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Correlation between Scoliosis Flexibility Degree on Preoperative Imaging with Postoperative Curve Correction and Mechanical Complications

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Abstract: (1) Background: In the preoperative planning stage of scoliosis surgery, it is routine to use radiographs obtained with and without traction to observe the curve flexibility in order to estimate curve correction, but its association with mechanical complications is not completely understood. (2) Methods: Retrospective cohort study of all patients undergoing infantile, congenital, neuromuscular or idiopathic adolescent scoliosis correction surgery at a single institution between 2015 and 2019, with a minimum follow-up of 24 months. Associations between qualitative variables were tested with the chi-square test. The association between qualitative and quantitative variables were tested with the Mann–Whitney test, and correlations between quantitative variables was tested with Spearman's correlation. (3) Results: A total of 330 patients, 88 males and 242 females, with a mean age of 16.98 years at surgery, were included. The mean value of preoperative main curves, its flexibility and postoperative value were 54.44 degrees, 21.73 degrees and 18.08 degrees, respectively. (4) Conclusions: Preoperative spinal X-ray examination with traction or bending films is a reasonable option for assessing scoliotic curve flexibility, and patients with neuromuscular scoliosis who are not ambulatory can be informed of the increased risks of late mechanical complications.

Keywords: scoliosis; neuromuscular scoliosis; mechanical complications

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1. Introduction

The most frequent etiological cause of scoliosis is idiopathic, neuromuscular is the second most frequent cause and congenital anomalies are the least frequent causes of scoliosis [1–3]. It is estimated that the prevalence of idiopathic scoliosis among patients aged 10 to 16 years is 2–3% [1]. Scoliosis causes multiple trunk deformations that can affect a person's perception of their body, and body image reflects a dynamic representation that changes according to actions, emotions and feelings, ultimately being an important factor when assessing health-related quality of life [4]. The proportion of individuals that require surgery is higher in neuromuscular and congenital scoliosis than in idiopathic scoliosis [5,6]. The socioeconomic impact of scoliosis is significant, affecting the individual, their families and health professionals. The average cost of surgery for idiopathic scoliosis correction varies, costing approximately US $50,000 [7]. For different types of scoliosis, early diagnosis might prevent more aggressive treatment and reduce the rate of complications [1,5–8]. School-based screening protocol using clinical examinations could be a reasonable option in the early diagnosis of adolescent idiopathic scoliosis due to its high specificity [9].

The most commonly used, available and cost-effective complementary diagnostic test for detecting scoliosis is spinal X-ray examination [8,10]. In the preoperative planning stage, it is common to use radiographs obtained with and without traction or bending films to observe curve flexibility [5,6]. Surgical planning must consider the perioperative clinical risks, need for osteotomies, quantity and quality (screws, hooks, tapes, cages, rods) of implants, possibility of reoperation and alignment of the possibilities of deformity correction with the expectations of the family. All complementary examinations must be ordered with rationality regarding changes in the surgical plan or therapy with respect to their additional cost and patient safety, especially in the case of examinations involving ionizing radiation [7,10,11].

There are studies in the literature associating the preoperative flexibility of the scoliotic curve with the degree of correction obtained in the postoperative period [12,13]. However, there are few reports on whether lower preoperative curve flexibility, i.e., greater spinal stiffness, is associated with a higher rate of late mechanical complications. This information is important for planning and therapeutic decision-making by both the multidisciplinary team and the family.

The present study aims to analyze whether greater preoperative curve flexibility is related to greater deformity correction and fewer late mechanical complications.

2. Materials and Methods

This was a retrospective cohort study of all patients undergoing the correction of scoliosis (idiopathic adolescent, infantile, congenital or neuromuscular) between 2015 and 2019 at a single institution.

The inclusion criteria were as follows: patients with scoliosis with surgical indications who had preoperative spinal X-rays in the frontal and lateral views with and without traction or bending films, as well as postoperative spinal X-rays; and minimum follow-up of 24 months. The exclusion criteria were as follows: incomplete records; adult and elderly patients with degenerative scoliosis.

All X-ray examinations were performed at the same institution, with standardized image acquisition for frontal, lateral, traction or bending films.

The primary variables were defined: Cobb angle, flexibility, mechanical failure, etiology, levels fused. All variables analyzed are available in Appendix A, Table A1.

Mechanical complications, including material failure, were defined as follows, according to an assessment based on spinal X-ray images: radiolucent halo, suggestive of loosening around the implant material greater than or equal to 2 mm; breakage of the implant material; presence of proximal or distal junctional kyphosis (defined as an increase greater than or equal to 10 degrees between the instrumented proximal or distal segment and the segment immediately distal to it).

Flexible curves were defined as the difference in percentages equal to or greater than 40% when comparing curves preoperatively without traction, with traction or bending films.

Data are described as the frequency and confidence interval for qualitative variables and measures of central tendency (mean and median) and dispersion (standard deviation, interquartile range, minimum and maximum) for quantitative variables. All analyses were performed using R software (Developer R Core Team, version 4.1.0—May 2021, Vienna, Austria), and results with a p-value < 0.05 were considered statistically significant. The existence of associations between qualitative variables was tested with the chi-square test. The association of qualitative variables with quantitative variables was tested with the Mann–Whitney test, and the correlation between quantitative variables was tested with Spearman's correlation. Nonparametric tests were selected because the quantitative variables of interest did not present a normal distribution (Kolmogorov–Smirnov test, $p < 0.05$). The strength of the correlation was classified as very weak (0 to 0.19), weak (0.20 to 0.39), moderate (0.40 to 0.69), strong (0.70 to 0.89) or very strong (0.90 to 1). The time to material failure and its association with qualitative variables were analyzed with Cox regression (survival analysis, using the survival package).

Statistical analyses were performed by an independent statistician blinded to the data. The study was approved by the institutional review board.

3. Results

A total of 330 patients, 88 males and 242 females, with a mean age of 16.98 years at surgery, were included. The mean outpatient follow-up time was 2.9 years (median, 934 days). Eighty-four patients were excluded due to a lack of adequate X-rays, complete medical records or a sufficient follow-up time. Descriptive statistics of primary variables are described in Tables 1 and 2.

Table 1. Descriptive statistics of qualitative variables.

Variable	Category	*n*	% (95% CI)
Sex	Female	242	73.33 (68.79–78.31)
	Male	88	26.67 (22.12–31.65)
Instrumented levels	T4-L4	66	20.00 (15.45–24.77)
	T3-Iliac	56	16.97 (12.42–21.74)
	T2-Iliac	25	7.58 (3.03–12.35)
	T4-L3	24	7.27 (2.73–12.04)
	T5-L4	19	5.76 (1.21–10.53)
	T4-L1	16	4.85 (0.30–9.62)
	T3-L4	13	3.94 (0.00–8.71)
Ambulation	Yes	232	70.30 (65.45–75.37)
	No	98	29.70 (24.85–34.77)
Pathology	Idiopathic	187	56.67 (51.21–62.14)
	Neuromuscular–Cerebral Palsy	79	23.94 (18.48–29.42)
	Neuromuscular	55	16.67 (11.21–22.14)
	Congenital	9	2.73 (0.00–8.20)
Pelvic obliquity within normal range (preoperative)	Yes	203	61.52 (56.36–67.10)
	No	127	38.48 (33.33–44.07)
Pelvic obliquity within normal range (postoperative)	Yes	236	71.52 (66.67–76.43)
	No	94	28.48 (23.64–33.40)
Comparison of pre- and postoperative normal-range pelvic obliquity	Kept in the normal range	202	61.21 (56.06–66.75)
	Kept out of the normal range	93	28.18 (23.03–33.72)
	Entered the normal range	34	10.30 (5.15–15.84)
	Out of the normal range	1	0.30 (0.00–5.84)
Main curve flexibility	Flexible	168	50.91 (45.45–56.58)
	Nonflexible	162	49.09 (43.64–54.76)
Secondary curve flexibility	Nonflexible	289	87.58 (84.24–91.01)
	Flexible	41	12.42 (9.09–15.86)
Material failure	No	309	93.64 (91.52–96.34)
	Yes	21	6.36 (4.24–9.07)
Need revision surgery	Without failure	309	93.64 (91.52–96.20)
	No	12	3.64 (1.52–6.20)
	Yes	9	2.73 (0.61–5.29)

Legend: number of patients per category (*n*) and percentage with 95% confidence interval (CI).

Testing the association between the flexibility of the curve (flexible or nonflexible) and the occurrence of material failure revealed no statistical association, despite the apparent excess of failures among patients with nonflexible curves (Table 3a). Additionally, there was no clear association between the degree of flexibility and material failure when evaluated as the absolute difference in degrees or in percentages (Table 3b).

Table 2. Descriptive statistics of quantitative variables.

Variable	*n*	Absent	Mean (±SD)	Median (IQR)	Min–Max
Outpatient follow-up time	330	0	1062.50 (±338.55)	934.50 (809.00–1228.50)	728.00–2346.00
Number of instrumented levels	330	0	12.68 (±2.76)	12.00 (11.00–15.75)	6.00–22.00
Curve 1, proximal thoracic, preoperative without traction	330	0	1.85 (±9.06)	0.00 (0.00–0.00)	0.00–76.00
Curve 1, preoperative with traction	330	0	1.34 (±7.13)	0.00 (0.00–0.00)	0.00–76.00
Curve 1, postoperative	330	0	0.71 (±3.83)	0.00 (0.00–0.00)	0.00–35.00
Curve 2, thoracic, preoperative without traction	330	0	26.81 (±26.32)	32.00 (0.00–49.00)	0.00–90.00
Curve 2, preoperative with traction	330	0	16.80 (±18.72)	12.00 (0.00–31.00)	0.00–78.00
Curve 2, postoperative	330	0	9.03 (±12.92)	2.00 (0.00–14.00)	0.00–74.00
Curve 3, thoracolumbar or lumbar, preoperative without traction	330	0	36.60 (±29.92)	42.00 (0.00–57.00)	0.00–144.00
Curve 3, preoperative with traction	330	0	20.90 (±22.30)	15.00 (0.00–35.00)	0.00–114.00
Curve 3, postoperative	330	0	12.78 (±17.48)	5.00 (0.00–19.00)	0.00–90.00
Main curve	330	0	54.44 (±16.52)	50.50 (43.00–63.00)	15.00–144.00
Sum of secondary curves	330	0	10.82 (±20.80)	0.00 (0.00–0.00)	0.00–108.00
Main curve flexibility, degrees	330	0	21.73 (±11.71)	21.00 (13.00–29.00)	0.00–56.00
Secondary curve flexibility, degrees	330	0	4.49 (±9.43)	0.00 (0.00–0.00)	0.00–41.00
Main curve flexibility, percentage	330	0	0.42 (±0.24)	0.40 (0.25–0.58)	0.00–1.00
Secondary curve flexibility, percentage	330	0	0.10 (±0.21)	0.00 (0.00–0.00)	0.00–0.95
Main curve (postoperative)	330	0	18.08 (±17.01)	13.00 (6.00–24.00)	0.00–90.00
Sum of secondary curves (postoperative)	330	0	4.44 (±10.58)	0.00 (0.00–0.00)	0.00–67.00
Main curve correction, degrees	330	0	36.36 (±13.20)	36.00 (29.00–43.00)	−17.00–76.00
Secondary curve correction, degrees	330	0	6.38 (±13.16)	0.00 (0.00–0.00)	−4.00–75.00
Main curve correction, percentage	330	0	0.70 (±0.23)	0.74 (0.58–0.86)	−0.52–1.00
Secondary curve correction, percentage	80	250	0.61 (±0.27)	0.58 (0.46–0.82)	−0.09–1.00
Time to surgery for complications, days	21	309	514.86 (±386.22)	399.00 (272.00–714.00)	38.00–1435.00
Revision surgeries	9	321	1.22 (±0.44)	1.00 (1.00–1.00)	1.00–2.00

Legends: number of patients included in the analysis (*n*), mean with standard deviation (SD), median with interquartile range (IQR) and minimum (min) and maximum (max) values of the variables.

Table 3. Analysis of curve flexibility and associations with the occurrence of material failure. (**a**) Chi-square test of main and secondary curve flexibility compared with occurrence of material failure; (**b**) Association of curve flexibility with occurrence of material failure; (**c**) Association of curve flexibility with percent postoperative correction; (**d**) Correlation of curve flexibility (in degrees) with percent correction; (**e**) Correlation of flexibility percentage with percent correction; (**f**) Chi-square test of etiological group compared with occurrence of material failure.

(a)

	Material Failure				
	Yes		**No**		**Total**
	n	**% (95% CI)**	***n***	**% (95% CI)**	***n***
Main curve flexibility				$p = 0.26$	
Flexible	8	4.76 (2.38–8.04)	160	95.24 (92.86–98.51)	168
Nonflexible	13	8.02 (4.32–11.89)	149	91.98 (88.27–95.84)	162
Secondary curve flexibility				$p = 0.31$	
Flexible	4	9.76 (2.44–17.70)	37	90.24 (82.93–98.19)	41
Nonflexible	17	5.88 (3.46–8.39)	272	94.12 (91.70–96.63)	289
Total	21		309		330

(b)

Flexibility and material failure		
	Main curve	Secondary curves
Degrees—*p*-value	0.6	0.6
Percentage—*p*-value	0.3	0.7
Method	Mann–Whitney	

Table 3. *Cont.*

(c)

Main curve flexibility and percent postoperative correction			Secondary curve flexibility and percent postoperative correction		
	Flexible	Nonflexible		Flexible	Nonflexible
Mean (SD)	78 (±17)	61 (±25)	Mean (SD)	67 (±29)	54 (±22)
Median (IQR)	81 (70–91)	64 (48–78)	Median (IQR)	69 (53–96)	53 (38–70)
Min–Max	20–100	−52–100	Min–Max	−9–100	6–100
p-value	**<0.001**		*p*-value	**0.01**	
Method	Mann–Whitney		Method	Mann–Whitney	

(d)

Degrees of flexibility and percent postoperative correction		
	Main curve	Secondary curves
p-value	<0.001	0.3
Spearman r	0.23	0.13
Effect size	**Weak**	Not significant

(e)

Flexibility percentage and percent postoperative correction		
	Main curve	Secondary curves
p-value	<0.001	0.005
Spearman r	0.41	0.31
Effect size	**Moderate**	Weak

(f)

Pathology	Material failure Yes		NO		Total
	n	% (95% CI)	*n*	% (95% CI)	*n*
Congenital	0	0.00 (0.00–18.11)	9	100.00 (100.00–100.00)	9
Idiopathic	7	3.74 (1.60–6.34)	180	96.26 (94.12–98.85)	187
Neuromuscular	7	12.73 (5.45–21.15)	48	87.27 (80.00–95.70)	55
Neuromuscular–Cerebral palsy	7	8.86 (3.80–14.86)	72	91.14 (86.08–97.14)	79
Total	21		309		330
$p = 0.058$					

Curve flexibility (flexible or nonflexible) was compared with the percent correction in the postoperative period, as described in Table 3c.

The results of Spearman's correlation between the difference in curves with and without traction and the percent correction in the postoperative period are shown in Table 3d,e.

Evaluating the occurrence of material failure by etiology did not yield a significant result, as shown in Table 3f. There were very few cases with a congenital etiology for inclusion in the proposed analysis, and among other causes, there was an apparent tendency toward greater failure among patients with a neuromuscular etiology.

On further group analysis, it was observed that revision surgery was more common among patients with a neuromuscular etiology (Table 4).

Table 4. Association between neuromuscular scoliosis and necessity of surgical revision.

Pathology	**Revision**				
	Yes		**No**		**Total**
	n	**% (95% CI)**	***n***	**% (95% CI)**	***n***
Congenital/Idiopathic	5	2.55 (0.51–4.92)	2	1.02 (0.00–3.39)	7
Neuromuscular	7	5.22 (0.75–9.89)	7	5.22 (0.75–9.89)	14
Total	12		9		21

$p = 0.02$.

Age, weight, and height at surgery and number of instrumented levels were tested for an association with the percent correction of the main and secondary curves (Table 5). Among them, the only factor that showed a correlation with the percent curve correction and material failure was the number of instrumented levels; paradoxically, the smaller the number of instrumented levels, the greater the correction percentage.

Table 5. Correlation of age, weight, height and number of instrumented levels with percent scoliotic curve correction, and material failure and association of sex, neuromuscular etiology and iliac fixation with material failure.

		Main Curve			**Secondary Curves**	
Correlation of age with percent postoperative correction						
p-value		0.3			0.3	
Spearman r		−0.019			0.11	
Effect size		Not significant			Not significant	
Correlation of weight with percent postoperative correction						
p-value		0.05			0.2	
Spearman r		0.11			0.13	
Effect size		Not significant			Not significant	
Correlation of height with percent postoperative correction						
p-value		0.2			0.4	
Spearman r		0.075			0.11	
Effect size		Not significant			Not significant	
Correlation of number of instrumented levels with percent postoperative correction						
p-value		<0.001			0.09	
Spearman r		−0.3			−0.19	
Effect size		Weak			Not significant	
	Age	Weight	Height		Number of instrumented levels	
Material failure				Mean (SD)	Median (IQR)	Min–Max
Yes	-	-	-	14.7 (±3.3)	15 (14–16)	7–22
No	-	-	-	12.5 (±2.7)	12 (11–15)	6–17
p-value	0.4	0.1	0.2		**0.002**	
Method				Mann–Whitney		
Percent postoperative correction of the main curve						
Sex—*p*-value				0.1		
Method				Mann–Whitney		
Percent postoperative correction of the main curve						
		Ambulation			Neuromuscular scoliosis	
	Yes		No	Congenital/Idiopathic	Neuromuscular	
Mean (SD)	74 (±19)		58 (±27)	75 (±19)	62 (±26)	
Median (IQR)	77 (64–88)		64 (39–78)	78 (65–89)	68 (46–81)	
Min–Max	12–100		−58–100	12–100	−0.52–100	
p-value		**<0.001**			**<0.001**	
Method		Mann–Whitney			Mann–Whitney	
Chi-square test of sex, ambulation and neuromuscular variables compared with the occurrence of material failure						
			Material failure			
		Yes			No	Total
	n		% (95% CI)	*n*	% (95% CI)	*n*
Sex						
Female	14		5.79 (3.31–8.63)	228	94.21 (91.74–97.06)	242
Male	7		7.95 (3.41–13.37)	81	92.05 (87.50–97.46)	88
Total	21			309		330
			$p = 0.45$			
Ambulation						
Yes	8		3.45 (1.72–5.83)	224	96.55 (94.83–98.93)	232
No	13		13.27 (7.14–19.42)	85	86.73 (80.61–92.89)	98
Total	21			309		330
			$\mathbf{p = 0.002}$			
Neuromuscular						
Yes	14		10.4 (5.3–15.6)	120	89.6 (84.4–94.7)	132
No	7		3.6 (1.0–6.2)	189	96.4 (93.8–99.9)	196
Total	21			309		330
			$\mathbf{p = 0.01}$			

Occurrence of material failure demonstrated a significant association with ambulation and etiology (Table 5).

As shown in Table 6, the overall cumulative risk of material failure in the first year after surgery was 2.73% and 10.1% in the four years after surgery. The variables that were compared with the occurrence of material failure (ambulation, sex, main curve flexibility and etiology) were submitted to Cox regression according to the follow-up time and time of material failure.

Table 6. Risk of failure per year of follow-up and Cox regression according to follow-up time, material failure, ambulation, sex, main curve, flexibility and etiology.

Estimated Failures per Year					
Time	**Patients at Risk**	**Number of Events**	**Probability, No**		**Probability, Yes**
1st year	321	9	0.973		0.0273
2nd year	311	16	0.952		0.0485
3rd year	93	19	0.939		0.0611
4th year	38	21	0.899		0.101
5th year	12	21	0.899		0.101
6th year	3	21	0.899		0.101
Variable		Reference	RR [1]	95% CI [1]	*p*-value
Ambulation		No	**0.27**	0.11–0.65	**0.003**
Sex		Female	1.34	0.54–3.31	0.5
Main curve flexibility		Flexible	1.67	0.69–4.03	0.3
Etiology					
	Neuromuscular	Idiopathic	**3.33**	1.17–9.52	**0.025**
	Neuromuscular–Cerebral Palsy	Idiopathic	2.24	0.78–6.40	0.13
	Congenital	Idiopathic	0.00	0.00	-

[1] RR = relative risk, CI = confidence interval.

4. Discussion

Scoliosis correction surgeries are complex and challenging [6,7,10] and lack of satisfactory bone fusion can lead to numerous mechanical and clinical complications [8,11,14]. In the present study, it was hypothesized that greater preoperative scoliotic curve flexibility is a protective factor for the occurrence of long-term mechanical complications. However, the findings do not statistically support this hypothesis, despite the apparent excess of failures among patients with nonflexible curves.

A higher percentage of correction in the postoperative period was observed among curves classified as flexible (Tables 1–3). On average, 21.73 degrees of main scoliotic curve correction was obtained, with an average correction of 70% of its value in degrees.

The results of Spearman's correlation between the difference in curves without and with traction or bending films and the percent correction in the postoperative period revealed a significant relationship only for the main curve, not the secondary curves. Additionally, the effect was weak, with an r of only 0.23 (Table 3d).

When evaluating flexibility as a percentage, both the main and secondary curves showed a significant correlation with the correction achieved and with a more intense effect than when observing absolute values in degrees. Even so, for the comparative flexibility of the main curve, which showed the greatest effect, the value is considered only moderate (Table 3e). This fact is consistent with findings from previous studies [15,16]. Among the hypotheses to explain this finding, the following stand out: technical variability between spinal X-ray images obtained with and without traction could perhaps underestimate the power of correction; the study sample had a large number of patients with severe and rigid curves, in whom the influence of traction during spinal X-ray examination could be smaller; and the reduction maneuvers, osteotomies and other reduction tactics used in different cases were not compared.

On comparison of age, weight, height and number of instrumented levels with the percent scoliotic curve correction, only the last variable showed a statistically relevant result, though with a weak effect; a smaller number of instrumented levels was associated with greater correction (Table 5). This fact may indicate bias in the study given that the sample is from a heterogeneous population with varying degrees of scoliotic curve severity and rigidity, as several studies comparing implant density and proximal and distal fixation with outcomes have shown results conflicting with those presented here [17–20].

The probability of material failure was 2.73% in the first year after surgery and 10.1% over four years (example, Figure 1). The average time from surgery to diagnosis of the complication was 309 days. Of the 330 patients included in the study, only 21 (6.36%) had implant failure, and of those, only 9 required revision surgery. This fact demonstrates that most patients, even those with mechanical failure, did not need revision surgery due to the absence of clinical complaints or neurological dysfunction.

Figure 1. Lateral X-ray showing pedicle screw breakage at L5.

The ability to ambulate is a protective factor against material failure (RR, 0.27), and patients with neuromuscular scoliosis, excluding cerebral palsy as an etiology, are 3.33 times more likely to have mechanical failure than patients with idiopathic scoliosis (example,

Figure 2). This fact agrees with previous findings in the literature, in which patients with neuromuscular scoliosis or who do not ambulate have higher rates of complications than those with idiopathic or congenital scoliosis [21–23]. Possible explanations for this fact are greater curve severity, poorer bone quality and nutrition, lower muscle mass, less subcutaneous and skin coverage, and more unfavorable clinical aspects, such as poor ventilatory function and recurrent infections, among other factors [24].

Figure 2. Anteroposterior X-ray showing rod breakage on the right.

Among the limitations of the study, there was a high percentage of patients lost to follow-up according to the exclusion criteria, especially regarding correct and complete data in medical records and sufficient postoperative follow-up. The peculiarity of dealing with a heterogeneous sample population may make it impossible to fully generalize the findings. Another limitation is the fact that patients were operated on by different surgeons within the same institution. We cannot fail to mention the fact that the manufacturers of the implants used in the studied patients are unknown as a possible limiting factor in the study. It is possible that different materials have different technical and mechanical properties, although the overall number of implant-related failures is relatively low.

5. Conclusions

Preoperative spinal X-ray examination with traction or bending films is a reasonable option for assessing scoliotic curve flexibility and can serve as another tool to facilitate decision making by surgical teams, patients and their families because flexible curves have a better chance of achieving better correction postoperatively. On the other hand, patients with neuromuscular scoliosis or who are not capable of ambulating can be informed of the increased risks of late mechanical complications. Although the rate of late mechanical complications was apparently smaller among patients with flexible curves, the findings do not statistically support the hypothesis.

Author Contributions: Conceptualization, all authors; methodology, M.C.M.T.J.; software, M.C.M.T.J.; validation, all authors; formal analysis, all authors; investigation, M.C.M.T.J. and O.B.L.; resources, O.B.L.; data curation, all authors; writing—original draft preparation, all authors; writing—review and editing, all authors; visualization, all authors; supervision, O.B.L.; project administration, M.C.M.T.J.; funding acquisition, O.B.L. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of AACD (CAAE 17954119.0.000.0085, date of approval: 29 October 2019).

Informed Consent Statement: All data were collected and anonymized centrally and retrospectively and due to ethical concerns if consent was required (the only link to participants would be the consent, contacting participants could inflict harm on individuals or their families), informed consent was waived by institutional review board.

Data Availability Statement: Datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

List of all variables:
Quantitative:

- Age at surgery (years);
- Weight at surgery (kilograms);
- Height at surgery (centimeters);
- Outpatient follow-up time (days);
- Number of fixed levels (vertebral intervals);
- Preoperative and postoperative pelvic obliquity (degrees);
- Preoperative and postoperative thoracic kyphosis (degrees);
- Preoperative and postoperative lumbar lordosis (degrees);
- Curve 1, proximal thoracic preoperative scoliosis without traction (degrees);
- Curve 2, thoracic preoperative scoliosis without traction (degrees);
- Curve 3, thoracolumbar or lumbar preoperative scoliosis without traction (degrees);
- Curves 1, 2 and 3, preoperative scoliosis with traction (degrees);
- Curves 1, 2 and 3, postoperative scoliosis (degrees);
- Time from surgery to complications (days);
- Number of revision procedures.

Qualitative:

- Sex (male or female);
- Instrumentation—description of fixed intervals with notation T# (T: thoracic vertebra, #: level), L# (L: lumbar vertebra, #: level), and iliac;
- Outpatient ambulatory (yes or no);

- Baseline pathology (neuromuscular–cerebral palsy {CP}, neuromuscular {other causes}, idiopathic or congenital);
- Material failure (yes or no);
- Revision surgery (yes or no).

To perform the statistical analysis, another 20 variables were created. Quantitative variables are marked with an asterisk.

Table A1. Definition of all variables, calculation method and unit.

	Variable	Calculation Method	Unit
1	Definition of scoliosis—main curve	Curve with the highest value in degrees on preoperative radiography without traction	Curve 1; Curve 2; Curve 3
2	* Degree of main curve flexibility	Difference in degrees of preoperative curves with and without traction or lateral tilting	Degrees
3	* Degree of secondary curve flexibility	Difference in degrees of preoperative curves with and without traction or lateral tilting	Degrees
4	* Main curve flexibility percentage	Difference in degrees of the curve without traction and with traction or lateral tilting, divided by the value of the curve without traction	%
5	* Secondary curve flexibility percentage	Difference in degrees of the sum of the curves without traction and with traction or lateral tilting, divided by the value of the sum of the curves without traction	%
6	Main curve flexibility	Flexibility percentage equal to or greater than 40%, flexible; flexibility percentage less than 40%, nonflexible	Flexible; Nonflexible
7	Secondary curve flexibility	Flexibility percentage equal to or greater than 40%, flexible; flexibility percentage less than 40%, nonflexible	Flexible; Nonflexible
8	* Degree of main curve correction	Difference in degrees of the curve without traction between pre- and postoperatively	Degrees
9	* Percentage of main curve correction	Percentage of correction achieved through dividing the difference between the pre- and postoperative curves (degrees) by the preoperative value (degrees)	%
10	* Degree of secondary curve correction	Difference in degrees of the curve without traction between pre- and postoperatively	Degrees
11	* Percentage of secondary curve correction	Percentage of correction achieved through dividing the difference between the pre- and postoperative curves (degrees) by the preoperative value (degrees)	%
12	Normal-range preoperative pelvic obliquity	Preoperative pelvic obliquity equal to zero	Yes; No
13	Normal-range postoperative pelvic obliquity	Postoperative pelvic obliquity equal to zero	Yes; No
14	Comparison of pre- and postoperative normal-range pelvic obliquity	Comparison between qualitative variables 12 and 13	
15	* Difference between pre- and postoperative pelvic obliquity	Difference in degree of pelvic obliquity between pre- and postoperative values	Degrees
16	* Percentage of pelvic obliquity correction	Percentage of correction achieved through dividing the difference between pre- and postoperative pelvic obliquity by the preoperative value	%
17	* Difference between pre- and postoperative kyphosis	Difference in degrees of postoperative and preoperative kyphosis	Degrees
18	*Percent correction of kyphosis	Percentage of correction achieved through dividing the difference between pre- and postoperative kyphosis by the preoperative value	%
19	* Difference between pre- and postoperative lumbar lordosis	Difference in degrees of postoperative and preoperative lumbar lordosis	Degrees
20	* Percent correction of lumbar lordosis	Percentage of correction achieved through dividing the difference between pre- and postoperative lumbar lordosis by the preoperative value	%

* Quantitative variables.

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