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Hybrid Thoracic Posterior Spinal Fusion Combined with Posterior Lumbar Vertebral Body Tethering in Adolescent Idiopathic Scoliosis: A Motion-Preserving Strategy

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Abstract

Purpose: Posterior spinal fusion (PSF) provides reliable correction in adolescent idiopathic scoliosis (AIS) but sacrifices lumbar motion when extended distally. Vertebral body tethering (VBT) preserves motion but carries significant mechanical complication rates in thoracic spine. We evaluated a hybrid strategy combining thoracic PSF with posterior lumbar vertebral body tethering (PLVBT) to preserve distal lumbar mobility while maintaining deformity correction.

Methods: Seventeen consecutive Lenke 1C, 3C or 6C AIS patients underwent thoracic PSF combined with PLVBT. Primary outcome was lumbar Cobb angle change at 2 years. Secondary outcomes included thoracic Cobb angle, sagittal parameters, perioperative data, and complications. Paired t-tests and Cohen's d effect sizes were calculated.

Results: Lumbar Cobb angle improved from 51° (± 7°) to 19° (± 8°) at 2 years ($p < 0.0001$, $d = 4.21$). Thoracic Cobb angle improved from (59° ± 12°) to (34° ± 8°) ($p < 0.0001$, $d = 2.85$). Thoracic kyphosis significantly increased from 14° (± 9°) to 24° (± 9)° ($p = 0.01$, $d = 1.11$).

Lumbar lordosis didn't change.

No tether rupture occurred.

Complication rate was 17.6%.

Conclusion: Hybrid thoracic PSF combined with PLVBT achieved large, durable correction while theoricaly preserving lumbar mobility. This approach may represent a rational alternative to extended lumbar fusion in selected AIS patients.

Keywords: Growth modulation; Vertebral body tethering; Idiopathic scoliosis

Introduction

Posterior spinal fusion (PSF) remains the gold standard for surgical management of adolescent idiopathic scoliosis (AIS), providing reliable three-dimensional correction and long-term stability. However, distal extension of fusion into the lumbar spine reduces motion segments and may impact long-term function. Vertebral body tethering (VBT) has emerged as a motion-preserving alternative.

We hypothesized that a hybrid approach combining rigid thoracic PSF with posterior lumbar vertebral body tethering (PLVBT) could provide stable thoracic correction while preserving distal lumbar mobility. This study

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evaluates the radiographic outcomes and safety profile of this strategy at 2-year follow-up.

Material and Methods

Patient selection:

The inclusion criteria were:

- Diagnosis of idiopathic scoliosis from 12 to 16 years old
- Severe progressive thoracic curves > 45° and lumbar > 35°
- Type 1C, 3C or 6C on the Lenke Classification
- Surgical treatment using a 'hybrid technique' as described in the operative technique
- A minimum follow up of 2 years.

Exclusion criteria were:

- Other types of curves
- Lumbar curves < 35° or > 60°
- Secondary scoliosis

Surgical technique:

Two senior surgeons performed all the hybrid procedures at a single institution.

The patient is positioned prone according to the surgeon's preference. A standard posterior midline incision is performed.

At the thoracic level, a conventional posterior approach is used with standard posterior spinal fusion instrumentation. We used both Medicrea™ (Medtronic®) and Mesa™ (Stryker®) instrumentations for this procedure.

At the lumbar level, the surgical technique is identical to the one described in our previous publication dedicated to posterior lumbar vertebral body tethering in Lenke 5C [1], it was also described by Mineiro [2] . We only used the Reflect™ from Globus®.

The transition vertebra (most commonly T12, (but occasionally T10, T11 or L1) is instrumented asymmetrically. One pedicle screw corresponds to the proximal end of the lumbar construct, while the other corresponds to the distal end of the thoracic construct. As a result, the rods are distally offset by one level (Figure 1).

Post operative management included pain control, mobilization as soon as possible, no brace.

Outcomes of interest:

Patient demographics included age at index operation, Risser staging, Lenke classification.

Perioperative data included levels instrumented with PSF and PLVBT, operative complication, case duration, estimate blood loss.

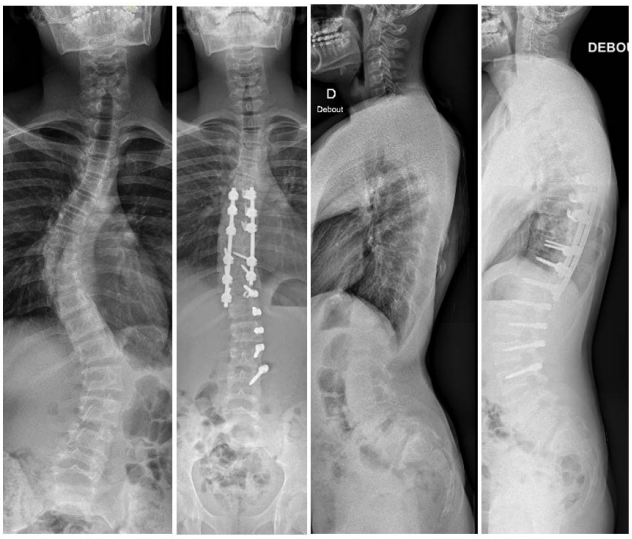

Figure 1: a 15 y.o. boy with a Lenke 3C before and at 2 years after the surgery.

Radiographic data were recorded pre-operatively, post-operatively and at most recent post-operative visits. Curve magnitude was measured using the Cobb angle. Other radiographic measurements were thoracic kyphosis (T4T12) and lumbar lordosis (L1S1).

Table 1: Patient Demographics and Surgical Characteristics.

Total patients	17
Mean age (years)	13.9 ± 1.05
Mean Risser grade	1.3 ± 0.95
Lenke type 1C	6
Lenke type 3C	9
Lenke type 6C	2
Mean thoracic fusion levels	6
Distal fusion levels	T10 (2), T11 (2), T12 (12), L1 (1)
Distal Lumbar VBT levels	L3/L4 (L5 in 1 case)

Seventeen consecutive AIS patients (Lenke 1C, 3C, 6C) were retrospectively reviewed. Mean age was 13.9 ± 1.05 years; mean Risser grade 1.3 ± 0.95. Thoracic PSF averaged six levels (typically T5–T12). Distal fusion extended to T10 (2), T11 (2), T12 (12), and L1 (1). PLVBT typically extended to L3/L4 (one case to L5).

Results

Lumbar Cobb decreased from 51°(± 7°) pre-operatively to 19° (± 8°) at 2 years ($p < 0.0001$; Cohen's $d = 4.21$). Thoracic Cobb decreased from 59° (± 12°) to 34° (± 8°) ($p < 0.0001$; $d = 2.85$). Thoracic kyphosis improved from 14° (± 9°) to 24° (± 9°) ($p = 0.01$; $d = 1.11$). Lumbar lordosis remained stable.

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Table 2: Radiographic Outcomes

Parameter	Preoperative	Postoperative	2 Years	p-value
Lumbar Cobb	51°(± 7°)	17° (± 9°)	19°(± 8°)	<0.0001
Thoracic Cobb	59°(± 12°)	31°(± 7°)	34° (± 8°)	<0.0001
Thoracic Kyphosis	14°(± 9°)	20° (± 8°)	24° (± 9°)	0.01
Lumbar Lordosis	53°(± 13°)	51°(± 13°)	48°(± 13°)	NS
Lumbar Bending Cobb	19° (± 6°)	-	-	-

Table 3: Peri-operative Data and Complications.

Mean operative time (minutes)	208 (± 54)
Estimated blood loss (mL)	390 (± 143)
Length of stay (days)	5.4 (± 0.98)
Total complications	3 (17.6%)
Infections	2 (irrigation + antibiotics)
Painful screw removal	1 (no loss of correction)

Mean operative time was 208 (± 54) minutes with a mean blood loss of 390 (± 143) mL. Three complications occurred (17.6%): two infections treated with irrigation and antibiotics and one patient had a painful screw. The removal of the screw resolved the problem without compromising the correction. No tether rupture or mechanical failure were observed.

Discussion

The present study reports the preliminary clinical and radiographic outcomes of a hybrid surgical strategy combining thoracic PSF with PLVBT in Lenke 1C, 3C, and 6C AIS.

The principals findings are:

1. Large and durable thoracic correction (including restoration of thoracic kyphosis) comparable to standard PSF.
2. Substantial lumbar correction maintained at 2-year follow-up.
3. Extremely large effect size for lumbar correction (Cohen's d = 4.21).
4. Absence of tether rupture or mechanical failure at 2 years.
5. Acceptable complication profile.

These results suggest that dissociating thoracic rigid correction from lumbar motion preservation may optimize the balance between correction magnitude, mechanical reliability, and preservation of function.

Isolated VBT has emerged as a motion-preserving alternative to fusion in AIS. However, it's mechanical durability remains debated. Systematic reviews and meta-analyses report tether rupture rates ranging from 20% to 50% and reoperation rates between 8% and 30%, depending on follow-up duration and patient selection [3–9]. Newton et al., in a prospective multicentre study, reported a 29% tether rupture rate at a mean follow-up of 2.4 years, with significantly better outcomes when immediate postoperative Cobb was <35° [10]. Similarly, a recent meta-analysis reported a pooled rupture rate of 21.9% and a secondary fusion rate of 7.2% [6]. Mechanical complications appear particularly frequent when VBT is applied to the thoracic spine, where rotational stiffness, rib cage constraint, and higher tensile stresses may increase tether fatigue [4,11,12]. By eliminating thoracic tethering and restricting modulation to the lumbar spine, the present hybrid strategy may reduce mechanical overload and therefore lower the risk of tether failure. Notably, no tether rupture occurred in this series at 2 years, contrasting with previously reported rates [3–6].

The hybrid concept is based on the premise that thoracic and lumbar segments serve distinct biomechanical roles and should therefore be treated differently:

The thoracic spine is less mobile, exhibits greater rotational deformity, and requires three-dimensional correction including derotation and kyphosis restoration. PSF remains highly reliable in achieving substantial coronal correction, sagittal restoration, and rotational control [13]. VBT does not consistently reproduce this degree of derotation or kyphosis restoration.

In contrast, the lumbar spine is the principal contributor to sagittal alignment, is essential for flexion–extension mobility, and plays a critical role in load transmission and long-term functional adaptation. Several comparative studies have demonstrated that VBT preserves greater lumbar range of motion and potentially superior functional scores compared with long PSF extending into the lumbar spine [14-16].

The hybrid approach preserves distal lumbar motion segments, particularly L2–S1, while still achieving substantial lumbar correction.

Additionally, posterior tether screw positioning may theoretically support restoration of lumbar lordosis through posterior compression modulation, although this hypothesis requires biomechanical confirmation. In this study there was no change in the lumbar lordosis before surgery and at 2 years, we found the same results on the study on the PLVBT for Lenke 5C curves [1], Mineiro in his study on PLVBT found an increase of 13,6% [2].

An important observation is that lumbar Cobb angle at 2 years closely matched preoperative bending Cobb. This

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finding supports a proportional correction strategy rather than aggressive overcorrection. Overcorrection has been identified as a potential risk factor for tether rupture in VBT series [17]. By respecting intrinsic flexibility, mechanical stress on the tether may be reduced. The very large effect size (d = 4.21) indicates not only statistical significance but a clinically meaningful magnitude of correction. This proportional approach may represent a biomechanically safer strategy than attempting maximal correction with modulation constructs.

Posterior spinal fusion remains the gold standard for reliable long-term correction in AIS [13]. Correction rates typically range from 60% to 75% with low mechanical complication rates. However, extension of fusion into the lumbar spine sacrifices segmental mobility. Long-term consequences may include reduced flexibility and potential adjacent segment degeneration [16,18]. Comparative studies have shown that motion-preserving strategies such as VBT may offer superior lumbar mobility and potentially improved functional outcomes, although at the cost of higher mechanical complication rates [13,15,19].

The hybrid technique aims to combine the mechanical reliability of thoracic1PSF with the motion-preserving benefits of lumbar VBT. In this series, thoracic correction mirrored standard PSF results, while lumbar mobility was preserved without tether rupture.

Selection of the lowest instrumented vertebra (LIV) remains critical in AIS surgery. In Lenke 3C or 6C curves, fusion frequently extends to L1–L4 to prevent distal adding-on [20]. Recent evidence suggests that more individualized selection based on flexibility and global balance may be appropriate [20,21]. In the present series : fusion rarely extended beyond T12 (only one case required L1 fusion) and no distal adding-on occurred. Lumbar modulation may therefore allow a more proximal fusion endpoint without compromising coronal balance. This finding challenges rigid distal fusion paradigms and supports a selective hybrid approach in flexible lumbar modifiers (Figure 2).

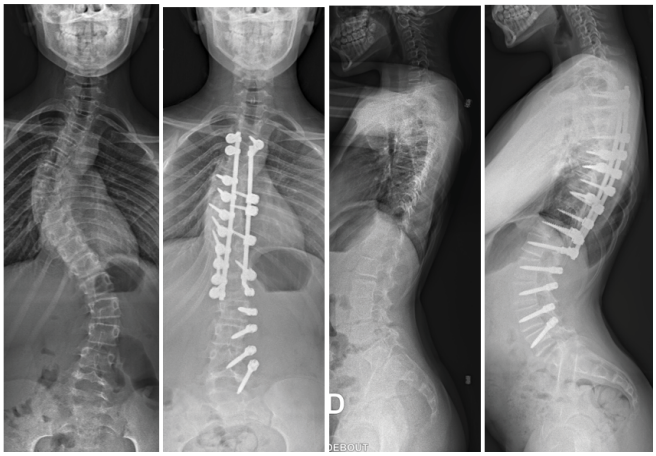

Figure 2: a 12 y.o. girls with a Lenke 3C before and at 3 years after the surgery.

The overall complication rate was 17.6%, consisting of two infections and one symptomatic screw who needed a removal. No tether rupture, no mechanical failure, and no loss of correction were observed. By contrast, a recent analysis using modified Clavien-Dindo classification reported a 32% overall complication rate for VBT, with a substantial proportion requiring reoperation [22]. Although the present cohort is small, the absence of mechanical tether complications is encouraging. Longer follow-up is required to confirm mechanical durability beyond 2 years.

The hybrid strategy may represent an intermediate pathway between: full PSF (maximal correction, complete rigidity) and full VBT (motion preservation, higher mechanical risk). In flexible lumbar modifier curves, this approach may optimize the correction–mobility–reliability balance (Figure 3).

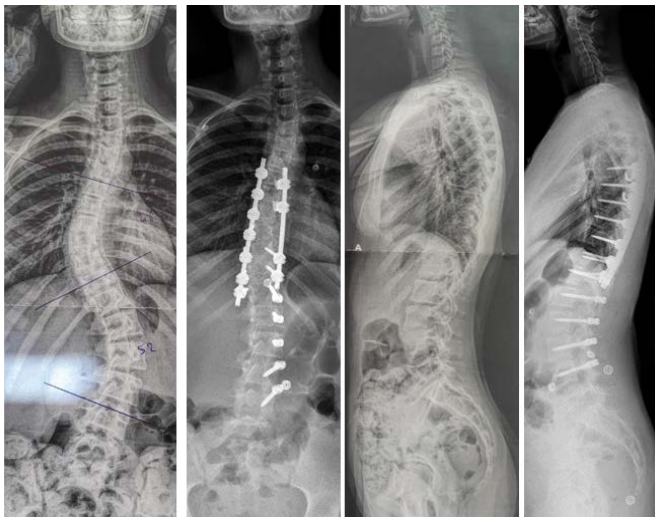

Figure 3: a 14 y.o. girl with a Lenke 3C before and just after surgery.

This study is limited by the retrospective design, the small sample size and the limited follow-up duration (2 years). These limitations prevent definitive conclusions regarding long-term durability and functional superiority.

Future investigations should include prospective multicentre comparative studies, long-term follow-up beyond skeletal maturity, functional and motion analysis. Biomechanical studies may also clarify the load-sharing characteristics of posterior lumbar tether constructs.

Conclusion

The hybrid strategy combining thoracic PSF with lumbar posterior VBT achieved significant, durable deformity correction with preservation of distal lumbar motion. By

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dissociating thoracic stabilization from lumbar modulation, this approach may represent a rational evolution in motion-preserving scoliosis surgery. Long-term validation is required.

Author Contribution:

All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement:

Ethical review and approval were waived for this study after consultation of the Committee of Protection of Persons EST 1 of Dijon. This trial was outside Jarde's law field.

Informed Consent Statement:

Informed consent was obtained from all the subjects involved in the study. Written informed consent has been obtained from the parents to publish this paper.

Conflicts of Interest:

The authors declare no conflicts of interest.

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