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CONSENSUS STUDY

To tether or fuse? Significant equipoise remains in treatment recommendations for idiopathic scoliosis

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Abstract

Purpose Vertebral body tethering (VBT) continues to grow in interest from both a patient and surgeon perspective for the treatment of scoliosis. However, the data are limited when it comes to surgeon selection of both procedure type and instrumented levels. This study sought to assess surgeon variability in treatment recommendation and level selection for VBT versus posterior spinal fusion (PSF) for the management of scoliosis.

Methods Surgeon members of the Pediatric Spine Study Group and Harms Study Group were queried for treatment recommendations and proposed upper instrumented vertebra (UIV) and lower instrumented vertebra (LIV) selection for PSF and VBT based on 17 detailed clinical vignettes. Responses were subdivided in each clinical vignette according to surgeon experience and treatment recommendations with assessment of intra-rater reliability. Binomial distribution tests were used to establish equipoise, selecting $p < 0.10$ to indicate the presence of a treatment choice with consensus set > 70% agreement. For treatment choice, responses were assessed first for consensus on the decision to proceed with PSF or VBT.

Results Thirty-five surgeons with varied experience completed the survey with 26 surgeons (74%) completing the second follow-up survey. Overall, VBT was the recommended treatment by 47% of surgeons, ranging by clinical vignette. Consensus in treatment recommendation was present for 6 clinical vignettes including 3 for VBT and 3 for PSF, with equipoise present for the remaining 11. Of the 17 vignettes, 12 demonstrated moderate intra-observer reliability including the 3 consensus vignettes for VBT. Sanders stage ≤ 3 and smaller curve magnitude were related with VBT recommendation but neither age nor curve flexibility significantly influenced the decision to recommend VBT. Surgeons with high VBT volume, ≥ 11 VBT cases/year, were more likely to recommend VBT than those with low volumes (0–10 cases per year ($p < 0.0001$)). High VBT volume surgeons demonstrated consensus in VBT recommendation for Lenke 5/6 curves (75% mean recommendation). High VBT volume surgeons had a significantly higher VBT recommendation rate for Lenke 1A, 2A curves (71.8% vs 48.0%, $p = 0.012$), and Lenke 3 curves (62% vs 26.9%, $p = 0.023$). Equipoise was present for all vignettes in low volume surgeons. In addition, high VBT volume surgeons trended toward including more instrumented levels than low VBT volume surgeons (7.17 vs 6.69 levels).

Conclusion Significant equipoise is present among pediatric spine surgeons for treatment recommendations regarding VBT and PSF. Surgeon-, patient-, and curve-specific variables were identified to influence treatment recommendations, including surgeon experience, curve subtype, deformity magnitude, and skeletal maturity. This study highlights the need for continued research in identifying the optimal indications for VBT and PSF in the treatment of pediatric spinal deformity.

Keywords Scoliosis · Vertebral body tethering · Posterior spinal fusion · Juvenile idiopathic scoliosis · Adolescent idiopathic scoliosis · Survey

Introduction

Vertebral body tethering (VBT) has emerged as a non-fusion treatment strategy for juvenile idiopathic scoliosis (JIS) and adolescent idiopathic scoliosis (AIS). Numerous studies

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have reported on the results of modern VBT showing the capacity for growth modulation in skeletally immature thoracic and thoracolumbar deformities but with varying rates of complications [1–7]. However, complication and reoperation rates have been reported to be significantly higher in patients undergoing VBT as compared to posterior spinal fusion (PSF) [2, 8], despite similar health-reported outcomes [2, 8, 9].

Numerous factors, including curve magnitude, curve location, skeletal maturity, flexibility, and others, influence the decision-making process for selection of VBT vs PSF for the management of JIS and AIS, but the exact indications remain controversial [10]. To help elucidate the current treatment recommendation patterns regarding VBT and PSF, this study sought to survey experienced, pediatric spine surgeons for the management of JIS and AIS using specified clinical vignettes. We hypothesized that there would be significant clinical equipoise in treatment recommendations which would vary based upon surgeon experience, curve, and patient characteristics.

Methods

Surgeons from the Pediatric Spine and Harms Study Groups were invited to participate in the survey. The survey consisted of 18 clinical vignettes, preceded by a series of qualifying questions ensuring that only surgeons who had performed VBT were to complete the survey. Respondents indicated their length of clinical practice, estimated annual spinal surgery volume, as well as their annual volume of VBT cases. They were then presented with 18 detailed clinical vignettes (Online Appendix 1) following which they were queried for their treatment recommendation and construct type (7 choices: selective thoracic (ST) fusion, ST tether, selective thoracolumbar (STL) fusion, STL tether, fuse both curves, double tether, and selective fusion with lumbar tether). After selection of procedure, responses were obtained regarding recommended upper instrumented level (UIV) and lower instrumented level (LIV). Respondents were then invited to complete the survey a second time > 4 weeks following the initial completion to assess for intra-rater reliability of treatment recommendations.

Responses were collated and subdivided in each clinical vignette according to surgeon experience and according to treatment recommendations. Based on the make-up of the respondents, surgeons were subdivided into two groups: (1) 0–10 VBT cases per year and (2) ≥ 11 VBT cases per year. Binomial distribution tests were used as previously described [11] to establish equipoise, selecting a p value < 0.10 to indicate the presence of a treatment choice. For treatment choice, responses were assessed first for consensus on the decision to proceed with either a fusion or VBT procedure. Consensus for proceeding with VBT or fusion was defined as > 70% response for a specific procedure.

Responses were then further characterized for equipoise on the recommended treatment construct. For this analysis, the ST and STL options were combined for both fusion and tethering responses leaving five options in the determination of equipoise. The influence of surgeon experience, clinical variables, and curve characteristics were analyzed with univariate analyses to identify factors influencing the decision to recommend VBT using independent T-test for dichotomous independent variables and linear regression analysis for continuous variables. Pearson correlation coefficients were used to identify significant correlations between percentage of responses recommending VBT with continuous variables. Intra-rater reliability was assessed with Cohen's kappa statistic. Statistical significance was pre-determined as $p = 0.05$ and SPSS software (version 27, IBM, Chicago, IL) was utilized.

Results

Out of 64 respondents, 35 pediatric spine surgeons indicated experience with vertebral body tethering and qualified to complete the survey. Respondent surgeons self-reported varied annual experience with VBT, Fig. 1. A summary of the clinical vignettes and mean treatment responses is provided in Table 1. Overall, VBT was the recommended treatment in 47.2% of responses, ranging by clinical vignette from 8.57 to 77.1%. Overall, there was strong agreement (kappa 0.8–0.9) in treatment decisions for clinical vignettes #6 and 10, with moderate agreement (kappa 0.6–0.79) in 10 additional vignettes and the remaining cases having weak agreement, Table 2.

Surgeons with greater annual VBT volume, ≥ 11 VBT cases per year, were more likely to recommend VBT for the presented clinical vignettes than those with annual

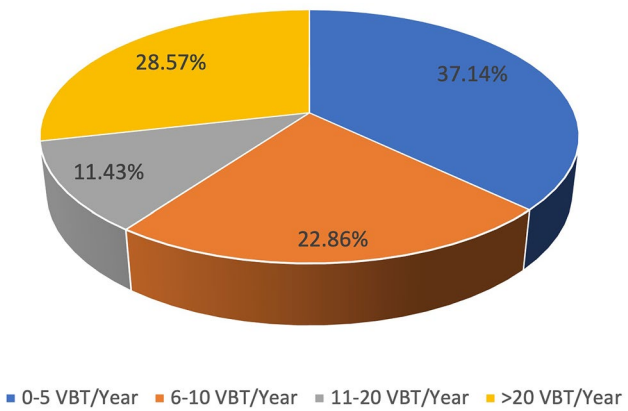

Fig. 1 Breakdown of VBT annual volume of respondent surgeons

Table 1 Summary of clinical vignettes and surgeon treatment recommendations for VBT

Case	Age	Gender	Diagnosis	Curve type	Lumbar modifier	Sagittal modifier	Risser	Modified sanders stage	Curve magnitude (°)	Bending magnitude (°)	% Recommending VBT	VBT vs fusion consensus?
1	11	F	JIS	Lenke 1AL	A	(−)	0	3	52	32	71.43%	Y
2	12	M	JIS	Lenke 1AL	A	N	0	2	54	50	42.86%	
3	13	F	JIS	Lenke 1AR	A	N	0	3	53	35	65.71%	
4	13	F	AIS	Lenke 3C	C	N	3	5	60	36	8.57%	Y
5	11	F	JIS	Lenke 3C	C	N	0	2	62	40	45.71%	
6	14	M	AIS	Lenke 5C	C	N	3	5	55	18	40.00%	
7	13	M	AIS	Lenke 2A	A	(−)	2	4	55	37	28.57%	Y
8	12	F	AIS	Lenke 1C	C	N	2	4	65	46	14.29%	Y
9	13	M	AIS	Lenke 2A	A	N	0	2	60	38	54.29%	
10	11	F	AIS	Lenke 1C	C	N	0	3	55	25	74.29%	Y
11	12	F	AIS	Lenke 1B	B	(−)	0	5	56	33	54.29%	
13	10	F	JIS	Lenke 1AR	A	(−)	0	3	47	25	77.14%	Y
14	13	F	AIS	Lenke 5C	C	N	2	5	48	32	31.43%	
15	15	M	AIS	Lenke 1AL	A	(−)	3	4	55	41	42.86%	
16	13	F	AIS	Lenke 1C	C	N	0	4	55	44	48.57%	
17	13	F	AIS	Lenke 3C	C	N	0	4	60	40	42.86%	
18	11	F	AIS	Lenke 6C	C	N	1	5	50	25	45.71%	

Table 2 Summary of intra-rater reliability for treatment recommendation for vertebral body tethering versus fusion

Case number	Curve type	Intra-rater reliability for treatment recommendation	*p* value
1	Lenke 1AL	0.738	< 0.001
2	Lenke 1AL	0.690	< 0.001
3	Lenke 1AR	0.428	0.024
4	Lenke 3C	0.529	< 0.001
5	Lenke 3C	0.634	< 0.001
6	Lenke 5C	0.923	< 0.001
7	Lenke 2A	0.719	< 0.001
8	Lenke 1C	0.578	< 0.001
9	Lenke 2A	0.462	0.018
10	Lenke 1C	0.898	< 0.001
11	Lenke 1B	0.629	0.001
13	Lenke 1AR	0.752	< 0.001
14	Lenke 5C	0.752	< 0.001
15	Lenke 1AL	0.677	< 0.001
16	Lenke 1C	0.455	0.005
17	Lenke 3C	0.628	< 0.001
18	Lenke 6C	0.615	0.002

volumes of 0–10 cases per year ($p < 0.0001$). Treatment recommendation for VBT also varied according to the surgeon's experience and the Lenke curve classification, Fig. 2. Specifically, those with annual VBT volumes of ≥ 11 cases demonstrated equipoise in the decision to recommend VBT for Lenke 5/6 curves (75%% mean recommendation), which was significantly higher than surgeons with annual volumes of 0–10 cases (11.9%, $p < 0.0001$). In addition, surgeons with greater annual volumes had a significantly higher VBT recommendation rate for Lenke 1A and 2A curves (71.8% vs 48.0%, $p = 0.012$), and Lenke 3 curves (62% vs 26.9%, $p = 0.023$). However, there was no statistical difference for Lenke 1C (54.2% vs 46.8%, $p = 0.64$). Deformities with lumbar C modifiers also influenced the decision to recommend VBT according to surgeon experience, with annual volumes ≥ 11 VBT cases being more likely to recommend VBT (60.3% of cases) than surgeons with volumes of 0–10 cases (28.5%, $p = 0.0007$) (see Fig. 3).

Consensus for VBT

Consensus in treatment recommendation was present for 6 out of the 17 clinical vignettes, Table 3, including 3 cases for VBT and 3 cases for spinal fusion. Within the 3 consensus cases (Cases 1, 10, and 13), the recommended surgical procedure (selective thoracic/thoracolumbar vs double tethering) demonstrated more variability with consensus for with selective thoracic/thoracolumbar tethering in 2 cases (Cases 1 and 13) and equipoise in treatment recommendation for the remaining case (Cases 10).

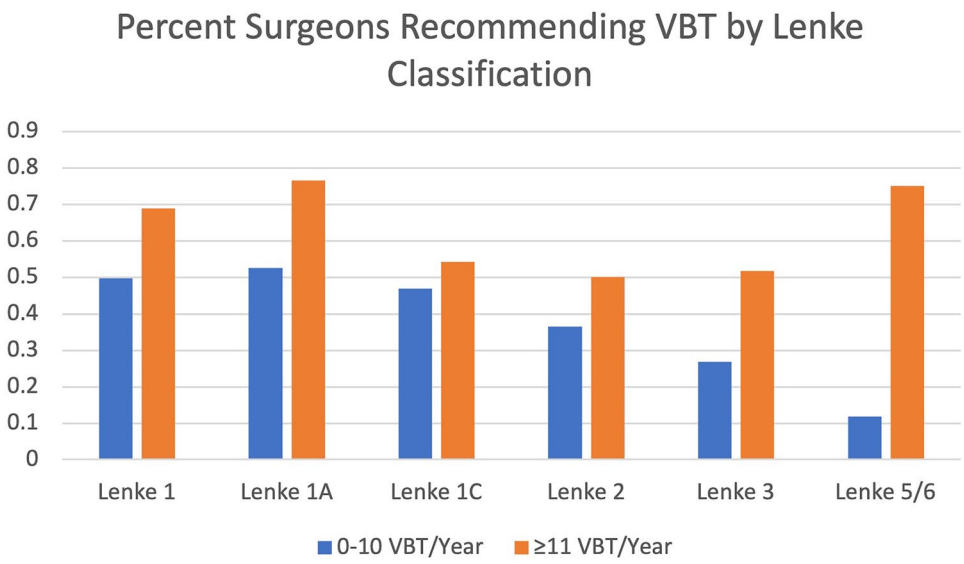

Fig. 2 Graphic depiction of VBT treatment recommendation by annual surgeon case volume and Lenke classification

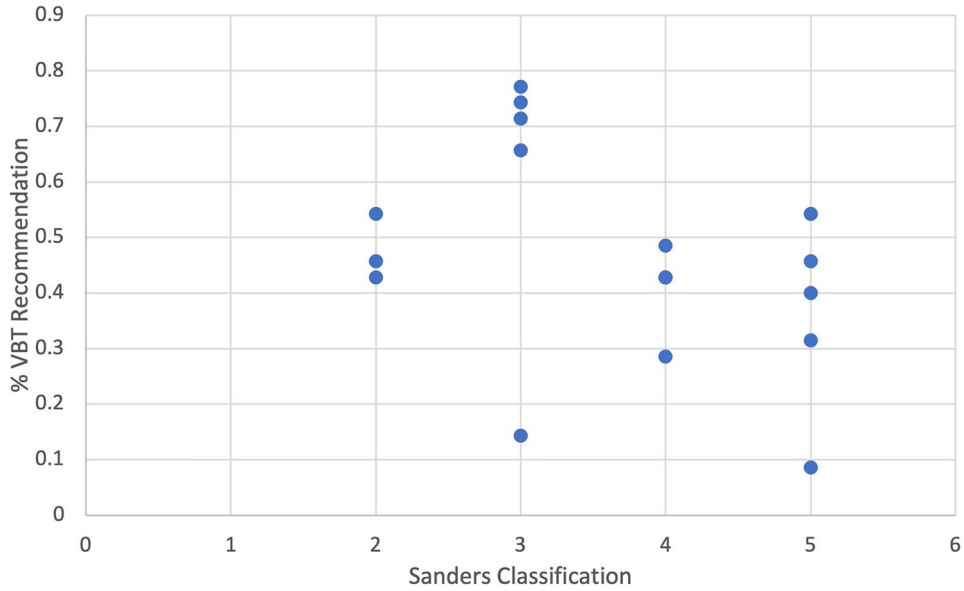

Fig. 3 Graphic depiction of the percentage of surgeons recommending VBT according to the patients Sanders classification

Recommended instrumented levels for VBT

There was wide variety across the clinical vignettes for the mean number of instrumented levels as well as UIV and LIV. Given this heterogeneity, the subsequent analysis was restricted to the three cases with consensus for VBT (Cases 1, 10, 13). The mean number of recommended instrumented levels ranged from 6.7 (Lenke 1A) to 7.46 (Lenke 1C), Table 3. There was consensus for the number of instrumented levels for Case 1 (7 levels indicated by 14 respondents) and Case 13 (7 levels indicated by 16 surgeons) with equipoise for Case 10. In subdividing responses by surgeon experience, surgeons performing ≥ 11 VBT cases per year trended toward including more instrumented levels in comparison to surgeons performing 0–10 cases per annum (7.17 vs 6.69 levels). This trend toward greater levels instrumented for more experienced surgeons was statistically significant for Case 1 (7.4 vs 6.67 levels, $p = 0.005$), but was not significant for Cases 10 (6.8 vs 6.81 levels, $p = 0.97$) or 13 (7.1 vs 6.61 levels, $p = 0.152$).

End instrumented vertebra in VBT

Consensus was present for Lenke 1 curves for a T5 VBT UIV, recommended by 75.5% of surgeons. Recommended instrumented levels were more varied for the remaining curve types. In focusing on the cases with demonstrated consensus in treatment recommendation (Table 3), agreement

Table 3 A summary of cases with demonstrated consensus/equipoise in treatment approach, with summary of surgical construct and instrumented vertebral levels

Case number	Curve type	% VBT	Recommended surgical procedure (*N*, %)	Mean VBT levels (SD)	Mean levels fused (SD)	UIV for VBT	LIV for VBT
1	Lenke 1AL	71.43%	Selective tethering—25 (71.4%)** Selective fusion—10 (28.6%)	8.5 (1.08)			
			Double tether—0				T11-1
			Double fusion—0	6.96 (0.67)		T5-20**	T12-19**
			Hybrid construct—0			T6-5	L1-5
4	Lenke 3C	8.57%	Selective tethering—0 Selective fusion—1 (2.8%) Double tether—6 (17.1%) Double fusion—25 (71.4%)** Hybrid construct—3 (8.6%)	8.0 (3.5)	11.48 (1.25)	T5-16** T10-1 T11-6** T12-2	T11-6** T12-0 L3-0 L4-9**
7	Lenke 2A	28.57%	Selective tethering—10 (28.6%) Selective fusion—22 (62.8%) Double tether—0 Double fusion—3 (8.6%) Hybrid construct—0	7.8 (0.42)	11.96 (0.69)	T5-6** T6-4	T11-1 T12-8** L1-1
8	Lenke 1C	14.29%	Selective tethering—3 (8.6%)		8.73 (1.31)		T12-3 L1-0
			Selective fusion—24 (68.6%)			T5-2	L2-0
			Double tether—2 (5.7%)			T6-1	L3-1
			Double fusion—3 (8.6%)			T12-2	L4-1
			Hybrid construct—3 (8.6%)	11.0 (3.5)		L2-1	L5-1
10	Lenke 1C	74.29%	Selective tethering—21 (60%) Selective fusion—8 (22.9%)		9.25 (1.3)	T4-1 T5-11 T6-13 T7-1	T11-3
			Double tether—5 (14.3%)			T11-2	T12-15**
			Double fusion—1 (2.8%)			T12-2	L1-8**
			Hybrid construct—0	7.46 (1.56)		L1-1	L4-5
13	Lenke 1AR	77.14%	Selective tethering—27 (77.1%)** Selective fusion—8 (22.9%)		8.12 (0.83)		
			Double tether—0			T4-2	T11-6
			Double fusion—0			T5-20**	T12-18
			Hybrid construct—0	6.78 (0.85)		T6-5	L1-3

VBT vertebral body tethering, *SD* standard deviation, *UIV* upper instrumented vertebra, *LIV* lower instrumented vertebra

** Indicates consensus in treatment selection for construct, UIV, and/or LIV

was present for T5 as the UIV for VBT in Cases 1 and 13 with Case 10 demonstrating equipoise in UIV, split between T5 and T6.

With regard to the LIV recommendations for VBT, levels varied based upon the underlying curve classification, Fig. 4. LIV recommendations were more varied than UIV with T12 being recommended by 45% of all surgeon respondents, followed by L1 (26%) and T11 (16). For the three cases with consensus for VBT, only Case 10 demonstrated consensus in LIV selection with recommendation for T12. For the remaining two cases, equipoise for level selection remained with Case 13 having a preponderance of responses for T12 as the LIV but this did not meet the binomial distribution threshold ($N = 19$), and Case 10 had a split recommendation between T12 and L1.

Influence of patient and curve characteristics on decision for VBT

A summary of patient and curve characteristics on the decision to recommend VBT is provided in Table 4. Patients with a Sanders classification of 3 or less were significantly more likely to be recommended for VBT and those with Sanders > 3 ($p = 0.003$). In addition, patients with a diagnosis of JIS were also more likely to be recommended for VBT than those with AIS (60.5% vs 40.5%, $p = 0.046$).

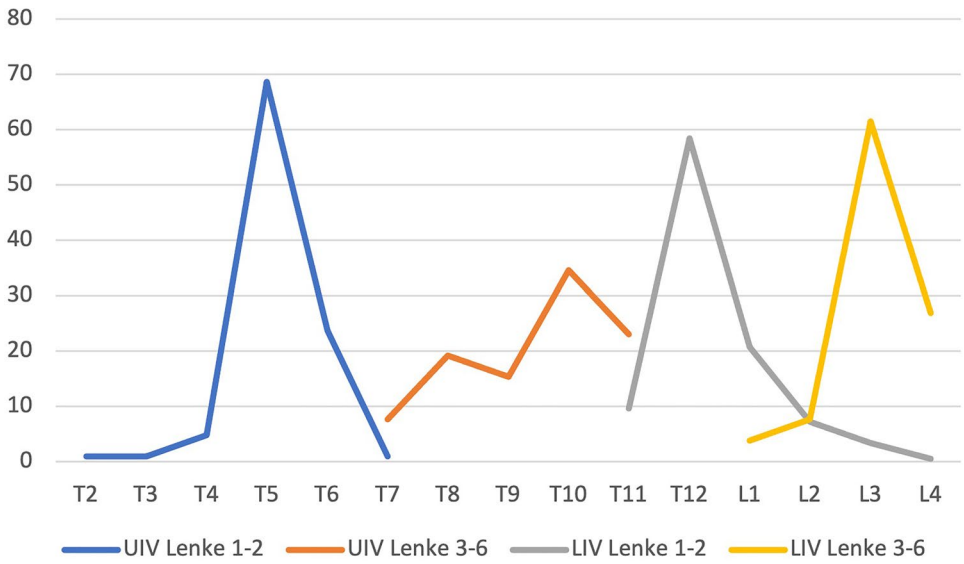

Fig. 4 Summary of recommended end vertebral levels for vertebral body tethering by Lenke curve classification

Table 4 Univariate analysis of clinical and curve characteristics on the decision to recommend vertebral body tethering

Variable	% Recommending VBT (St Dev)	*p* value
Sanders classification ≤3	61.5% (13.9%) vs 35.7% (14.9%)	0.003**
Open triradiate cartilage	47.6% (5.9%) vs 46.1% (21.2%)	0.907
Juvenile idiopathic scoliosis diagnosis	60.6% (15.4%) vs 40.5% (17.9%)	0.046**
Female gender	48.3% (22.2%) vs 41.7% (9.1%)	0.536
Normal kyphosis	42.8% (18.6%) vs 54.8% (20.1%)	0.254
Isolated thoracic curve	52.2% (19.6%) vs 35.7% (14.3%)	0.092
Lumbar modifier A/B	54.6% (16.3%) vs 39.1% (19.5%)	0.096

**Indicates statistical significance $p < 0.05$

Analysis of continuous variables with mean recommendation for VBT were assessed with Pearson correlation coefficients which identified a significant correlation between smaller coronal curve magnitude and the decision to recommend VBT($r = -0.492$, $p = 0.045$). Neither patient age ($r = -0.462$, $p = 0.062$) nor curve flexibility ($r = 0.236$, $p = 0.361$) significantly influenced the decision to recommend VBT.

Discrepancy in treatment terminology

A unique lack of consensus in terminology was identified through the surgeon respondents with regard to the definition of a selective thoracic/thoracolumbar fusion or tether, as demonstrated in clinical vignettes 3 and 14. Vignette #3 details a 13-year-old female with a Lenke 1AR(N) JIS deformity measuring 53 degrees of coronal magnitude, Fig. 5. The patient was a Risser 0 with OTRC and a Sanders 3. Overall, 65.7% of surgeons recommended VBT for this patient with the remaining 34.3% recommending a fusion. However, the specific responses indicated 60% recommending a selective thoracic tether with 5.7% recommending a selective thoracolumbar tether, whereas 14.2% recommended a selective thoracic fusion with 17.1% recommending a selective thoracolumbar fusion. All surgeons recommending a selective thoracic tether indicated their LIV was in the lumbar spine. In addition, all PSF recommendations also indicated a lumbar LIV.

Clinical vignette #14 details a 13-year-old F with AIS, Lenke 5C(N), measuring 48% in coronal deformity magnitude, Fig. 6. Her radiographs were classified as Risser 2 with a Sanders Stage 5. Overall, 31.4% of surgeons recommended VBT while 68.6% recommended spinal fusion, with 22.8% of the responses recommending a selective thoracolumbar fusion, 25.7% selective thoracolumbar tether, 17.1% a selective thoracic fusion, 5.7% a selective thoracic tether and 5.7% a fusion of both curves. All selective thoracic fusion recommendations included a lumbar LIV, as well as for all selective thoracic tethering recommendations. However, of those recommending a STL fusion, 10 respondents indicated a UIV of T7 or above. Mean recommended instrumented levels was 7.8, ranging from 5 to 11 levels.

Discussion

Although VBT has emerged as a viable non-fusion treatment strategy for the management of JIS and AIS, deciding when to proceed with VBT versus PSF has not been clearly defined. In the current survey of pediatric spinal deformity surgeons, we identified significant clinical equipoise remaining in the decision-making process with an overall VBT recommendation of 47% by all respondents. Consensus in

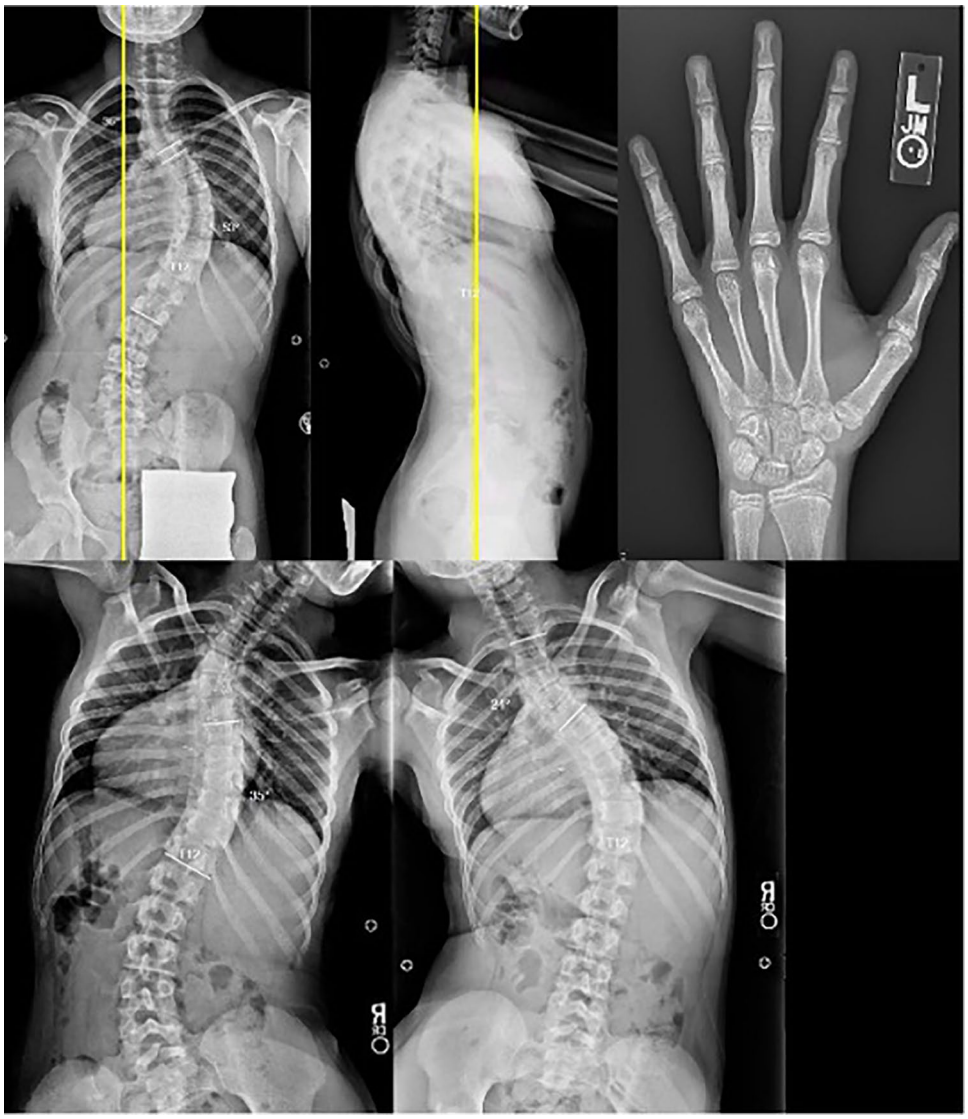

Fig. 5 Presented radiographs for clinical vignette #3

treatment recommendations was present in only 6 cases (3 for VBT and 3 for PSF). Factors impacting the decision for VBT recommendation includes higher annual surgeon VBT volume, skeletal immaturity (Sanders stage ≤ 3), deformity location, and smaller curve magnitude.

The concept of growth modulation of the vertebral body in the management of scoliosis is not new [12]; however, the premise behind these approaches, despite the implant utilized, is to exploit the Hueter–Volkmann principle to facilitate deformity correction [13]. A prerequisite variable to facilitate this aim is the ability to identify patients with sufficient remaining growth to facilitate correction. Early studies using stapling devices relied upon the Risser classification to define the extent of skeletal immaturity [12, 14], an approach which has since been shown to result in significant mismatch with peak height velocity [15]. With the Sanders Staging Classification of skeletal maturity [16], we have gained an improved ability to assess the onset of peak skeletal growth and its use has also been shown to have particular influence on scoliosis correction with VBT [4].

In the current study, the Sanders classification was found to be a significant factor influencing VBT recommendation with Sanders ≤ 3 being significantly more likely to be recommended for VBT. This finding aligns with the FDA Investigational Device Exemption criteria for VBT, including ages 8–16 years, Sanders stage ≤ 4, primary thoracic curves from 35° to 60°, and lumbar curve < 35° [17]. Interestingly, patient age did not influence the decision-making process in the current study, although all subjects did fall in the age indication range; however, smaller coronal curve magnitude was correlated with the decision to recommend VBT.

The interplay between coronal curve magnitude and skeletal maturity as they relate to successful curve treatment is a particularly poignant one in VBT. Takahashi et al. [4] identified that the rate of coronal curve correction with VBT significantly varies based upon the Sanders stage at 2 years

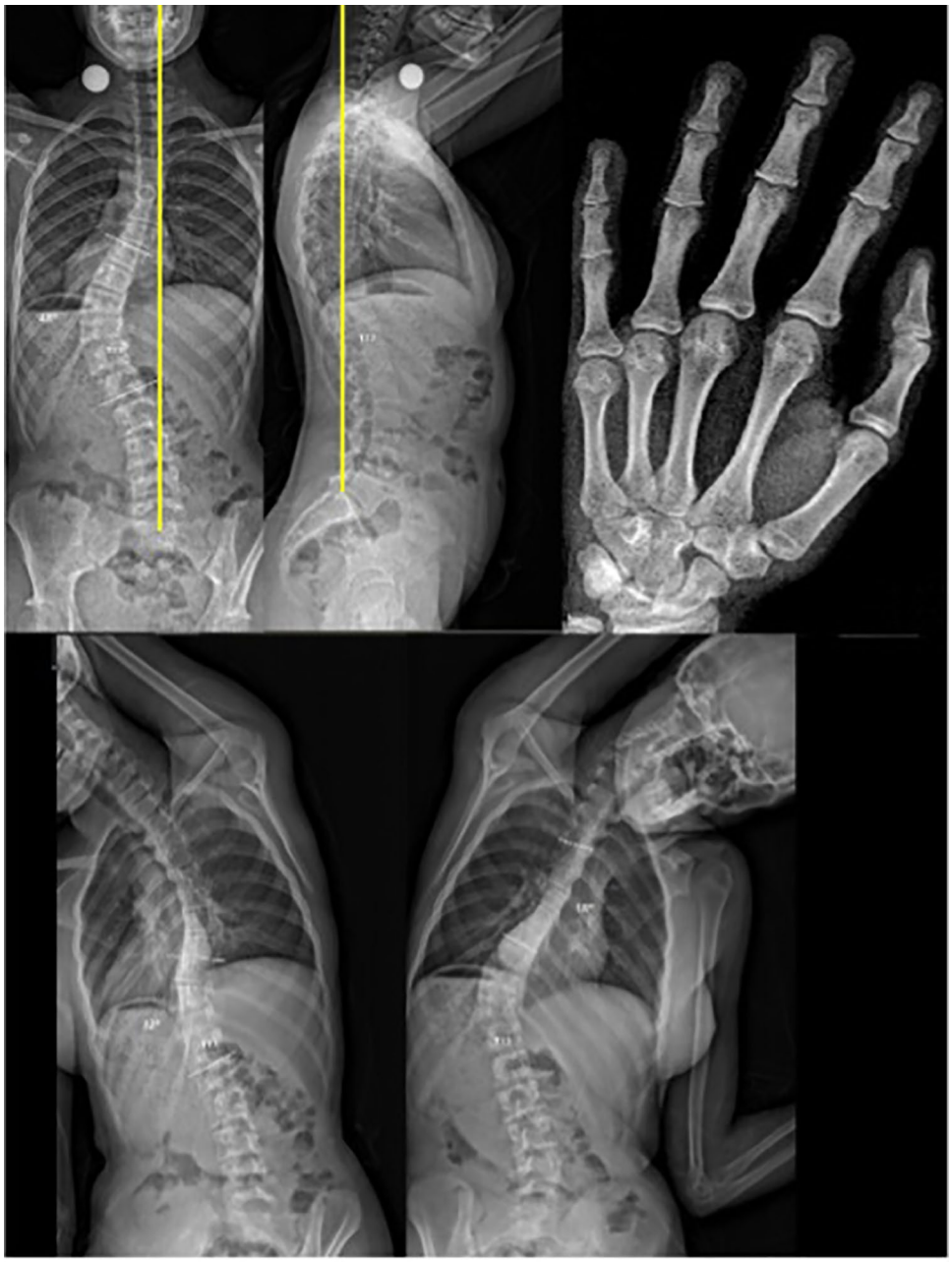

Fig. 6 Presented radiographs for clinical vignette #14

following surgery. Specifically, children Sanders stage 2 demonstrated more than twice the correction rate when compared to Sanders stage 3 children, correcting at a rate of 2.8° per segment per year versus 1.2°. This not only has direct implications on the presenting deformity magnitude for intervention, but also on the degree of intra-operative correction and the risk of over-correction [18].

Of the variables assessed in the current study, surgeon experience exerted the greatest influence on VBT treatment recommendations. Not only were high VBT volume surgeons, ≥ 11 VBT cases per year, more likely to recommend VBT for all cases relative to lower VBT volume surgeons, they also were more likely to recommend VBT for lumbar curves (75% vs 11.9%, $p < 0.0001$), Lenke 1A/2A curves (71.8% vs 48.0%, $p = 0.012$), and recommended instrumenting more levels in their VBT constructs (7.17 vs 6.69 levels). These findings likely reflect a more facile understanding of the performance and potential complication profile with VBT. Previous studies using staple devices have demonstrated that lumbar curves have greater success following treatment with less complications in comparison to thoracic deformities [14, 19]. These data, however, are lacking with modern designed VBT implants.

An unexpected finding in the current study was the presence of confusion with regard to treatment terminology in the management of thoracic deformities requiring treatment

extending into the lumbar spine. As highlighted above in clinical vignettes #3 and #14, there was wide confusion from surgeon respondents in what differentiates a selective lumbar or thoracolumbar tether/fusion. This is viewed in contrast to the well-established and accepted terminology regarding deformity classification, distinguished based upon the location of the apex of the deformity [20, 21]. This discrepancy is also seen in the literature regarding selective thoracic fusion for adolescent idiopathic scoliosis [22–24], and highlights the need for better defined treatment terminology. This discrepancy appears to arise from how the end instrumented vertebral levels influence the terminology of the procedure, i.e., Lenke 1AL curve treated with posterior spinal fusion with LIV of L1 being classified as selective thoracolumbar fusion. To address this discrepancy, we recommend surgical constructs in selective fusions/tethering be named according to the well-established definitions for spinal deformity based on the apex of deformity. Using this system, selective fusion/tether procedures would be named thoracic for apices occurring from T2 to the T11–T12 disc space, thoracolumbar for apices at T12 to L1, and lumbar for apices at L1–2 disc space and distally. If fusing or tethering both curves whether considered structural or non-structural, consider utilizing non-selective as the term to describe these constructs.

This study cannot be viewed without recognition of its limitations. Given the specialized topic of the survey, sampling bias may limit the extrapolation of these results to the general pediatric spine community, particularly in light of the small sample size. As denoted in Fig. 1, over 65% of respondent surgeons were classified as low volume (< 10 case/year). The bias of experience, or lack thereof, may also impact the current results. In addition, there is the potential for bias in the threshold value of 10 annual cases in distinguishing low from high volume VBT surgeons. As a survey inquiry, the potential for response bias was considered in the development of this survey instrument. To minimize the potential impact of response bias, detailed clinical vignettes were provided for each case regarding deformity parameters and skeletal maturity status with corroborative radiographic images to provide the respondent surgeons with ample information to provide an informed treatment recommendation.

In conclusion, this survey of pediatric spinal deformity surgeons identified significant equipoise in treatment recommendations regarding VBT and PSF for the management of JIS and AIS. Significant influences on treatment recommendation include surgeon experience, patient skeletal maturity, curve location, and deformity magnitude. Further research is needed to better define the optimal indications for VBT vs. PSF in the management of idiopathic scoliosis. An unexpected discrepancy in terminology was identified between the definition of selective thoracic and thoracolumbar procedures. To address this lack of consensus, we recommend surgical constructs in selective fusions/tethering be defined by the apex of deformity rather than the location of the end instrumented vertebral levels.

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References

1. Samdani AF, Pahys JM, Ames RJ et al (2021) Prospective follow-up report on anterior vertebral body tethering for idiopathic scoliosis: interim results from an FDA IDE Study. J Bone Jt Surg Am 103(17):1611–1619

2. Newton PO, Bartley CE, Bastrom TP et al (2020) Anterior spinal growth modulation in skeletally immature patients with idiopathic scoliosis: a comparison with posterior spinal fusion at 2 to 5 years postoperatively. J Bone Jt Surg Am 102(9):769–777
3. Wong HK, Ruiz JNM, Newton PO et al (2019) Non-fusion surgical correction of thoracic idiopathic scoliosis using a novel, braided vertebral body tethering device: minimum follow-up of 4 years. JB JS Open Access. 4(4):e0026
4. Takahashi Y, Saito W, Yaszay B et al (2021) Rate of scoliosis correction after anterior spinal growth tethering for idiopathic scoliosis. J Bone Jt Surg Am 103(18):1718–1723
5. Abdullah A, Parent S, Miyanji F et al (2021) Risk of early complication following anterior vertebral body tethering for idiopathic scoliosis. Spine Deform 9(5):1419–1431
6. Hoernschemeyer DG, Boeyer ME, Robertson ME et al (2020) Anterior vertebral body tethering for adolescent scoliosis with growth remaining: a retrospective review of 2 to 5-year postoperative results. J Bone Jt Surg Am 102(13):1169–1176
7. Newton PO, Kluck DG, Saito W et al (2018) Anterior spinal growth tethering for skeletally immature patients with scoliosis: a retrospective look two to four years postoperatively. J Bone Jnt Surg Am 100(19):1691–1697
8. Shin M, Arguelles GR, Cahill PJ et al (2021) Complications, reoperations, and mid-term outcomes following anterior vertebral body tethering versus posterior spinal fusion: a meta-analysis. JBJS Open Access 6(2):e21.00002
9. Qiu C, Talwar D, Gordon J, Capraro A, Lott C, Cahill PJ et al (2021) Patient-reported outcomes are equivalent in patients who receive vertebral body tethering versus posterior spinal fusion in adolescent idiopathic scoliosis. Orthopedics 44(1):24–28
10. Newton PO (2020) Spinal growth tethering: indications and limits. Ann Transl Med 8(2):27
11. Corona J, Miller DJ, Downs J et al (2013) Evaluating the extent of clinical uncertainty among treatment options for patients with early-onset scoliosis. J Bone Jt Surg Am. 95(10):e67
12. Betz RR, Kim J, D'Andrea LP et al (2003) An innovative technique of vertebral body stapling for the treatment of patients with adolescent idiopathic scoliosis: a feasibility, safety, and utility study. Spine (Phila Pa 1976) 28(20):S255–S265
13. Jain V, Lykissas M, Trobisch P et al (2014) Surgical aspects of spinal growth modulation in scoliosis correction. Instr Course Lect 63:335–344
14. Lavelle WF, Samdani AF, Cahill PJ et al (2011) Clinical outcomes of nitinol staples for preventing curve progression in idiopathic scoliosis. J Pediatr Orthop 31(1 Suppl):S107–S113
15. Minkara A, Bainton N, Tanaka M et al (2020) High risk of mismatch between sanders and risser staging in adolescent idiopathic scoliosis: are we guiding treatment using the wrong classification? J Pediatr Orthop 40(2):60–64
16. Sanders JO, Khoury JG, Kishan S et al (2008) Predicting scoliosis progression from skeletal maturity: a simplified classification during adolescence. J Bone Jt Surg Am 90(3):540–553
17. Krakow AR, Magee LC, Cahill PJ et al (2021) Could have tethered: predicting the proportion of scoliosis patients most appropriate for thoracic anterior spinal tethering. Spine Deform 9(4):1005–1012
18. Alanay A, Yucekul A, Abul K et al (2020) Thoracoscopic vertebral body tethering for adolescent idiopathic scoliosis: follow-up curve behavior according to sanders skeletal maturity staging. Spine (Phila Pa 1976) 45(22):E1483–E1492
19. Cahill PJ, Auriemma M, Dakwar E et al (2018) Factors predictive of outcomes in vertebral body stapling for idiopathic scoliosis. Spine Deform 6(1):28–37
20. Lenke LG, Betz RR, Harms J et al (2001) Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Jt Surg Am 83(8):1169–1181
21. Slattery C, Verma K (2018) Classification in brief: SRS-Schwab classification of adult spinal deformity. Clin Orthop Relat Res 476(9):1890–1894
22. Lonstein JE (2018) Selective thoracic fusion for adolescent idiopathic scoliosis: long-term radiographic and functional outcomes. Spine Deform 6(6):669–675
23. Larson AN, Fletcher ND, Daniel C et al (2012) Lumbar curve is stable after selective thoracic fusion for adolescent idiopathic scoliosis: a 20-year follow-up. Spine (Phila Pa 1976) 37(10):833–839
24. Lenke LG, Edwards CC 2nd, Bridwell KH (2003) The Lenke classification of adolescent idiopathic scoliosis: how it organizes curve patterns as a template to perform selective fusions of the spine. Spine (Phila Pa 1976) 28(20):S199-207

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