



Correlation between age, coronal and sagittal parameters and spine flexibility in patients with adolescent idiopathic scoliosis

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Abstract

Purpose To investigate the correlation between spine flexibility and age, skeletal maturity, coronal and sagittal parameters for adolescent idiopathic scoliosis (AIS).

Methods All AIS patients evaluated for surgery were included. Following parameters were obtained: age, gender, skeletal maturity (Risser and Sanders), Cobb angle at high thoracic (HT), mean thoracic (MT) and thoracolumbar/lumbar (TL/L) level, flexibility of HT, MT and TL/L curves, coronal and sagittal parameters. A multivariate diagnostic through the Pearson Product–Moment Correlation Coefficient (r) was performed.

Results Data from 200 patients were obtained (30 males, age 15 ± 1.9 years). No significant correlation was found between curve flexibility and age or gender. A negative correlation was observed between flexibility of MT curves and magnitude of HT ($r = -0.4$) and MT curves ($r = -0.4$). A weak correlation among curve flexibility at different levels was observed: the flexibility of HT curves correlated with the flexibility of MT and TL/L curves, and the flexibility of MT curves correlated with flexibility TL/L curves. A negative correlation between flexibility of MT curves and AVT-T (thoracic apical vertebral translation) ($r = -0.2$) was evidenced. No correlations between flexibility and sagittal parameters were observed.

Conclusions No strong correlation were observed between curve flexibility and age or skeletal maturity. A negative correlation between curve magnitude and flexibility at thoracic level was demonstrated. Furthermore, a weak positive correlation between flexibility of PT, MT and TL/L curves was observed.

Keywords Spine flexibility · radiographic parameters · adolescent idiopathic scoliosis · surgical planning

Introduction

Spine flexibility plays a central role in patients affected by adolescent idiopathic scoliosis (AIS), as this parameter is required to determine whether a curve is structural or not and consequently determine the extent of spine fusion when surgery is required [1, 2]. In case of fusion-less techniques, such as vertebral body tethering (VBT)/non-fusion anterior scoliosis correction (ASC), spine flexibility assessment

is necessary to evaluate whether a patient is a good candidate for VBT and whether correction techniques (e.g., disk release, double tether) need to be employed during surgery [3]. Multiple studies have focused on the methods to obtain the most reliable X-rays to predict intraoperative curve flexibility and consequently curve correction, with fulcrum and bending X-rays resulting the techniques with the highest predictive value [4]. However, data regarding the associations between demographic and radiologic characteristics and spine flexibility are limited. Deviren and colleagues observed a correlation between spine flexibility and curve magnitude or age in patients with adolescent or adult idiopathic scoliosis [5]. Eyvazov et al. [6] analyzed the relationship between range of motion and curve magnitude in AIS patients with lumbar curves. To the best of our knowledge, the evidence regarding the correlation between baseline characteristic, such as age, radiographic skeletal maturity measurements, coronal and sagittal parameters with

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flexibility of high thoracic (HT), main thoracic (MT) and thoracolumbar/lumbar (TL/L) curves in AIS patients is limited. At the same time, the influence of skeletal maturity on other radiographic parameters is gaining importance in the context of VBT (Vertebral Body Thethering). Therefore, a retrospective, two-center study was conducted to investigate potential correlation between spine flexibility and the listed demographic and radiographic parameters.

Materials and methods

Study design

A two-center study was performed according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [7]. Clinical records from all AIS patients who underwent spine fusion or VBT for AIS between March 2017 and March 2020 at two spine surgery departments were accessed. Regarding spine fusion, surgery was performed via a posterior access; the extent of fusion and implant density was defined by the surgeon according to the curve type. Starting June 2017, patients who were eligible for VBT [8] were also offered this treatment option. The choice of instrumented levels was made according to a previously published algorithm [8]. Inclusion criteria were (1) age between 10 and 18 years; (2) preoperative radiological assessment. Exclusion criteria were (1) any other noteworthy musculoskeletal condition that could interfere with the study; (2) low-quality images (e.g., femoral head not included, imprecise stitching). Preoperative radiological assessment included whole spine anteroposterior and lateral, right and left standing side bending X-rays. Due to the retrospective nature of this study, local law did not require an informed consent to participation.

Data extraction and outcomes of interest

The collection of radiographic data (coronal and sagittal parameters, skeletal maturity parameters) was performed by two independent authors, disagreements were resolved by a third author. Following data were collected: age, gender, skeletal maturity according to Risser and Sanders, HT, MT and TL/L Cobb angles [1] in standing and bending X-rays, apical vertebral translation at thoracic and lumbar level (AVT-T and AVT-L), coronal balance (CB). AVT was measured as the distance between the centre of the apical vertebra or disk and C7 Plumb Line (for thoracic curves) or the central sacral vertical line (for thoracolumbar/lumbar curves). Sagittal parameters as lumbar lordosis (L1–S1—LL), thoracic kyphosis (T1–T12—TK), pelvic incidence (PI) and pelvic tilt (PT) and sagittal vertical alignment (SVA) were also measured. The measurements of coronal

and sagittal parameters were performed with Surgimap™ (Surgimap Spine Software, Nemaris Inc., New York, USA). Curve flexibility was calculated as $100 - (\text{curve magnitude in bending} \times 100 / \text{curve magnitude in standing})$ (e. g. curve magnitude standing = 60° , curve magnitude bending = 20° , flexibility = 67%).

Statistical analysis

The statistical analyses were performed by one author (FM). For statistical analysis, STATA software (StataCorp, College Station, TX) was used. A multivariate diagnostic through the Pearson Product–Moment Correlation Coefficient (r) was performed to analyse potential correlation between spine flexibility and the aforementioned demographic and radiographic parameters. According to the Cauchy–Schwarz equation of inequality, the final effect scores between +1 (positive linear correlation) and –1 (negative linear correlation). Values of $0.1 < |r| < 0.3$, $0.3 < |r| < 0.5$, and $|r| > 0.5$ detected weak, medium, and strong correlation, respectively. The overall significance was assessed through the χ^2 test, with values of $P > 0.05$ considered statistically significant.

Results

Patient recruitment

Data from 258 patients were considered for inclusion. Fifty-eight patients were excluded: lack of complete radiological assessment ($N = 41$), low-quality images ($N = 17$). This left 200 patients available for the study.

Patient demographic

The mean age was 15 ± 1.9 years, 30 (15%) patients were male. Risser grade was available for all patients, while Sanders stage was available for 132 patients. The distribution of the patients according to skeletal maturity is presented in Table 1. Regarding curve magnitude, HT curves averagely measured $24.5 \pm 12.2^\circ$, MT ones $54.2 \pm 19.4^\circ$ and TL/L ones $43.7 \pm 15.8^\circ$. HT curves reduced to 12.4 ± 11.0 , MT ones to $36.4 \pm 21.3^\circ$ and TL/L ones to $19.5 \pm 13.4^\circ$ on bending X-rays, which translated into an average correction by $51.0 \pm 32.0\%$, $36.3 \pm 24.8\%$ and $55.1 \pm 26.0\%$. Overall, 109 patients were Lenke type 1, 14 type 2, 22 type 3, 3 type 4, 37 type 5 and 15 type 6. Radiographic data are summarized in Table 2. No significant difference between flexibility of HT, MT and TL/L curves in males and females was observed (Table 3).

Table 1 Summary of the distribution of the skeletal maturity of the patients according to Risser and Sanders stage

Risser stage	N	Sanders stage	N
0	39	1	3
1	38	2	16
2	22	3	16
3	21	4	12
4	40	5	9
5	40	6	13
		7	39
		8	24
TOT	200		132

Table 2 Summary of radiographic parameters expressed as mean and standard deviation

Parameter	Mean	Standard deviation
Cobb angle HT (°)	24.5	12.2
Cobb angle MT (°)	54.2	19.3
Cobb angle TL/L (°)	43.7	15.8
Bending HT (°)	12.4	11.0
Bending MT (°)	36.4	21.3
Bending TL/L (°)	19.5	13.4
HT curve flexibility (%)	51.0	32.0
MT curve flexibility (%)	36.3	24.8
TL/L curve flexibility (%)	55.1	26.0
AVT-T (mm)	48.3	26.1
AVT-L (mm)	23.9	27.3
CB (mm)	14.1	18.7
LL (°)	53.6	12.4
TK (°)	36.3	15.6
PI (°)	48.2	11.9
PT (°)	10.6	7.8
SVA (mm)	12.5	30.1

Cobb angle curve magnitude on standing, anteroposterior X-rays; *Bending* curve magnitude on side-bending X-rays; *Curve flexibility* 100 – (curve magnitude in bending X 100 / curve magnitude in standing X-rays)

Table 3 Summary of curve flexibility at HT, MT and TL/L level in female and male subjects

Parameter	HT curve Flexibility (%)		MT curve Flexibility (%)		TL/L curve Flexibility (%)	
	F	M	F	M	F	M
Mean	50.7	52.3	37.4	32.8	56.0	50.7
Standard deviation	32.3	31.4	25.0	26.3	25.4	30.8
P	0.81		0.35		0.31	

Data analysis

Age correlated significantly with the Risser grade right and left and with the Sanders stage. Regarding the association between flexibility and skeletal maturity, the only significant correlation was observed between Risser on the right side and flexibility of the TL/L curve ($r = 0.1, P = 0.02$). However, some significant correlations were observed between curve magnitude and skeletal maturity. In particular, a significant, weak negative correlation was observed between magnitude of the HT curve and Risser stage ($r = -0.1, P = 0.02$ both right and left). Furthermore, a significant, medium negative correlation was found between magnitude of HT curves and Sanders stage ($r = -0.3, P < 0.0001$), while a weak negative correlation was found between magnitude of MT curves and Sanders stage ($r = -0.2, P = 0.001$). A weak correlation was also observed between LL and Risser right ($r = 0.1, P = 0.02$) and left ($r = 0.1, P = 0.007$).

Considering the correlation between magnitude and flexibility of the curves, a significant, medium negative correlation was observed between flexibility of MT curves and magnitude of HT ($r = -0.4, P = 0.001$) and MT curves ($r = -0.4, P = 0.003$). No other significant correlation between curve magnitude and flexibility at other levels was observed.

Observing the association between curve flexibility at different levels of the spine, a significant, weak correlation between flexibility of HT, MT and TL/L curves was observed: the correlation between flexibility at HT and MT level was $r = 0.1 (P = 0.03)$, between HT and TL/L level $r = 0.2 (P = 0.001)$ and between MT and TL/L level $r = 0.2 (P = 0.003)$.

Considering the correlation between flexibility and coronal balance (AVT-T, AVT-L and CB), there was only evidence of negative correlation between flexibility of MT curves and AVT-T ($r = -0.2; P = 0.0006$).

Table 4 reports an overview of the results of the study.

Discussion

Data obtained from a cohort of 200 patients evidenced no significant correlation between curve flexibility, age and gender. Curve magnitude associated with flexibility only at thoracic level; however, the flexibility of HT, MT and

Table 4 Summary of the results of the multivariate analysis

Endpoints	Age	Risser right	Risser left	Sanders	Cobb HT	Cobb MT	Cobb TL/L	Flexibility HT	Flexibility MT	Flexibility TL/L	AVT-T	AVT-L	CB	LL	TK	PI	PT	SVA
Age	<i>r</i> 1																	
	<i>P</i>																	
Risser right	<i>r</i> 0.5	1																
	<i>P</i> 0.000																	
Risser left	<i>r</i> 0.5	0.9	1															
	<i>P</i> 0.000	0.000																
Sanders	<i>r</i> 0.6	0.7	0.7	1														
	<i>P</i> 0.000	0.000	0.000															
Cobb HT	<i>r</i> -0.1	-0.1	-0.1	-0.3	1													
	<i>P</i> 0.012	0.016	0.016	0.000														
Cobb MT	<i>r</i> -0.1	-0.1	-0.1	-0.2	0.7	1												
	<i>P</i> 0.070	0.075	0.081	0.001	0.000													
Cobb TL/L	<i>r</i> 0.0	-0.0	-0.0	-0.0	-0.1	0.2	1											
	<i>P</i> 0.500	0.468	0.602	0.781	0.033	0.002												
Flexibility HT	<i>r</i> 0.0	-0.0	-0.0	-0.0	-0.0	-0.0	0.0	1										
	<i>P</i> 0.838	0.721	0.618	0.233	0.200	0.700	0.800											
Flexibility MT	<i>r</i> 0.0	0.1	0.1	0.1	-0.4	-0.4	-0.0	0.1	1									
	<i>P</i> 0.596	0.151	0.109	0.071	0.000	0.000	0.600	0.031										
Flexibility TL/L	<i>r</i> 0.0	0.1	0.1	0.1	-0.0	-0.0	0.0	0.2	0.2	1								
	<i>P</i> 0.840	0.017	0.063	0.106	0.300	0.300	0.400	0.001	0.003									
AVT-T	<i>r</i> -0.0	0.0	0.0	-0.1	0.5	0.6	-0.0	0.0	-0.2	0.0	1							
	<i>P</i> 0.300	0.651	0.841	0.076	0.000	0.000	0.250	0.900	0.001	0.210								
AVT-L	<i>r</i> 0.1	0.0	0.0	0.1	-0.3	-0.2	0.6	0.0	0.0	0.0	-0.3	1						
	<i>P</i> 0.121	0.364	0.271	0.134	0.000	0.001	0.000	0.500	0.100	0.700	0.000							
CB	<i>r</i> 0.1	0.0	0.0	0.1	-0.2	-0.2	0.1	-0.0	0.1	0.0	-0.1	0.4	1					
	<i>P</i> 0.133	0.537	0.444	0.051	0.000	0.003	0.040	0.300	0.100	0.600	0.010	0.000						
LL	<i>r</i> 0.0	0.1	0.1	0.0	-0.0	-0.0	0.0	0.0	0.0	-0.0	0.0	0.0	0.0	1				
	<i>P</i> 0.400	0.015	0.007	0.459	0.250	0.700	0.700	0.500	0.500	0.300	0.500	0.500	0.900					
TK	<i>r</i> 0.0	0.0	0.0	-0.0	0.0	0.0	0.1	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	0.3	1			
	<i>P</i> 0.842	0.691	0.503	0.310	0.500	0.300	0.150	0.600	0.600	0.800	0.300	0.550	0.330	0.000				
PI	<i>r</i> -0.0	-0.0	-0.0	-0.0	-0.0	0.0	0.0	-0.0	-0.0	-0.1	-0.1	0.0	0.0	0.4	-0.0	1		

Table 4 (continued)

Endpoints	Age	Risser right	Risser left	Sanders	Cobb HT	Cobb MT	CobbTL/L	Flexibility HT	Flexibility MT	Flexibility TL/L	AVT-T	AVT-L	CB	LL	TK	PI	PT	SVA
<i>P</i>	0.827	0.378	0.589	0.566	0.200	0.900	0.590	0.600	0.600	0.050	0.100	0.400	0.700	0.000	0.400			
<i>r</i>	0.1	-0.0	-0.0	-0.0	-0.1	-0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0	-0.0	-0.0	0.4	1	
<i>P</i>	0.120	0.534	0.624	0.374	0.100	0.600	0.600	0.500	0.500	0.800	0.400	0.200	0.330	0.330	0.600	0.000	1	
<i>r</i>	0.3	-0.0	-0.0	-0.0	0.1	0.1	-0.0	-0.0	-0.0	-0.9	0.1	-0.0	-0.0	-0.0	0.0	0.2	0.0	1
<i>P</i>	0.617	0.596	0.795	0.508	0.059	0.090	0.800	0.200	0.200	0.190	0.020	0.220	0.200	0.400	0.700	0.001	0.600	

r = Pearson coefficient, *P* = *P* value

TL/L curves correlated with one another. There was a weak to moderate association between HT curve magnitude and skeletal maturity, and a weak association between MT curve magnitude and Sanders stage. In addition, a weak association between TL/L flexibility and Risser on the right side was reported. Among the other coronal parameters, only AVT-T showed a negative correlation with thoracic flexibility and LL was weakly associated to Risser stage. None of the sagittal parameters had a significant correlation to curve flexibility. To our best knowledge, no data are yet available regarding the association between flexibility and skeletal maturity, global sagittal parameters (SVA, PI, PT) or concerning the association between flexibility and lumbar parameters, such as AVT-L or LL.

As expected, a strong correlation between age and skeletal maturity parameters was observed. As Risser stage is not always symmetrical between the two sides, a separate analysis was conducted for Risser stage on the right and on the left side. As the correlation between these two parameters was very strong ($r = 0.97, P < 0.0001$) and all associations between Risser right and left and all other observed items were very similar, we can conclude that the Risser stage on the right or on the left can be used interchangeably. Furthermore, only weak to moderate correlations were observed between Risser or Sanders stage and all other parameters, so that it is questionable whether these have a clinical value. Further studies on a larger cohort are required to investigate this aspect, as the Sanders stage was available for only 132 patients.

The literature regarding the correlation between curve flexibility and demographic and radiologic parameters is scarce. Ameri and colleagues [9] conducted a study on 100 patients to investigate relationships between flexibility of MT curve and following parameters: age, gender, curve direction, number of vertebrae in the curve, AVT-T and apical vertebral rotation, and TK. They did not observe any correlation between flexibility and age, gender or sagittal parameters, but reported an inverse correlation between magnitude and flexibility of MT curves [9]. The present study reported similar findings, as a negative correlation between MT flexibility and MT and HT curve magnitude was observed. Notably, flexibility of the thoracic spine is affected by the movement limitations posed by the rib cage, and these results may thus not be an accurate reflection if the mobility of the thoracic spine itself. Deviren et al. [5] performed the analysis of data from 75 patients with adult and adolescent idiopathic scoliosis with thoracolumbar and lumbar curves. They concluded that curve magnitude and age were the main predictors of curve flexibility [5]. These results differ from the ones of the present study, but the different age range in the observed cohorts may cause this discrepancy. In a cohort that includes adult patients, the reduction in flexibility due to disc degeneration and arthrosis

of facet joints need to be taken into account [10], and these phenomena are even more relevant in patients affected by scoliosis, in which coronal curves associate with disc degeneration [11, 12]. In the present study, only patients with AIS were considered and the limited age range among the patients may be not sufficient to observe any connection with curve flexibility. However, it may be inferred that not age itself, but more so degenerative changes connected to curve progression over time affect the relationship between curve magnitude and curve flexibility.

With the introduction of vertebral body tethering (VBT), curve flexibility is becoming one of the parameters used to assess the indication for this new, fusion-less technique [8, 13]. Since age, skeletal maturity and curve magnitude do not have a strong correlation to curve flexibility, these parameters may not be considered per se as exclusion criteria for VBT [8]. In fact, patients with large curves (e. g. 60–70°) or approaching skeletal maturity (e.g., Sanders 7/Risser 4), who are not considered good VBT candidates by most authors, may potentially present a high flexibility and thus still profit from VBT. However, targeted research is required to confirm this hypothesis. Thus, at present time, we do not recommend performing VBT in skeletally mature patients or in patients with curves > 70°.

Interestingly, flexibility of the curves at HT, MT and TL/L level correlate with one another. The association between this finding and the fact that curve flexibility only showed very limited correlation with curve magnitude and coronal parameters may suggest that curve flexibility in AIS patients may be less connected with the skeletal changes observed in scoliosis and more with a patient's characteristics. It is known that muscular structure and function, along with intervertebral disc shape and composition, play a role in AIS aetiology and progression [14–18]. Thus, factors like disc maturity or muscular and fascial structures may influence curve flexibility more than other parameters, such as age and curve magnitude. Following this hypothesis, the inverse correlation between AVT-T and flexibility of MT curves may be explained with a stiffening of soft tissue on the convex side of the curve, aiming to contrast scoliosis progression. Conversely, rib obstruction may also explain the reduction of MT flexibility with the increase of AVT-T. Further studies are required to investigate the relationship between curve flexibility and muscular and fascial structures. Shall a correlation be confirmed, this would have a great impact in the pre-surgical treatment of scoliosis, most of all given the advent of fusion-less technique, such as VBT, as physiotherapy would gain considerable importance in the influence and/or maintenance of curve flexibility required for surgery [13].

According to these findings, flexibility of MT curves decreases with increasing curve magnitude and AVT-T. This may suggest that, once indication to surgery for main

thoracic curves is given, surgery should not be delayed to avoid flexibility reduction.

This study does not come without limitations. First, the retrospective nature of the conducted analysis. As bending X-rays would not be conducted outside of the setting of preoperative evaluation, only patients evaluated for surgery were considered: this represents a potential selection bias that reflects on the characteristics of the analyzed curves (e. g. small curves may be underrepresented). Furthermore, while it is known that segmental flexibility is not uniform throughout a determined curve, further subgroup analyses on this topic were not performed [19]. Since analysis were performed starting from side-bending X-rays, correlation performed with another radiographic evaluation of curve flexibility (e.g., fulcrum or traction X-rays) may yield different results. Finally, the age range of the analyzed patients was relatively small: as growth is not a linear process, it is difficult to extend our results to patients outside of our age range and compare data with the available literature. Thus, the conclusion of this work only apply to patients within the range of age and skeletal maturity of the presented cohort. However, the relevant number of patients involved represent a strength of this work. As only two centers were involved, the bias created by the use of different radiological protocols are limited.

Conclusion

In the presented cohort of AIS patients, we observed a negative correlation between curve magnitude and flexibility at thoracic level and a positive correlation between flexibility of PT, MT and TL/L curves. No significant correlations between flexibility and patients' age and or sagittal parameters were detected. These findings may play a role in the planning and timing of surgical management for AIS, most of all when considering VBT as a therapeutic option.

Authors' contributions Substantial contributions to the design of the work; or the acquisition/analysis/interpretation of data, Draft of the work or critical revision for important intellectual content, Approval of the version to be published, Agreement to be accountable for all aspects of the work: AB, PDT, PB, CL, PK, MT, FM. All authors read and approved the final manuscript.

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Availability of data and materials Data can be made available in anonymized form and upon reasonable request.

Declarations

Ethics approval and consent to participate RWTH Aachen, Faculty of Medicine, approval EK 130/19. Due to the retrospective nature of the study, consent to participate was not required.

Consent for publication Due to the retrospective nature of the study, consent for publication was not required.

Competing interests PDT: Globus Medical (personal fees), Medtronic (personal fees), K2M (travel support). PB, CL: Nuvasive (personal fees), Depuy Sinthes (personal fees), Medacta (personal fees), Zimmer (personal fees), K2M (personal fees), Medtronic (personal fees), Stoeckli Medical (grants). AB, FM: none.

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