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RESEARCH ARTICLE

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Range of international surgical strategies for adolescent idiopathic scoliosis: Evaluation of a multi-center survey

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Abstract

Background: Surgical treatment of adolescent idiopathic scoliosis (AIS) is very complex and modern instrumentation techniques offer multiple possibilities. Despite numerous publications, there is no clear consensus on the optimal strategy for the correction of scoliotic deformities. The goal of this study was to summarize the current surgical strategies for specific AIS cases within various countries.

Method: Thirty-two experienced scoliosis surgeons from 15 countries were asked to plan surgeries on 12 representative AIS cases. All AIS cases had an indication for surgery. A questionnaire was provided to document surgical planning. The surgeons were provided with the patients' age and sex, together with radiographs in the lateral and sagittal planes during upright standing and in lateral bending to the left and right, as well as with clinical images. The angles of the main spinal curvatures were specified in the questionnaire. The surgeons were asked to specify their preferred classification system, their surgical approach, the planned fusion length, the type of implants, the rod type, and the resection steps. The data were analyzed with respect to the inter-rater variability, which was quantified using the Fleiss-Kappa Method.

Results: There was a good agreement ($k = 0.61$) between the surgeons in choosing the Lenke curve type, and a moderate agreement for the lumbar (0.41) and sagittal (0.56) modifiers. The most frequently planned resection procedure was complete facetectomy (67%). The posterior approach was the most commonly (91%) selected strategy to treat AIS. Anterior approaches were chosen most for Lenke 5 type with a rate of 20%. The upper instrumented vertebra (UIV) varied most for Lenke 1, 5, and 6 cases, with a vertebral level discrepancy of up to 10 levels at Lenke 6. The lowest instrumented vertebra varied most for Lenke 1 and 4 by up to five levels. Polyaxial screws were chosen most (56%), followed by monoaxial (20%) and uniplanar (19%) screws and hooks (5%).

Conclusions: The results highlight the commonalities and discrepancy in the surgical treatment of AIS in between surgeons. The selected LIV and UIV can vary depending

on the curve type and surgeon. Hook constructs appear to be generally replaced by transpedicular screws. The survey indicates open questions in the AIS treatment and in the understanding of scoliosis biomechanics.

KEYWORDS
adolescent idiopathic scoliosis, biomechanics, deformity, orthopedics

1 | INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformity of the spine with an incidence of approximately 0.5%–5.2% amongst children and adolescents.[1] While AIS is initially treated conservatively, surgical intervention is generally indicated for a progressive deformity above a 40° Cobb-angle [srs.org]. The main goal of surgical intervention is to prevent curve progression and correct the deformity.[2]

Surgical correction is generally performed by first mobilizing the spine by resecting soft tissue and joints, followed by curvature straightening and fusion of the treated spinal segments using instrumentation techniques. Surgical treatment of AIS involves many critical decisions and modern instrumentation techniques offer multiple possibilities, including, the direction of the approach (from anterior or posterior), performed resection steps to mobilize the spine, number of instrumented and fused spinal segments, and type of anchoring implants used.

Due to the variety of spinal deformities and the complex pathology, classification systems have been introduced, which serve as a guideline on how to treat a specific spinal curvature. King et al. grouped AIS into five deformity types according to the location of the main curvatures.[3] Lenke et al. further refined the classification by grouping AIS into six deformity types by considering the location of the main deformity and the amount and flexibility of the secondary curvatures, as well as three types of lumbar modifiers and three types of sagittal profiles.[4]

A survey with 32 North-American surgeons published in 2007 revealed very good inter- and intra-rater variability amongst surgeons regarding AIS classification.[5,6] Within this study, the surgeons were asked to plan surgical correction on five representative AIS cases, which were all instrumented with a posterior fixation. The authors identified three groups of surgeons: one which used pedicle screws only, one with hooks only, and a third group which used hooks and screws.

Majdouline et al. further identified a high variability in the correction objectives among surgeons.[7] They concluded that this variability was both surgeon and curve-type dependent, and may be a cause for the variation in the instrumentation.

In a survey published in 2013, 48 surgeons were asked to specify which aspects should be included in an optimal AIS-surgical treatment.[2] The authors obtained an average census among 70% of all surgeons. Consensuses were documented particularly within the required preoperative images and instrumentation selection, as well as the mobilization using Ponte osteotomies in high-grade deformities.

While the studies discussed above already provide a comprehensive view of the techniques preferred by surgeons for AIS correction, none of these studies were conducted in the last decade, during which the surgical strategies and instrumentation techniques have evolved. This includes significant research to improve surgical outcome and quality of life of the patients.

We, therefore, believe that conducting an up-to-date survey would be valuable at this stage. Such a survey was already performed within Germany,[8] yet, the surgical strategies may deviate in-between countries.

The goal of this study was to document and analyze the current international variability within surgical strategies for AIS. This data would help to provide an overview of the surgical strategies, and could further be used as a reference for biomechanical studies to investigate the influence of the different surgical strategies.

2 | METHOD

Surgical strategies to treat specific AIS curves were documented. To be able to compare surgical strategies in between surgeons, all surgeons ideally would need to diagnose and treat the same patient. Because this is not possible, 12 representative AIS cases were retrospectively collected and presented to experienced AIS surgeons (Table 1). The surgeons were asked to document their surgical strategy using a questionnaire. Because the surgical strategy might vary in between countries, surgeons from different countries were included in the survey.

2.1 | The questionnaire

The questionnaire was designed to include the main biomechanical aspects of the surgical treatment. In addition, the questionnaire needed to be simple to use, self-explaining, and to be completed rapidly to minimize the time-load of the participating surgeons.

The questionnaire was implemented in a PDF forms (Adobe Acrobat Pro, Adobe Inc.), which could be filled out on all prevalent computer systems, could be readily distributed digitally, and could potentially also be filled out in print. The content of the questionnaire and its usability were verified together with two surgeons who tested the questionnaire.

Initially, the surgeons were asked to specify the country in which they were currently working, their age, how long they have operated

TABLE 1 Specifications of the patient cases included in the survey: age in years, and Cobb-angles of the main curvatures.

#	Age	Proximal thoracic	Main thoracic	Thoracolumbar/lumbar
1	16	37° (T2–T5)	**56°** (T5–L1)	28° (L1–L4)
lb left		*33°*	*56°*	*8°*
lb right		*36°*	*33°*	*27°*
2	14	11° (T2–T5)	49° (T5–T11)	**77°** (T11–L4)
lb left		*12°*	*55°*	*42°*
lb right		*23°*	*36°*	*65°*
3	20	29° (T2–T5)	42° (T5–T10)	**58°** (T10–L3)
lb left			*49°*	*25°*
lb right			*39°*	*60°*
4	14	25° (C7–T3)	**49°** (T3–T11)	41° (T11–L3)
lb left		*5°*	***53°***	*18°*
lb right		*20°*	***23°***	*40°*
5	14	31° (T1– T7)	**56°** (T7–L2)	11° (L2–L4)
lb left		*10°*	*63°*	*8°*
lb right		*33°*	*17°*	*17°*
6	15	27° (C7–T4)	73° (T4–T10)	**87°** (T10–L3)
lb left		*13°*	*73°*	*53°*
lb right		*41°*	*62°*	*69°*
7	15	16° (C7–T5)	**84°** (T5–T12)	53° (T12–L3)
lb left		*1°*	*74°*	*15°*
lb right		*25°*	*61°*	*53°*
8	16	3° (C7–T3)	20° (T3–T9)	**51°** (T9–L2)
lb left		*2°*	*33°*	*22°*
lb right		*3°*	*11°*	*50°*
9	17	53° (C7–T5)	**99°** (T5–T12)	64° (T12–L4)
lb left		*31°*	*101°*	*39°*
lb right		*61°*	*77°*	*65°*
10	12	43° (T1–T6)	**79°** (T6–T12)	53° (T12–L5)
lb left		*45°*	*64°*	*21°*
lb right		*53°*	*36°*	*45°*
11	15	44° (T1–T6)	**85°** (T6–T11)	64° (T11–L4)
lb left		*40°*	*80°*	*33°*
lb right		*43°*	*63°*	*65°*
12	17		29° (T2–T9)	**56°** (T9–L2)
lb left			*8°*	*58°*
lb right			*30°*	*27°*

Note: The Cobb angles in lateral bending (lb) to the left and right are indicated in italic. The bold numbers indicate the highest Cobb-angle.

AIS patients (in years), how many patients they operated annually, and the school/teacher where they learned to operate scoliosis.

The questionnaire included three pages for each AIS patient case (Figure 1). Within the first page, four radiographic images of the patient were presented, including the Cobb angles of the spinal curvatures in each plane. The radiographic images included the sagittal and coronal planes during upright standing, as well as in lateral bending to the left and right sides in the supine position. The radiographic images were acquired retrospectively. Therefore, no radiographic images were taken explicitly for this study. In this part, the surgeons were asked to classify the scoliosis according to the Lenke classification system and select the direction of the surgical approach (anterior/posterior). Additionally, an empty field was available to add comments regarding the AIS case.

On the second page, the surgeons were asked to specify the planned resection steps, used implants for each vertebral segment on the left and right sides, and potential intervertebral disc substitute. Resection steps included of anterior and posterior ligaments,

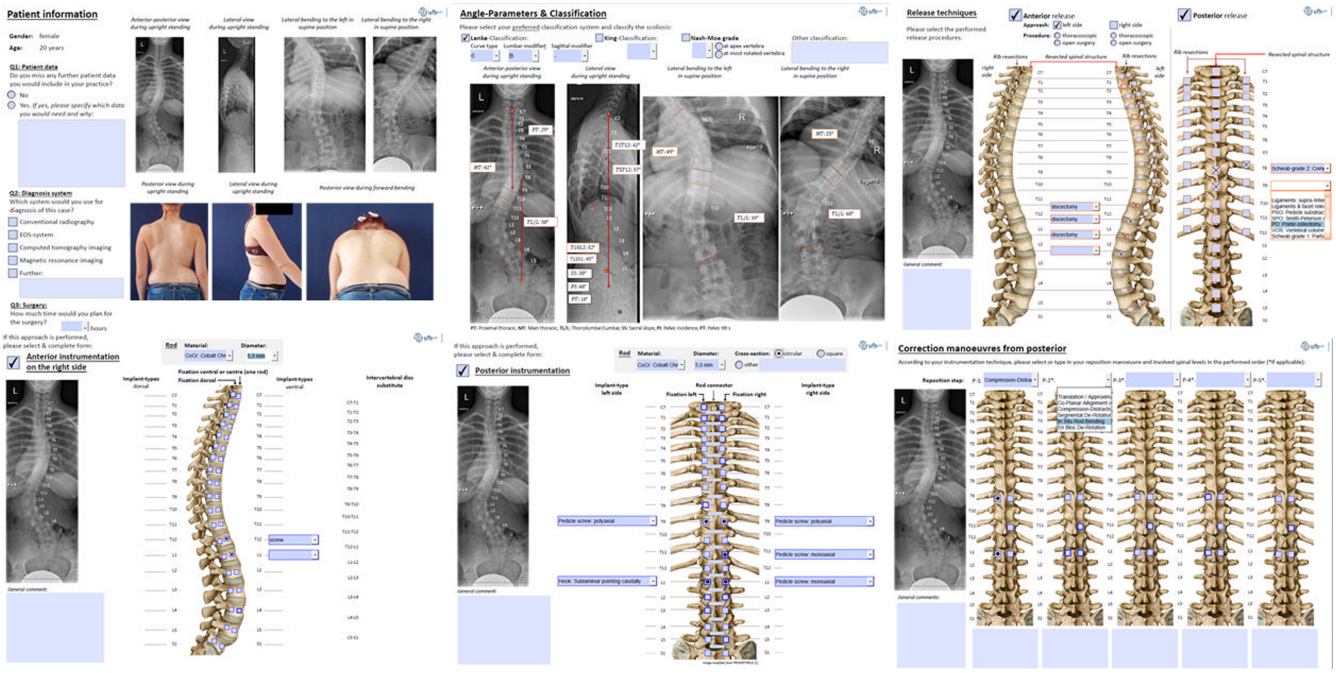

FIGURE 1 The questionnaire sheet to document the surgical planning for an anterior and/or posterior approach. The surgical planning includes the selection of the AIS classification, the resected structures, the used implants on each side of a spinal level, and the intervertebral substitute.

nucleotomy, discectomy, flavectomy, and of interspinous ligaments, as well as the resections according to Schwab-grades 1–6: partial facetectomy (G1), complete facetectomy (G2), pedicle/partial vertebral body (G3), pedicle/partial vertebral body and disc (G4), total vertebra (G5), and entire segment (G6) resections. An additional option was the selection of level-specific rib-head resection on the left and right sides. The implant options on each vertebral level and side included anterior plate, mono-/poly-axial screws, hooks, and cerclage wire.

2.2 | Ethical concerns

In consultation with the Ethical Committee, no ethical permission was required for the survey. Each patient case was anonymized and the survey had no effect on the treatment of the patients.

2.3 | Evaluation

Fields that were not selected were considered to be "not relevant" and excluded in the evaluation. The data were mainly evaluated in a descriptive manner.

The inter-rater reliability was quantified using the Fleiss' Kappa-Statistic. We had to calculate the kappa-value manually using Excel, since the number of surgeons, who classified each case, was not consistent throughout the 12 cases. The Kappa value was interpreted according to Landis and Koch.[9]

To determine whether a surgeon addressed a scoliotic curvature, the position of the upper and lower instrumented levels were evaluated. A curve was considered to be "surgically addressed" when the instrumentation did not extend more than on level above or below the inflection vertebra of a curvature (Figure 2). In addition, the anatomical spinal regions (proximal thoracic, main thoracic, and lumbar region) that were covered by the instrumentation were evaluated. These anatomical regions could be of interest for the biomechanical condition post-operatively.

3 | RESULTS

3.1 | Study population

Thirty-two surgeons conducted and documented their surgical planning on the AIS cases using the questionnaire. The surgeons originated from 15 different countries: Australia (1 surgeon), Austria (1), Belgium (1), Brazil (1), China (1), Finland (1), France (2), Germany (1), Great Britain (1), Hong Kong (1), India (5), Italy (1), Japan (6), Netherlands (3), North America (2), Switzerland (1) and Turkey (3). The age range of the surgeons was 40–50 years, with an experience of 10–20 years. Most of the surgeons (34.8%) operated 50–100 AIS cases annually.

3.2 | Classification

The surgeons applied the Lenke classification system to classify the scoliosis type. The inter-rater variability of the Lenke classification resulted in a Fleiss-Kappa value of 0.61 for the curve type, 0.41 of the

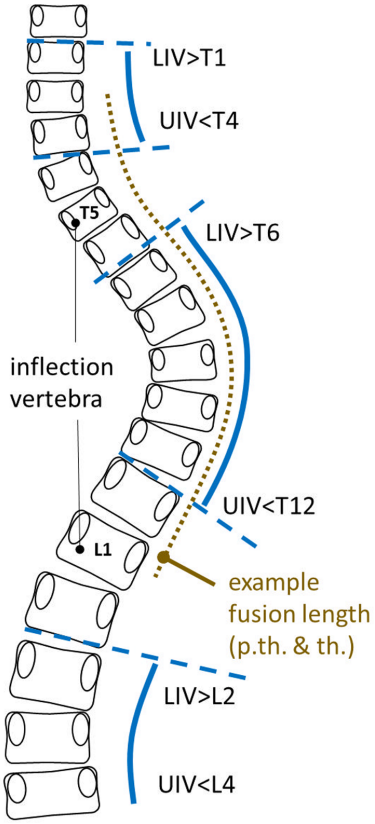

FIGURE 2 Sketch on how to determine whether a scoliotic curvature was addressed by the surgeon, with a tolerance of one level above/below the inflection vertebra. Here, an example of case #1 with a proximal thoracic Cobb-angle of 37°, thoracic Cobb-angle of 56°, and lumbar Cobb-angle of 28°. The inflection vertebrae are T5 and L1. When the upper instrumented vertebra (UIV) was above T12, the thoracic curve was addressed, and above T4, the proximal thoracic curve was addressed. Whenever the lowest instrumented vertebra (LIV) ended below L2, the lumbar curve was addressed, and below T6, the thoracic curve was addressed. The dotted brown line indicates an exemplary fusion length, in which the proximal thoracic and thoracic scoliotic curve was surgically addressed. (p.th., proximal thoracic; th., thoracic.)

lumbar modifiers, and 0.56 for the thoracic sagittal modifier. One surgeon indicated not using the classification system, because it would not be of any help.

3.3 | Addressed curvature

The major scoliotic curvatures were almost always instrumented by the surgeons (Table 2). Strong variation in the instrumentation of the secondary curvature was documented for Lenke 1 cases, with a range of 13%–83% for the lumbar region and 0%–69% in the proximal thoracic region. The surgeons deviated also by addressing the thoracic curve for Lenke-5 (27%–38%) and Lenke-6 curves (68%–97%).

The instrumentation always extended from the lumbar area into the thoracic area (T4–T11), but never into the proximal thoracic area (T1–T3) in Lenke-5 curve-types.

3.4 | Direction of approach

For Lenke 1 curves, 93% of the surgeons planned a posterior approach, 6% an anterior approach, and 1% a hybrid approach (Figure 3). All surgeons planned a posterior instrumentation for Lenke curve types 2 and 4. For Lenke-4 curves, 22% of the surgeons planned an additional anterior approach to mobilize the spine, while all of them instrumented from the posterior. The highest portion of anterior instrumentations were planned for Lenke 5 curve types, with 20% of the surgeons. Hybrid instrumentations were extremely rare for Lenke-1, 2, and 6 cases.

3.5 | Resections

The prevalent resection steps included discectomies, resections of the interspinous ligaments, and partial (Schwab G1) and complete (Schwab G2) facectomies. Most posterior resections were indicated at the Lenke 4 curve, as by 93% of all the surgeons. Of them, 87% planned complete facetectomies (Schwab grade 2) at on average 60% (20%–100%) of the addressed spinal levels (Figure 3). All surgeons who planned anterior resections for Lenke 4 (22% of surgeons), specified discectomies in 32% (20%–47%) of the instrumented levels.

It should be noted that some surgeons performed resections on the anterior and posterior spinal columns. Particularly at Lenke 4, all anterior mobilizations were planned in combination with a posterior instrumentation.

3.6 | Fusion levels

The length of the instrumented levels varied for each Lenke curve type depending on the selection of the upper instrumented vertebra (UIV) and lowest instrumented vertebra (LIV), as well as the direction of the approach (Figure 4).

Strongest deviations were reported in the selection of the UIV for Lenke-6, with an average weighted offset of 1.7 vertebral levels relative to the most selected level. The absolute difference between the most selected cranial and caudal vertebrae was nine levels, ranging from three levels above and six levels below the most selected vertebra (case #3). Lenke 2 and 4 indicated the smallest deviation in the UIV, with a maximum offset of up to four spinal levels. Strongest deviations in the LIV were obtained in Lenke 1, with up to five spinal levels. The selected fusion length was generally shorter when choosing anterior instrumentations.

Detailed variations, also separated into anterior and posterior approaches, can be obtained from the results of the individual AIS cases within the appendix of the manuscript (Figure appendix A1–A5).

3.7 | Implants

Of the overall specified implants, polyaxial pedicle screws were selected most frequently with 56%, followed by monoaxial (20%) and uniplanar (19%) screws (Figure 5). Hooks were only used in an isolated number of

TABLE 2 Percentage of surgeons who addressed a specific coronal curvature and anatomical region of the spine.

		Scoliotic specific curve region			Anatomical region			
Lenke	Case #	prox. th.	thoracic	th.lumbal/lumbal	prox. th. C7-T3	thoracic T4-T11	th.lumbal T12-L1	lumbal L2-S1
1	4	0%	100%	25%	47%	100%	50%	22%
	5	69%	100%	13%	22%	100%	100%	97%
	7	43%	100%	83%	43%	100%	97%	83%
2	1	66%	100%	6%	66%	100%	97%	44%
	10	90%	100%	33%	90%	100%	100%	33%
4	9	90%	100%	97%	90%	100%	100%	97%
	11	100%	100%	94%	90%	100%	97%	90%
5	8	0%	38%	100%	0%	100%	100%	83%
	12	0%	27%	100%	0%	100%	100%	93%
6	2	13%	78%	100%	13%	100%	100%	100%
	3	16%	68%	100%	16%	100%	100%	100%
	6	10%	97%	97%	52%	100%	97%	97%

Note: The patient case-specific scoliotic curvature levels are listed in Table 1. The inclusion criteria of surgically addressing a curvature are defined in Figure 2. Abbreviations: prox. th., proximal thoracic; th. lumbal, thoracolumbal.

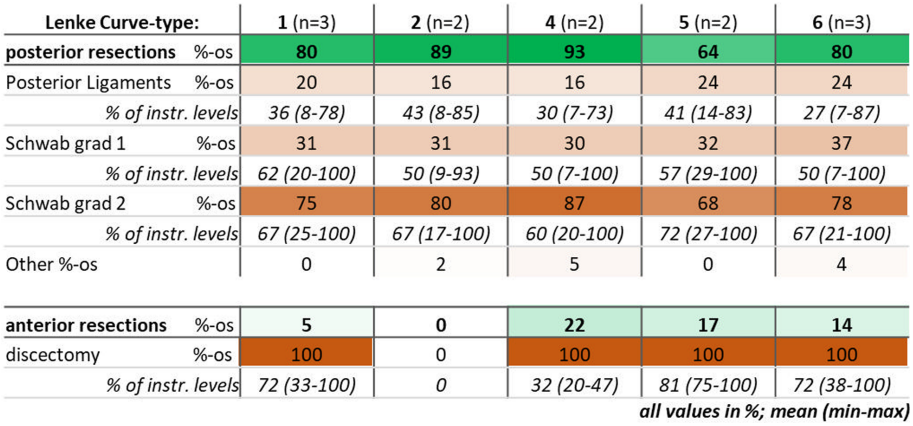

FIGURE 3 Percentage of surgeons (%-os) who planned posterior (colored green) and anterior resections (colored red) depending on the Lenke curve type. Below each resection type is given the number of levels on which the resection was actually performed in % of the planned instrumentation (instr.) length. (n = the number of AIS cases.).

cases (5%). A posterior rod was chosen most frequently with a diameter of 5.5 mm (56%) and of a cobalt-chrome material (53%).

3.8 | Comments of the surgeons

Four surgeons requested radiographs during passive bending and/or traction in the standing position. Five surgeons would have preferred to evaluate major curve flexibility with fulcrum bending film. One surgeon would evaluate the flexibility in the thoracolumbar kyphosis using fulcrum backward bending film. Further surgeons requested the menarchal status and the patient history, for example, what was previously done and whether there were any complaints or neurological deficits.

3.9 | Country dependencies

The healthcare system within a country and associated financial reasons are extrinsic factors, which may have influence on the surgical strategies. Yet, country dependencies of the surgical strategy could not be identified. Particularly, because the number of surgeons who participated in the survey from for each country was not statistically relevant.

4 | DISCUSSION

The proposed surgical strategies of 32 experienced scoliosis surgeons from 15 different countries for 12 representative AIS cases were documented using a developed questionnaire. The results indicated that commonalities and discrepancies between surgeons vary depending on the Lenke curve type and the surgeon. The main discrepancies within the resections steps and fusion length were found for Lenke curve-types 1, 5, and 6.

4.1 | Curve classification

The quantified Fleiss' Kappa values indicated a good agreement of the grouping of the AIS cases according to the Lenke-Classification

Lenke-curve:	1						2				4				5				6					
case	*#4*		*#5*		*#7*		*#1*		*#10*		*#9*		*#11*		*#8*		*#12*		*#2*		*#3*		*#6*	
	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV	UIV	LIV
T1									7%		7%													
T2	13%		6%		17%		**53%**		**70%**		**69%**		**68%**								3%		10%	
T3	**34%**		16%		27%		13%		13%		14%		23%						13%		13%		**42%**	
T4	34%		22%		**40%**		25%		10%		10%		10%		14%				22%		19%		39%	
T5	19%		**25%**		17%		6%								10%		13%		**31%**		**29%**		6%	
T6			19%				3%								7%		10%		9%		3%			
T7			9%												7%		3%							
T8															17%		7%		3%					
T9			3%												**45%**		**40%**				10%			
T10		3%															20%		9%		10%			
T11		**47%**											3%				7%		13%		13%		3%	
T12		25%				3%		9%		7%			3%			3%								
L1				3%		7%		**47%**		**60%**		3%	3%			14%		7%						
L2		3%		16%		**40%**		38%		10%						**45%**		23%						
L3		22%		**69%**		33%		6%		13%		10%		32%		34%		**40%**		22%		**52%**		26%
L4				13%		17%				10%		**86%**		**55%**		3%		30%		**53%**		45%		**68%**
L5														3%						25%		3%		6%
S1																								
ΔL wAvg	0.8	1.3	1.2	0.3	0.8	0.8	0.9	0.6	0.4	0.7	0.4	0.2	0.4	0.7	1.6	0.6	1.3	0.7	1.9	0.5	2.2	0.5	0.9	0.3
ΔL cranial	-1	-1	-3	-2	-2	-2	0	-1	-1	-1	-1	-3	0	-5	-5	-2	-4	-2	-2	-1	-3	0	-1	-1
ΔL caudal	2	4	4	1	1	2	4	2	2	3	2	0	2	1	0	2	2	1	6	1	6	2	8	1
ΔL UIV	0.9 (-3 to +4 levels)						0.7 (-1 to +4 levels)				0.4 (-1 to +2 levels)				1.5 (-5 to +2 levels)				1.7 (-3 to +8 levels)					
ΔL LIV	0.8 (-2 to +4 levels)						0.7 (-1 to +3 levels)				0.5 (-5 to +1 levels)				0.6 (-2 to +2 levels)				0.4 (-1 to +2 levels)					

FIGURE 4 Upper colored table indicates the percentage of surgeons who selected a specific upper (UIV) and lower instrumented (LIV) vertebra for all individual patient cases. ΔL: indicates the offset number of levels relative to the most selected vertebral level. wAvg: is the average number of levels weighted with the percentage of surgeons; cranial: the number of levels cranial to the most selected vertebra; caudal: the number of levels caudal to the most selected vertebra. ΔL UIV/LIV: indicates the average for each Lenke-curve type, while the brakes indicate the greatest cranial and caudal level offset.

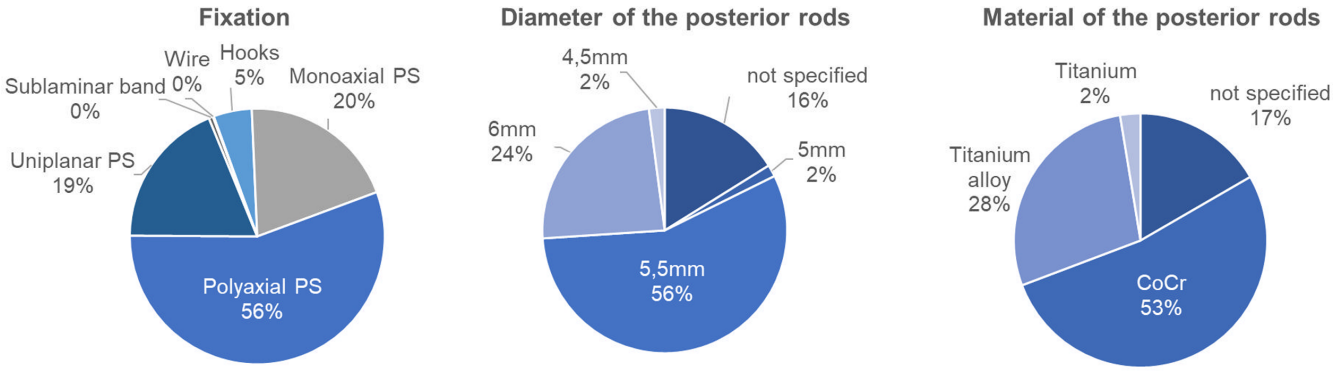

FIGURE 5 Percentage of the used implants, rod diameter, and rod material. CoCr, cobalt-chrome; PS, pedicle screw.

system.[9] However, the presented Fleiss-Kappa values were below previously published values,[10] indicating a slightly less reliability of the Lenke system.

Further uncertainty was involved in the selection of the end, neutral, and stable vertebrae because it has been demonstrated that their radiographic determination involves only poor interobserver reliability.[11] This may have an effect on the predefined curvature region and angles within the questionnaire. These boundaries indicated that the selection of the UIV and LIV may vary in between one or two vertebrae.

4.2 | Surgical approach

The posterior approach was overall the most commonly selected strategy to treat AIS. The most anterior approaches were selected for the Lenke 5 type with a rate of 20%. De Kleuver et al. (2014) obtained similar results, where 96% of the surgeons indicated the posterior approach as optimal.[2] In the same study, more than 50% of the surgeons indicated the anterior approach as optimal in the case of Lenke 5 curve types.

4.3 | Resection steps/osteotomies

The documented resection steps revealed that osteotomies of Schwab-grade 2 are the most commonly used. Kleuver et al.[2] also reported that (ponte) osteotomies are considered to be optimal in some cases, particularly at large structural curvatures. Facetectomies in combination with flavectomies were considered to be optimal at long rigid curves by 73% of the surgeons, which corresponds to the findings within the present study. Discectomies were planned most frequently at Lenke type 4, which reflects the current literature.[12]

4.4 | Fusion length

Deviations within the UIV and LIV in between surgeons can be referred to the consideration whether to instrument additionally the secondary curvature. This was particularly observed for Lenke 1, 5, and 6. Aubin et al.[6] earlier obtained a high variability in the fusion length within a small group of surgeons. Robitaille et al.[5] observed the lowest consensus in between surgeons in the fusion length at Lenke 5 types. These authors further documented an average fusion length of 10.6 ± 1.4 levels for Lenke 1 cases, which agrees with the fusion length observed in the present study of 10.8 ± 1.9 levels. For Lenke 5 cases, our study documented a lower fusion length (8.2 ± 2.2 levels) compared to the study of Robitaille et al. with 10.8 ± 1.7 levels. This discrepancy between the studies can be explained by the anterior approaches, which generally lead to a lower fusion length, and where not considered within the study of Robitaille et al.

In a single-center study, Erken et al.[13] documented a variability of 31% amongst four surgeons, who each evaluated 100 AIS cases. Most variability was observed for the selection of the UIV.

4.5 | Implants

Pedicle screws accounted for 90% of all used implants, and hooks only 5%. Aubin et al. and Robitaille et al. reported in 2007 that hooks accounted for 9%–24% of all implants. Robitaille et al. reported all-hook constructs in 3% of the reported surgical strategies, while in the present study, hooks were only used sporadically, with no all-hook constructs. The present study agrees with the findings of the AO survey, which reported pedicle screw constructs as the optimal treatment option.[2]

The surgeons further considered rod diameters of 5.5 or 6 mm as optimal, which agrees with the present study.[2] The selected rod material was mainly cobalt-chrome (53%) and titan alloy (28%), whereas in the AO survey, 54% of the surgeons considered titan as optimal.[2]

4.6 | Limitations of the study

Although the reported instrumentation strategies were planned by surgeons in a controlled environment, the surgeons did not have access to the patient in person and thus could not perform additional diagnosis procedures. Indeed, some surgeons requested further information of the patients. The results, therefore, only reflect the surgical opinion based on the presented radiographic and clinical images. This limitation was, however, necessary to standardize and be able to compare the surgical strategies. Additional factors which may have an effect on the surgical planning include the patient's history and activity.

4.7 | General remark

In general, the surgical treatment of AIS patients is considered to be reliable with low revision rates. Because the surgical treatment is irreversible, it is important to understand the influence and effect of the surgery.

Open questions that remain: How many resections need to be performed to mobilize the spine? What is the biomechanical benefit of retaining soft tissue on treated spinal segments? What are the best UIV and LIV to stabilize and correct the spinal deformity, particularly for the Lenke 1, 5, and 6 curve types?

5 | CONCLUSION

The results highlighted the commonalities and discrepancies in the surgical treatment of AIS in between surgeons. The selected LIV and UIV can vary dependent on the curve type and surgeon. Hook constructs appear to have been generally replaced by transpedicular screws. The survey indicated open questions in AIS treatment and the understanding of scoliosis biomechanics.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation and data collection and analysis were performed by Maresa Großkinsky and Benedikt Schlager. The first draft of the manuscript was written by Benedikt Schlager and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

All authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

1. Konieczny MR, Senyurt H, Krauspe R. Epidemiology of adolescent idiopathic scoliosis. *J Child Orthop*. 2013;7:3-9.
2. de Kleuver M, Lewis SJ, Germscheid NM, et al. Optimal surgical care for adolescent idiopathic scoliosis: an international consensus. *Eur Spine J*. 2014;23:2603-2618.
3. King HA. The selection of fusion levels in thoracic id-Iopathic scoliosis. *J Pediatr Orthop*. 1984;4:391.
4. Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am*. 2001;83:1169-1181.
5. Robitaille M, Aubin CE, Labelle H. Intra and interobserver variability of preoperative planning for surgical instrumentation in adolescent idiopathic scoliosis. *Eur Spine J*. 2007;16:1604-1614.
6. Aubin C-EE, Labelle H, Ciolofan OC. Variability of spinal instrumentation configurations in adolescent idiopathic scoliosis. *Eur Spine J*. 2007;16:57-64.
7. Majdouline Y, Aubin CE, Robitaille M, et al. Scoliosis correction objectives in adolescent idiopathic scoliosis. *J Pediatr Orthop*. 2007;27:775-781.
8. Schlager B, Großkinsky M, Ruf M, Wiedenhöfer B, Akbar M, Wilke HJ. Range of surgical strategies for individual adolescent idiopathic scoliosis cases: evaluation of a multi-centre survey. *Spine Deform* [Internet]. 2024;12:35-46.
9. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33:159.
10. Lenke LG. The Lenke classification system of operative adolescent idiopathic scoliosis. *Neurosurg Clin N Am*. 2007;18:199-206.
11. Potter BK, Rosner MK, Lehman RAJ, Polly DWJ, Schroeder TM, Kuklo TR. Reliability of end, neutral, and stable vertebrae identification in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2005;30(14):1658-1663.
12. Lonner BS, Haber L, Toombs C, et al. Is anterior release obsolete or does it play a role in contemporary adolescent idiopathic scoliosis surgery? A matched pair analysis. *J Pediatr Orthop*. 2020;40:E161-E165.
13. Erken HY, Burc H, Saka G, Aydogan M. Disagreements in surgical planning still exist between spinal surgeons in adolescent idiopathic scoliosis: a multisurgeon assessment. *Eur Spine J*. 2014;23:1258-1262.

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APPENDIX: General caption for all figures

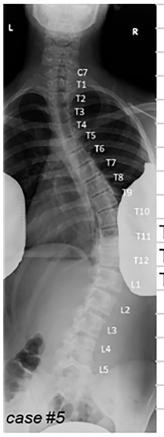
Frontal radiograph and surgical strategies for the Lenke 1, 2, 4, 5, and 6 cases. The upper left table indicates the percentage of surgeons (%os) who chose posterior (post.), anterior (ant.), or posterior and anterior (p. &a.) resections (res.) and instrumentation (inst.). Further parameters include the upper (UIV) and lower (LIV) instrumented vertebra, as well as the percentage of instrumented levels (IL) on the left (IL-l) and right (IL-r) side, the used connector (Conn.), resected ligaments (Ligg.), Schwab grad 1 & 2 (SG 1/2), resected rib head on the left (ribh-L) and right (ribh-R) side, and discectomy (disc.).

Lenke-1 cases

#4	post.	ant.	p&a
res.	92%	8%	0%
inst.	91%	9%	0%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	14%	-	14%	14%	-	-	-	4%	-	-	-	-	-	-
T3	38%	-	52%	52%	-	8%	8%	21%	-	-	-	-	-	-
T4	38%	-	72%	86%	24%	8%	17%	29%	-	-	-	-	-	-
T5	10%	-	83%	72%	14%	8%	25%	50%	-	-	100%	-	100%	50%
T6	-	-	62%	66%	-	13%	21%	58%	-	-	-	-	100%	50%
T7	-	-	93%	69%	-	8%	25%	67%	-	-	-	-	100%	50%
T8	-	-	72%	83%	-	13%	25%	63%	4%	4%	-	-	100%	50%
T9	-	-	72%	66%	10%	17%	25%	54%	4%	4%	-	-	100%	50%
T10	-	-	79%	66%	14%	13%	29%	46%	-	-	-	33%	100%	50%
T11	-	45%	93%	97%	3%	13%	17%	38%	-	-	-	67%	67%	50%
T12	-	28%	52%	52%	-	8%	8%	21%	-	-	-	-	-	-
L1	-	-	24%	21%	10%	4%	8%	13%	-	-	-	-	-	-
L2	-	3%	24%	24%	-	-	8%	13%	-	-	-	-	-	-
L3	-	24%	24%	24%	-	-	-	8%	-	-	-	-	-	-
L4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

#5	post.	ant.	p&a
res.	92%	8%	0%
inst.	91%	9%	0%



	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	7%	-	7%	7%	-	-	-	-	-	-	-	-	-	-
T3	17%	-	24%	24%	-	-	-	17%	-	-	-	-	-	-
T4	24%	-	41%	48%	7%	4%	-	17%	-	-	-	-	-	-
T5	24%	-	59%	59%	3%	9%	9%	35%	-	-	33%	-	33%	-
T6	21%	-	66%	62%	7%	4%	22%	39%	-	4%	-	-	33%	-
T7	7%	-	76%	72%	17%	4%	22%	57%	-	4%	33%	-	67%	50%
T8	-	-	72%	48%	-	9%	22%	57%	-	4%	-	-	67%	50%
T9	-	-	76%	76%	-	9%	22%	65%	4%	9%	33%	-	100%	50%
T10	-	-	83%	66%	-	4%	22%	74%	4%	9%	-	-	100%	100%
T11	-	-	72%	76%	-	4%	22%	70%	4%	9%	-	-	100%	100%
T12	-	-	86%	66%	3%	4%	26%	65%	-	4%	-	-	100%	100%
L1	-	-	76%	69%	17%	9%	22%	52%	-	-	-	33%	100%	50%
L2	-	14%	86%	86%	14%	4%	17%	43%	-	-	-	33%	67%	-
L3	-	72%	86%	90%	-	-	4%	22%	-	-	-	33%	33%	-
L4	-	14%	14%	14%	-	-	-	9%	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

#7	post.	ant.	p&a
res.	93%	0%	7%
inst.	97%	0%	0%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	RK-L	RK-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	17%	-	17%	17%	3%	3%	-	-	-	-	-	-	-	-
T3	27%	-	40%	40%	-	7%	10%	10%	-	-	-	-	-	-
T4	40%	-	70%	77%	13%	3%	21%	21%	-	-	-	-	-	-
T5	17%	-	93%	77%	7%	3%	24%	34%	-	3%	-	-	-	-
T6	-	-	73%	77%	7%	3%	17%	55%	-	3%	-	-	-	50%
T7	-	-	90%	70%	-	10%	10%	69%	7%	10%	-	-	-	100%
T8	-	-	93%	80%	-	3%	10%	79%	10%	14%	-	-	-	100%
T9	-	-	90%	80%	-	3%	10%	83%	10%	14%	-	-	-	100%
T10	-	-	90%	77%	-	3%	14%	79%	7%	7%	-	-	-	50%
T11	-	-	80%	70%	7%	-	24%	59%	-	3%	-	-	-	50%
T12	-	3%	90%	83%	10%	3%	24%	48%	-	-	-	-	-	-
L1	-	7%	70%	87%	10%	7%	24%	34%	-	-	-	-	-	-
L2	-	40%	83%	87%	3%	10%	7%	28%	-	-	-	-	-	-
L3	-	33%	50%	50%	-	3%	3%	14%	-	-	-	-	-	-
L4	-	17%	17%	17%	-	-	-	7%	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FIGURE A1 Frontal radiograph and surgical strategies for the Lenke 1 cases. The upper left table indicates the percentage of surgeons (%os) who chose posterior (post.), anterior (ant.), or posterior and anterior (p.&a.) resections (res.) and instrumentation (inst.). Further parameters include the upper (UIV) and lower (LIV) instrumented vertebra, as well as the percentage of instrumented levels (IL) on the left (IL-l) and right (IL-r) side, the used connector (Conn.), resected ligaments (Ligg.), Schwab grad 1 & 2 (SG 1/2), resected rib head on the left (ribh-L) and right (ribh-R) side, and discectomy (disc.).

Lenke-2 cases

#1	post.	ant.	p&a
res.	100%	0%	0%
inst.	97%	0%	3%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	ligg.	SG-1	SG-2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	3%	-	-	-	-	-	-
T2	53%	-	53%	53%	3%	-	10%	10%	-	-	-	-	-	-
T3	13%	-	66%	63%	3%	7%	10%	23%	-	-	-	-	-	-
T4	25%	-	78%	66%	13%	3%	20%	30%	-	-	-	-	-	-
T5	6%	-	75%	72%	13%	3%	23%	40%	3%	-	100%	-	100%	-
T6	3%	-	81%	56%	-	3%	17%	57%	3%	-	-	-	100%	-
T7	-	-	81%	63%	-	3%	13%	70%	10%	7%	-	-	100%	-
T8	-	-	84%	75%	-	7%	13%	73%	17%	10%	-	-	100%	-
T9	-	-	81%	81%	-	7%	13%	73%	13%	10%	-	-	100%	-
T10	-	-	84%	72%	3%	7%	17%	70%	13%	10%	-	-	100%	-
T11	-	-	72%	59%	9%	3%	17%	50%	3%	3%	-	-	100%	-
T12	-	9%	91%	75%	16%	7%	13%	43%	-	-	-	100%	100%	-
L1	-	47%	78%	84%	3%	7%	-	30%	-	-	-	-	-	-
L2	-	38%	44%	44%	-	-	-	7%	-	-	-	-	-	-
L3	-	6%	6%	6%	-	-	-	3%	-	-	-	-	-	-
L4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

#10	post.	ant.	p&a
res.	100%	0%	0%
inst.	100%	0%	0%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	7%	-	7%	7%	-	-	-	-	-	-	-	-	-	-
T2	70%	-	77%	73%	3%	7%	11%	18%	-	-	-	-	-	-
T3	13%	-	83%	80%	13%	7%	18%	39%	-	-	-	-	-	-
T4	10%	-	73%	70%	10%	11%	21%	50%	-	-	-	-	-	-
T5	-	-	73%	73%	3%	14%	25%	50%	-	4%	-	-	-	-
T6	-	-	83%	80%	-	7%	21%	57%	7%	4%	-	-	-	-
T7	-	-	80%	47%	-	11%	18%	64%	7%	7%	-	-	-	-
T8	-	-	83%	73%	-	11%	21%	64%	11%	11%	-	-	-	-
T9	-	-	93%	73%	-	11%	21%	64%	11%	11%	-	-	-	-
T10	-	-	83%	67%	3%	11%	21%	61%	4%	11%	-	-	-	-
T11	-	-	67%	67%	17%	14%	21%	46%	4%	-	-	-	-	-
T12	-	7%	83%	90%	7%	7%	21%	43%	-	-	-	-	-	-
L1	-	60%	93%	87%	-	4%	4%	29%	-	-	-	-	-	-
L2	-	10%	27%	30%	-	-	4%	14%	-	-	-	-	-	-
L3	-	13%	23%	23%	-	-	4%	11%	-	-	-	-	-	-
L4	-	10%	10%	10%	-	-	-	4%	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FIGURE A2 Frontal radiograph and surgical strategies for the Lenke 2 cases. The upper left table indicates the percentage of surgeons (%os) who chose posterior (post.), anterior (ant.), or posterior and anterior (p.&a.) resections (res.) and instrumentation (inst.). Further parameters include the upper (UIV) and lower (LIV) instrumented vertebra, as well as the percentage of instrumented levels (IL) on the left (IL-l) and right (IL-r) side, the used connector (Conn.), resected ligaments (Ligg.), Schwab grad 1 & 2 (SG 1/2), resected rib head on the left (ribh-L) and right (ribh-R) side, and discectomy (disc.).

Lenke-4

#9	post.	ant.	p&a
res.	69%	7%	24%
inst.	100%	0%	0%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	rib-R	UIV	LIV	IL	disc.
T1	7%	-	7%	7%	-	-	4%	-	-	-	-	-	-	-
T2	69%	-	77%	77%	-	4%	15%	11%	-	-	-	-	-	-
T3	14%	-	80%	80%	10%	7%	19%	26%	-	-	-	-	-	-
T4	10%	-	83%	80%	10%	7%	26%	30%	-	-	-	-	-	-
T5	-	-	77%	60%	7%	7%	15%	52%	4%	4%	-	-	-	22%
T6	-	-	77%	70%	-	4%	15%	67%	11%	4%	-	-	-	67%
T7	-	-	87%	73%	-	-	11%	85%	30%	7%	-	-	-	89%
T8	-	-	90%	83%	-	-	7%	89%	33%	11%	-	-	-	89%
T9	-	-	90%	63%	-	4%	7%	85%	33%	11%	-	-	-	78%
T10	-	-	83%	77%	-	4%	15%	70%	22%	11%	-	-	-	67%
T11	-	-	83%	73%	-	7%	19%	52%	-	4%	-	-	-	11%
T12	-	-	80%	90%	-	7%	22%	48%	-	-	-	-	-	-
L1	-	3%	83%	67%	3%	7%	15%	52%	-	-	-	-	-	-
L2	-	-	83%	73%	13%	7%	22%	48%	-	-	-	-	-	-
L3	-	10%	87%	87%	3%	7%	22%	37%	-	-	-	-	-	-
L4	-	86%	87%	87%	-	4%	11%	15%	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

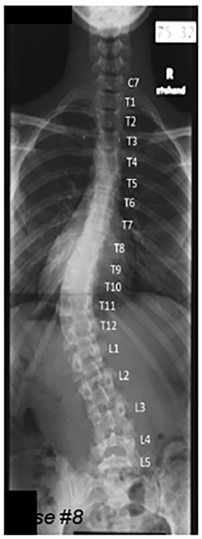
#11	post.	ant.	p&a
res.	81%	3%	16%
inst.	97%	0%	3%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	68%	-	68%	68%	3%	3%	10%	10%	-	-	-	-	-	17%
T3	23%	-	84%	81%	6%	7%	23%	17%	-	-	-	-	-	17%
T4	10%	-	81%	74%	13%	7%	27%	30%	-	3%	-	-	-	17%
T5	-	-	84%	58%	-	7%	23%	43%	7%	3%	-	-	-	33%
T6	-	-	77%	77%	-	7%	7%	73%	10%	3%	-	-	-	67%
T7	-	-	81%	74%	-	-	7%	87%	20%	7%	-	-	-	100%
T8	-	-	81%	74%	-	-	7%	87%	23%	10%	-	-	-	100%
T9	-	-	87%	74%	-	-	7%	87%	23%	10%	-	-	-	100%
T10	-	-	81%	74%	-	3%	13%	73%	10%	7%	-	-	-	50%
T11	-	3%	84%	74%	-	7%	20%	50%	3%	-	-	-	-	33%
T12	-	3%	81%	77%	-	10%	20%	43%	-	-	-	-	-	17%
L1	-	3%	74%	65%	10%	3%	17%	43%	-	-	-	-	-	17%
L2	-	-	74%	74%	10%	3%	13%	43%	-	-	-	-	-	17%
L3	-	32%	84%	81%	3%	3%	17%	30%	-	-	-	-	-	-
L4	-	55%	58%	58%	-	-	-	13%	-	-	-	-	-	-
L5	-	3%	3%	3%	-	-	-	3%	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FIGURE A3 Frontal radiograph and surgical strategies for the Lenke 4 cases. The upper left table indicates the percentage of surgeons (%os) who chose posterior (post.), anterior (ant.), or posterior and anterior (p.&a.) resections (res.) and instrumentation (inst.). Further parameters include the upper (UIV) and lower (LIV) instrumented vertebra, as well as the percentage of instrumented levels (IL) on the left (IL-l) and right (IL-r) side, the used connector (Conn.), resected ligaments (Ligg.), Schwab grad 1 & 2 (SG 1/2), resected rib head on the left (ribh-L) and right (ribh-R) side, and discectomy (disc.).

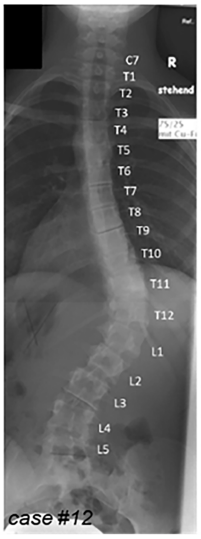
Lenke-5

#8	post.	ant.	p&a
res.	83%	17%	0%
inst.	83%	17%	0%



	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T4	17%	-	17%	17%	-	-	-	10%	-	-	-	-	-	-
T5	13%	-	29%	25%	-	5%	-	15%	-	-	-	-	-	-
T6	8%	-	21%	25%	-	5%	-	15%	-	-	-	-	-	-
T7	8%	-	21%	42%	4%	10%	-	30%	-	-	-	-	-	-
T8	17%	-	46%	42%	-	15%	10%	30%	-	-	20%	-	20%	-
T9	38%	-	88%	96%	21%	15%	20%	45%	-	-	80%	-	100%	100%
T10	-	-	83%	79%	-	10%	20%	60%	-	-	-	-	100%	100%
T11	-	-	71%	88%	-	15%	15%	65%	-	-	-	-	100%	100%
T12	-	-	83%	88%	8%	10%	15%	65%	-	-	-	20%	100%	75%
L1	-	4%	83%	92%	13%	5%	25%	55%	-	-	-	60%	80%	25%
L2	-	54%	92%	92%	4%	10%	5%	30%	-	-	-	-	20%	-
L3	-	38%	42%	42%	-	-	5%	10%	-	-	-	20%	20%	-
L4	-	4%	4%	4%	-	-	-	-	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

#12	post.	ant.	p&a
res.	77%	23%	0%
inst.	77%	23%	0%



	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	rib-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T4	-	-	-	-	-	-	-	5%	-	-	-	-	-	-
T5	17%	-	17%	17%	-	-	-	5%	-	-	-	-	-	-
T6	13%	-	29%	29%	4%	10%	5%	5%	-	-	-	-	-	-
T7	4%	-	17%	17%	-	5%	5%	15%	-	-	-	-	-	-
T8	9%	-	21%	29%	-	5%	10%	15%	-	-	-	-	-	-
T9	42%	-	71%	63%	22%	10%	20%	25%	-	-	29%	-	29%	33%
T10	17%	-	83%	79%	9%	5%	20%	55%	-	-	43%	-	57%	67%
T11	-	-	92%	96%	-	10%	15%	70%	-	-	29%	-	100%	100%
T12	-	-	96%	79%	-	10%	20%	65%	-	-	-	-	100%	100%
L1	-	-	92%	83%	13%	10%	30%	55%	-	-	-	29%	100%	67%
L2	-	13%	79%	75%	17%	5%	15%	50%	-	-	-	57%	71%	-
L3	-	46%	88%	88%	4%	5%	-	35%	-	-	-	14%	14%	-
L4	-	42%	42%	42%	-	5%	5%	15%	-	-	-	-	-	-
L5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FIGURE A4 Frontal radiograph and surgical strategies for the Lenke 5 cases. The upper left table indicates the percentage of surgeons (%os) who chose posterior (post.), anterior (ant.), or posterior and anterior (p.&a.) resections (res.) and instrumentation (inst.). Further parameters include the upper (UIV) and lower (LIV) instrumented vertebra, as well as the percentage of instrumented levels (IL) on the left (IL-l) and right (IL-r) side, the used connector (Conn.), resected ligaments (Ligg.), Schwab grad 1 & 2 (SG 1 / 2), resected rib head on the left (ribh-L) and right (ribh-R) side, and discectomy (disc.).

Lenke-6

#2	post.	ant.	p&a
res.	79%	14%	7%
inst.	78%	19%	3%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T3	15%	-	12%	15%	-	-	-	-	-	-	-	-	-	-
T4	27%	-	38%	38%	-	4%	-	8%	-	-	-	-	-	-
T5	38%	-	81%	77%	15%	-	24%	20%	-	-	-	-	-	-
T6	12%	-	58%	65%	15%	8%	28%	40%	-	-	-	-	-	-
T7	-	-	73%	65%	4%	8%	28%	40%	-	-	-	-	-	-
T8	4%	-	58%	65%	-	8%	24%	56%	-	-	-	-	-	-
T9	-	-	85%	69%	-	4%	24%	60%	-	-	-	-	-	-
T10	-	-	58%	62%	-	4%	16%	72%	-	-	50%	-	50%	33%
T11	4%	-	81%	69%	-	4%	12%	72%	-	-	50%	-	100%	83%
T12	-	-	92%	96%	-	8%	16%	76%	-	-	-	-	100%	83%
L1	-	-	100%	85%	8%	12%	16%	68%	-	-	-	-	100%	83%
L2	-	-	88%	81%	23%	8%	16%	76%	-	-	-	-	100%	83%
L3	-	8%	100%	96%	4%	4%	28%	52%	-	-	-	83%	100%	33%
L4	-	62%	92%	92%	-	4%	-	36%	-	-	-	17%	17%	-
L5	-	31%	31%	31%	-	-	-	4%	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

#3	post.	ant.	p&a
res.	79%	21%	0%
inst.	77%	23%	0%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	4%	-	4%	4%	-	-	-	-	-	-	-	-	-	-
T3	17%	-	21%	21%	-	-	-	9%	-	-	-	-	-	-
T4	25%	-	42%	33%	4%	9%	-	9%	-	-	-	-	-	-
T5	38%	-	71%	79%	8%	5%	14%	23%	-	-	-	-	-	-
T6	4%	-	71%	58%	8%	9%	27%	27%	-	-	-	-	-	-
T7	-	-	58%	46%	4%	9%	27%	27%	-	-	-	-	-	-
T8	-	-	58%	67%	-	5%	27%	27%	-	-	-	-	-	-
T9	8%	-	75%	54%	4%	5%	27%	36%	-	-	17%	-	17%	-
T10	4%	-	71%	75%	-	5%	18%	55%	-	-	17%	-	33%	33%
T11	-	-	96%	71%	-	5%	18%	64%	-	-	67%	-	100%	83%
T12	-	-	83%	88%	-	9%	23%	59%	-	-	-	-	100%	83%
L1	-	-	92%	83%	21%	9%	23%	64%	-	-	-	-	100%	83%
L2	-	-	100%	92%	8%	14%	27%	55%	-	-	-	-	100%	83%
L3	-	42%	100%	100%	-	9%	-	55%	-	-	-	83%	100%	17%
L4	-	54%	58%	54%	-	5%	-	32%	-	-	-	17%	17%	-
L5	-	4%	4%	4%	-	-	-	5%	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

#6	post.	ant.	p&a
res.	90%	3%	7%
inst.	97%	3%	0%

	posterior										anterior			
	UIV	LIV	IL-l	IL-r	Conn.	Ligg.	SG 1	SG 2	ribh-L	ribh-R	UIV	LIV	IL	disc.
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	10%	-	10%	7%	-	-	-	3%	-	-	-	-	-	-
T3	43%	-	53%	53%	-	7%	-	14%	-	-	-	-	-	-
T4	40%	-	87%	87%	17%	3%	21%	28%	-	-	-	-	-	-
T5	7%	-	83%	73%	10%	7%	24%	41%	3%	-	-	-	-	33%
T6	-	-	80%	77%	3%	14%	14%	69%	7%	-	-	-	-	33%
T7	-	-	93%	77%	-	10%	10%	79%	14%	3%	-	-	-	33%
T8	-	-	87%	87%	-	10%	10%	79%	14%	3%	-	-	-	67%
T9	-	-	83%	70%	-	3%	14%	69%	14%	3%	-	-	-	33%
T10	-	-	80%	90%	-	3%	17%	55%	3%	-	-	-	-	33%
T11	-	-	90%	77%	-	3%	21%	62%	-	-	100%	-	100%	100%
T12	-	-	87%	87%	-	10%	21%	62%	-	-	-	-	100%	100%
L1	-	-	97%	80%	13%	7%	17%	69%	-	-	-	-	100%	100%
L2	-	-	87%	90%	13%	3%	14%	66%	-	-	-	-	100%	67%
L3	-	23%	100%	93%	3%	3%	10%	48%	-	-	-	100%	100%	-
L4	-	70%	77%	73%	-	-	-	24%	-	-	-	-	-	-
L5	-	7%	7%	7%	-	-	-	3%	-	-	-	-	-	-
S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FIGURE A5 Frontal radiograph and surgical strategies for the Lenke 6 cases. The upper left table indicates the percentage of surgeons (%os) who chose posterior (post.), anterior (ant.), or posterior and anterior (p.&a.) resections (res.) and instrumentation (inst.). Further parameters include the upper (UIV) and lower (LIV) instrumented vertebra, as well as the percentage of instrumented levels (IL) on the left (IL-l) and right (IL-r) side, the used connector (Conn.), resected ligaments (Ligg.), Schwab grad 1 & 2 (SG 1/2), resected rib head on the left (ribh-L) and right (ribh-R) side, and discectomy (disc.).