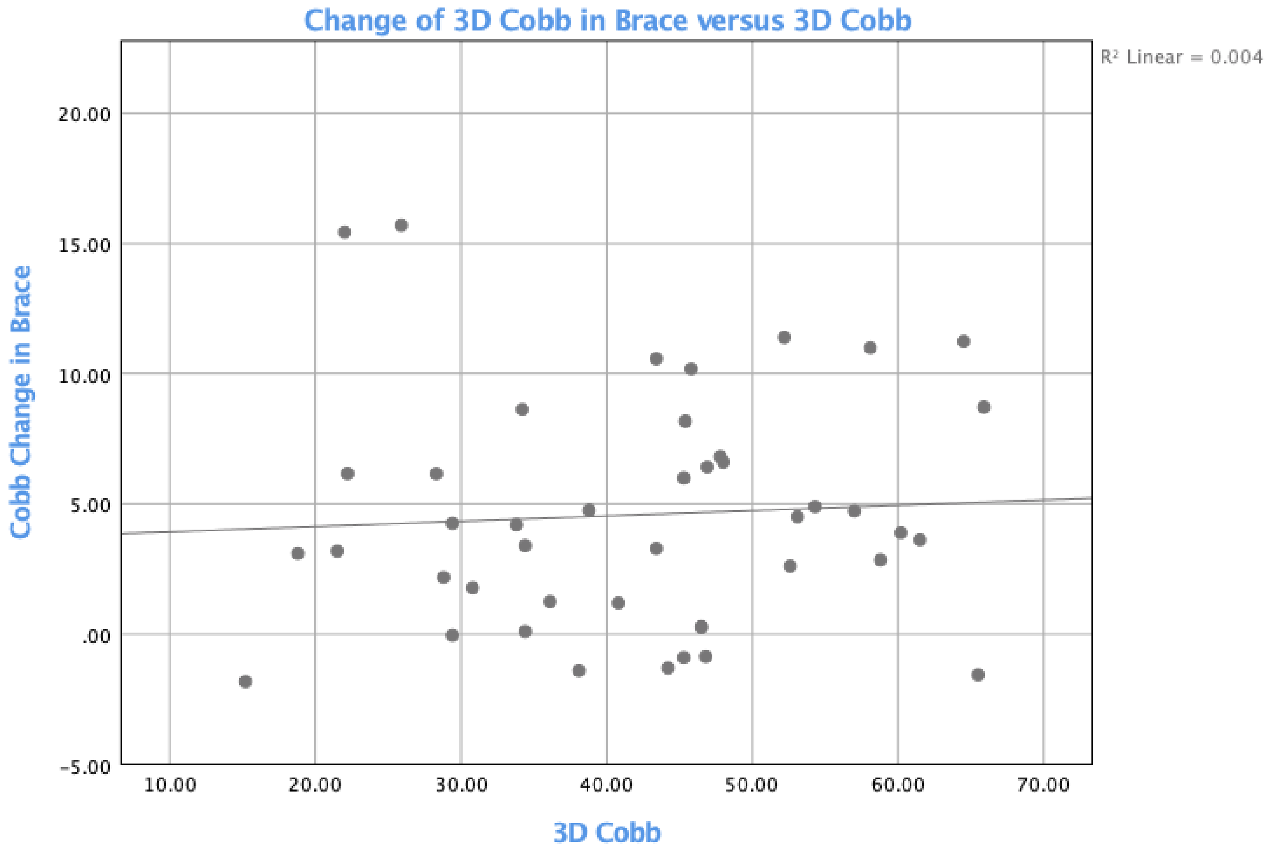

Figure 3

Change in Cobb versus 3D Cobb for all curve

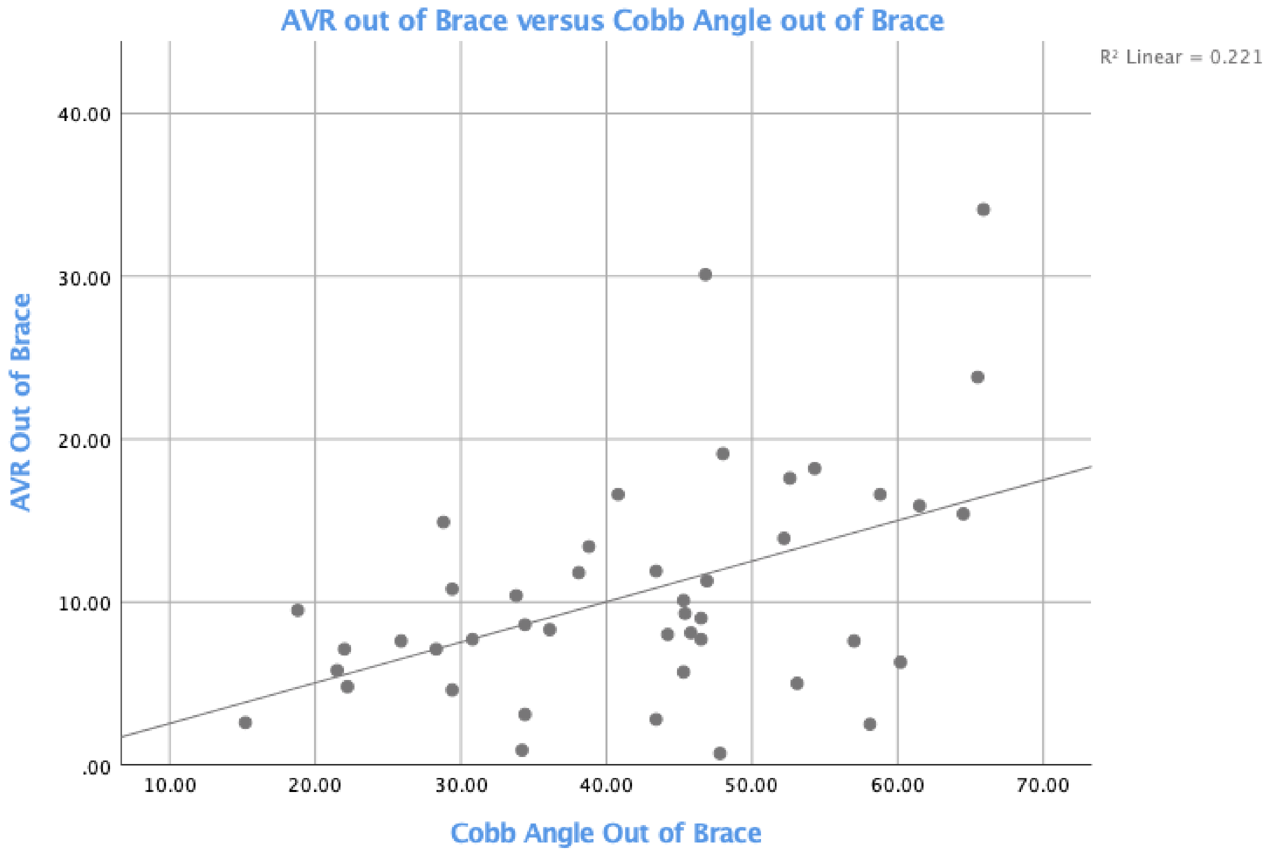

Figure 4

AVR out of brace versus major coronal Cobb angle out of brace

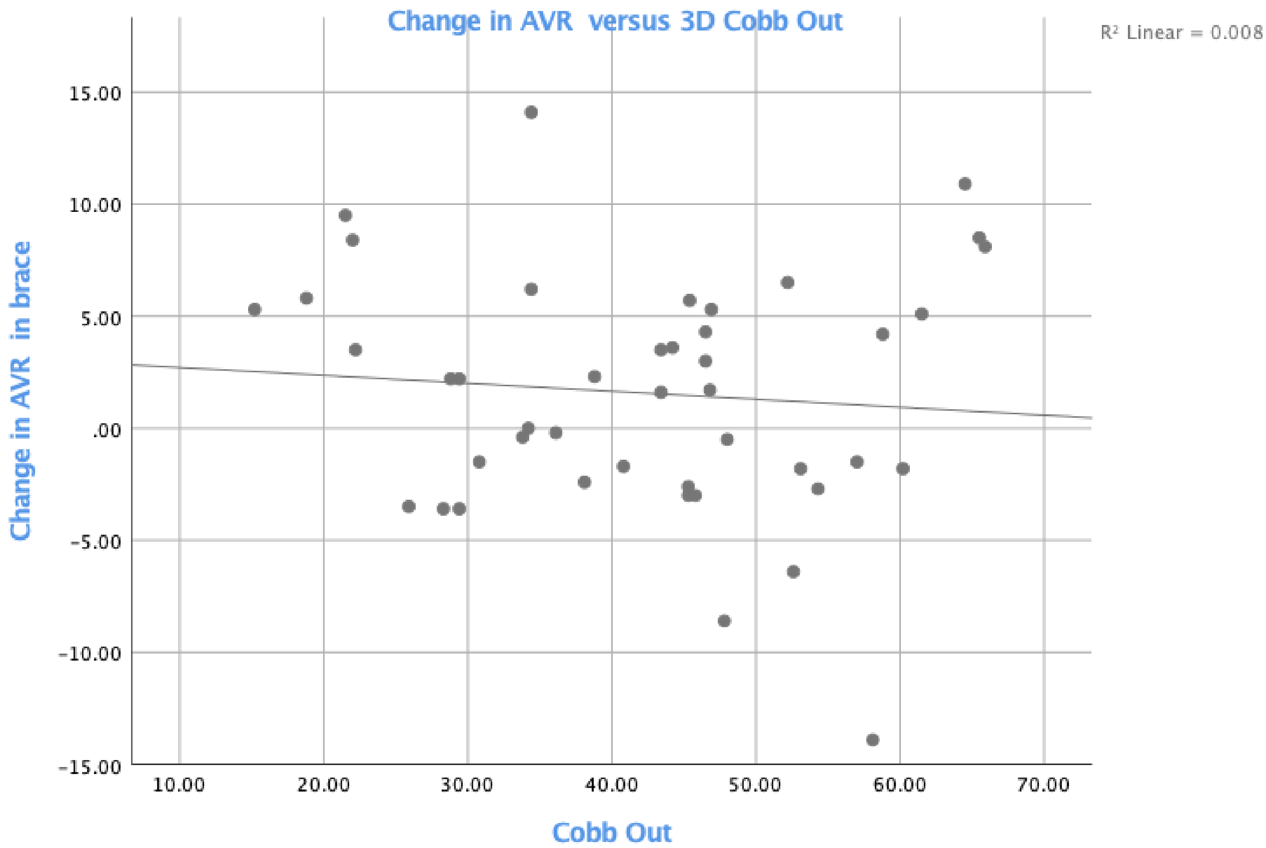

Figure 5

Change of AVR versus 3D coronal Cobb angle Out of the brace

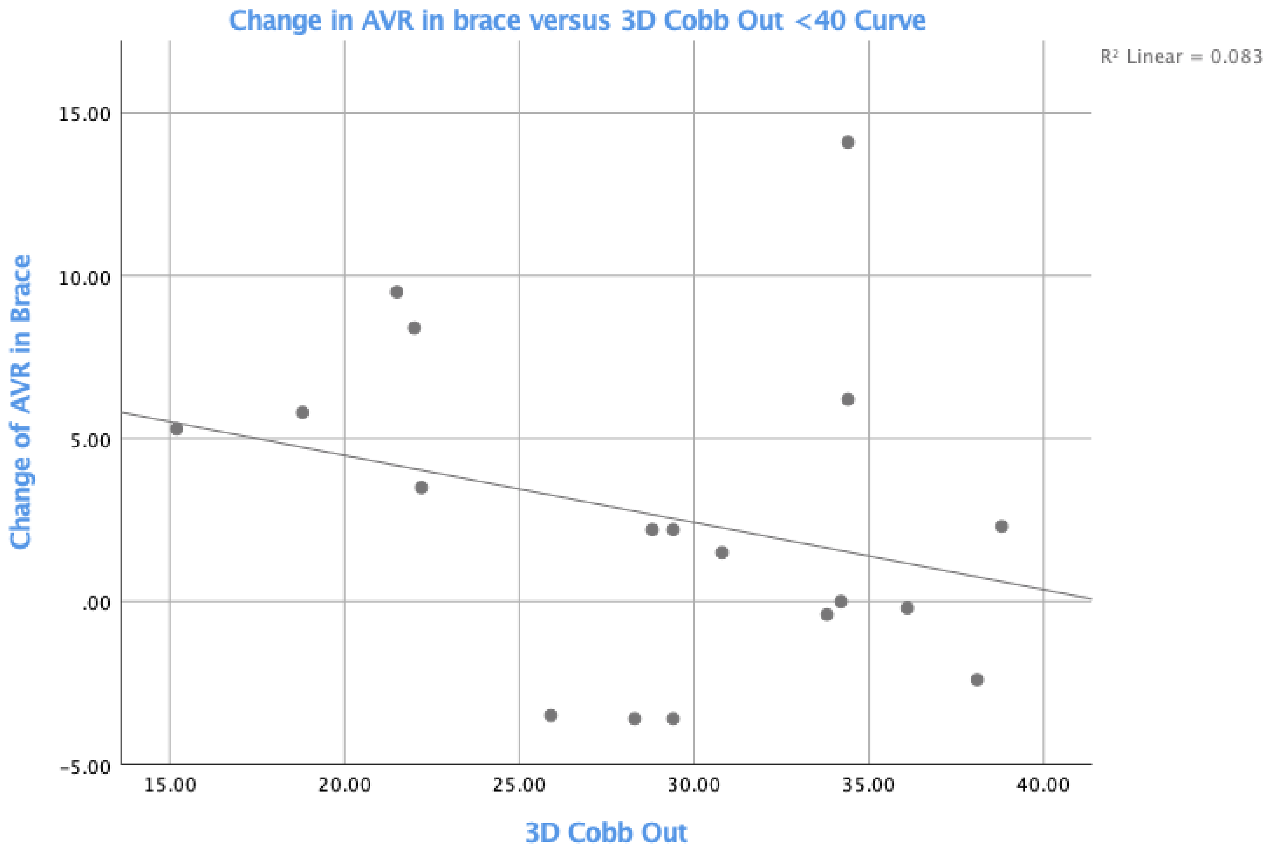

Figure 6

Change in AVR in brace versus 3D coronal Cobb angle out of the brace for curves <40°