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Early outcomes in hybrid fixation for idiopathic scoliosis: posterior fusion combined with anterior vertebral body tethering. Patient series

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BACKGROUND Anterior vertebral body tethering (AVBT) and posterior spinal fusion (PSF) are options for patients with idiopathic scoliosis. Combining both procedures in patients with double curves, a procedure in which PSF is performed for the thoracic curve and AVBT for the lumbar curve, provides maximal correction of the thoracic curve with a theoretical maintenance of motion in the lumbar spine.

OBSERVATIONS The authors retrospectively reviewed 20 skeletally immature patients diagnosed with idiopathic scoliosis at a single institution with an average age of 12.7 ± 1.6 years and who had undergone hybrid treatment with an average follow-up of 8 months. The PSF procedures averaged 276 ± 63 minutes with 442.8 ± 295 mL of blood loss, and the AVBT averaged 275 ± 54 minutes with 118.3 ± 80 mL of blood loss. Following the hybrid correction, the thoracic and lumbar coronal curve angles improved from 67.6° to 21.6° and from 65.2° to 24°, respectively. The three-dimensional kyphosis improved from 3.3° to 24°.

LESSONS A combined approach of PSF and AVBT is safe and effective for idiopathic scoliosis. This approach combines the gold standard of thoracic fusion with the motion preservation benefits of AVBT in the lumbar spine. This study will continue to refine indications for AVBT.

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KEYWORDS adolescent idiopathic scoliosis; posterior spinal fusion; anterior vertebral body tethering; hybrid; pediatric spinal deformity

Progressive adolescent idiopathic scoliosis (AIS) is a debilitating condition that may lead to significant pain and disability if left untreated.[1] Many children, particularly those who are skeletally mature or have severe or fixed deformities, require surgical intervention to correct their spinal deformity.[2] Surgical intervention is indicated in these patients to treat pain, correct the existing deformity, and prevent disease progression, which can lead to worsened pain, cardiopulmonary compromise, and even early death.[3] For more than half a century, rigid fixation with posterior spinal fusion (PSF) has been the gold standard treatment for progressive AIS. To date, there are strong outcomes with 20-year data showing excellent results compared with age-matched control subjects treated without surgery.[4] Despite these results, patients with AIS who have undergone rigid fixation experienced decreased lumbar spinal motion and muscle endurance, which led to impaired physical function.[4] Furthermore, it remains unclear what happens to these patients later in life. Because the number of levels included in rigid fixation is inversely proportional to lumbar spine mobility, providing a solution to accomplish curve correction while minimizing loss of mobility would provide maximal benefit to this pediatric population.

Anterior vertebral body tethering (AVBT) offers deformity correction in patients with idiopathic scoliosis while preserving motion. After a decade of experience, AVBT has been shown to be a safe and effective treatment for thoracic and thoracolumbar idiopathic scoliosis, with overcorrection being the most common reason for reoperation.[5,6] In the first U.S. Food and Drug Administration (FDA)-approved device study on AVBT, Samdani et al.[7] showed that this novel treatment allowed effective coronal correction while preserving

ABBREVIATIONS 3D = three-dimensional; AIS = adolescent idiopathic scoliosis; AVBT = anterior vertebral body tethering; EBL = estimated blood loss; FDA = U.S. Food and Drug Administration; IRB = institutional review board; LIV= lowest instrumented vertebra; PSF = posterior spinal fusion.

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the natural kyphosis of the thoracic spine. In a recent meta-analysis,[8] AVBT was shown to provide effective correction in the main thoracic, proximal thoracic, and thoracolumbar curves while maintaining physiological thoracic kyphosis and lumbosacral lordosis. In addition to providing effective curve correction, AVBT is a motion-preserving procedure, with a comparative study showing less loss of trunk motion with AVBT than with PSF at 2 years postoperatively.[9] Unfortunately, this motion preservation comes at the cost of increased reoperation and an unpredictable final deformity correction.[10]

Hybrid fixation of the spine in patients with double curves uses a combination of PSF of the thoracic spine and AVBT of the lumbar spine. This novel paradigm combines the benefits of rigid fixation and motion-preserving tethering. PSF through the relatively less mobile thoracic spine allows excellent three-dimensional (3D) correction, whereas tethering into the lumbar spine allows relative motion preservation of these more mobile segments. In this study, we assessed our initial experience with this hybrid approach for the correction of idiopathic scoliosis in juvenile and adolescent patients.

Study Description

Pediatric patients (aged $<$21 years) diagnosed with idiopathic scoliosis who had undergone thoracic PSF combined with lumbar AVBT between March 2021 and February 2023 were included in this analysis. We identified 20 patients diagnosed with juvenile idiopathic scoliosis or AIS who had undergone both thoracic PSF and lumbar AVBT. Of note, 92 additional patients with double curves had undergone fusion alone during this period because they did not meet the criteria for the hybrid procedure. Patient demographic variables, including age, sex, body mass index, and genetic conditions, were collected. Preoperative radiographic variables, including Lenke curve type, Sanders score, thoracic and lumbar Cobb angles, and sagittal T2–12 and T5–12 Cobb angles, were calculated. The formula of Parvaresh et al.[11] [18.1 + (0.81 $\times$ 2D T5–12 sagittal Cobb) − (0.54 $\times$ 2D coronal Cobb)] was used to estimate 3D T5–12 kyphosis. Surgical variables included the number of levels instrumented or tethered, time between procedures, estimated blood loss (EBL; in mL), transfusions, use of cell saver, and duration of the procedure. The hospital variables included postoperative drain output and length of hospital stay. Patients returned for multiple follow-up visits after both procedures and underwent postoperative radiography at 6 and 12 weeks and 1 year after surgery. Thoracic and lumbar Cobb angles were calculated for each postoperative radiograph. Clinical variables and univariate statistics were compared using *t* tests (Prism 9.5.0, GraphPad Software) with a confidence interval of 95% and $\alpha = 0.05$.

Patient Demographics and Radiographic Parameters

Twenty patients had an average age of 12.7 ± 1.6 years. Sixty-five percent of the patients were female, and the follow-up averaged 8 months (range 1–24 months). The included patients were skeletally immature (Sanders score 3.8 ± 1.8). They were classified according to their Lenke curve type as follows: 6C (11; 55%), 3C (5; 25%), 1C (3; 15%), and 4C (1; 5%). The patient descriptive statistics are summarized in Table 1.

TABLE 1. Summary of descriptive statistics of patients undergoing hybrid tether/fixation correction

Variable	Value
No. of patients	20
Age in yrs	12.7 ± 1.6
Female, no. (%)	13 (65)
Lenke curve type, no. (%)	
1C	3 (15)
3C	5 (25)
4C	1 (5)
6C	11 (55)
Sanders score	3.8 ± 1.8
Time btwn procedures in days	3.3 ± 2.0
Surgical time in mins	
PSF	276 ± 64
AVBT	275 ± 55
EBL in mL	
PSF	442.8 ± 294.0
AVBT	118.3 ± 80.6

Surgical Data

All patients underwent staged PSF and AVBT procedures, and of the 19 patients who underwent both procedures at the index admission, procedures were performed an average of 3.3 ± 2.0 days apart. The PSF procedure took an average of 276 ± 64 minutes, and the AVBT procedure took an average of 275 ± 55 minutes. EBL was 442.8 ± 294.0 mL for PSF procedures and 118.3 ± 80.6 mL for AVBT procedures. No neuromonitoring changes were observed in this cohort. The patients were followed up for an average of 231 days (range 16–701 days).

Radiographic Outcomes

Following the hybrid scoliosis correction, thoracic Cobb angles improved from 67.6° to 21° ($p < 0.001$), and lumbar Cobb angles improved from 65.2° to 24° ($p < 0.001$). The 2D sagittal T2–12 Cobb angles remained unchanged from 31.5° preoperatively to 29.4° postoperatively ($p = 0.438$), as did the sagittal 2D T5–12 Cobb angles (25.1° preoperatively and 22.5° immediately postoperatively; $p = 0.322$). 2D kyphosis underestimated rotation. However, we found that 2D kyphosis underestimated the degree of rotation, and, by using the formula of Parvaresh et al.[11] for estimating 3D kyphosis, we found that kyphosis was restored in most cases with an average increase of 20° (preoperatively 3.3° versus 6- to 12-week follow-up 24.6°; $p < 0.001$). Two hyperkyphotic cases ($>$40° preoperative 2D sagittal Cobb) of likely syndromic patients were excluded; thus, restoration of kyphosis yielded greater significance (preoperative mean kyphosis 0.7° versus 27.8° postoperatively; $p < 0.001$). In patients with a 1-year follow-up, Cobb angles did not progress in either the thoracic ($p < 0.001$) or lumbar ($p = 0.002$) regions. No patients required revision surgery, and there were no major perioperative complications in the cohort (Table 2).

Complications

In the current cohort, there were no complications that required a return to the operating room because of an adverse event. There were no revision surgeries for either PSF or AVBT and no tether breakages in the patient cohort.

TABLE 2. Radiographic parameters of patients undergoing hybrid tether/fixation correction

	Preoperative Cobb Angle	6- to 12-Wk Postoperative Cobb Angle	Most Recent Cobb Angle	p Value
Thoracic	67.6°	21.0°	21.6°	**<0.001**
Lumbar	65.2°	22.6°	24.0°	**0.002**
Sagittal T2–12	28.0°	28.9°	28.9°	—
Sagittal T5–12	23.2°	20.9°	20.9°	—
3D kyphosis	3.3°	24.6°	24.6°	**<0.001**

Boldface type indicates statistical significance.

Institutional Review Board Statement and Patient Informed Consent

Institutional review board (IRB) approval for the study was obtained from Western IRB. The necessary patient informed consent was obtained in this study.

Illustrative Cases

The hybrid technique involves a PSF through the thoracic curve and a double tether cord along the lumbar curve (Fig. 1). A 14-year-old girl with AIS presented with a Lenke 3C double major curve and was treated with a staged T3–11 PSF and T11–L4 AVBT (Fig. 2A–D). A 10-year-old girl with AIS presented with a Lenke 3C double major curve that was treated with a staged T4–12 PSF and T12–L4 AVBT (Fig. 2E–H). A 14-year-old girl with AIS presented with a Lenke 6C double curve that was treated with a staged T1–10 PSF and T10–L4 AVBT (Fig. 3A–D). A 14-year-old girl with AIS presented with a Lenke 6C double curve that was treated with a staged T3–11 PSF and T11–L4 AVBT (Fig. 3E–H).

Discussion

Hybrid correction for idiopathic scoliosis in the pediatric population offers deformity correction with the potential to preserve lumbar range of motion and mobility. In our initial experience, staged PSF and AVBT procedures were well tolerated by patients. The majority of patients underwent both procedures during the index admission, with an average of 3 days between procedures. In all but one case, thoracic PSF was performed prior to lumbar AVBT, which we recommend to correct the thoracic curve and facilitate the correction of lumbar scoliosis. Although the use of PSF for the revision of a previous AVBT has been investigated,[12] there are currently no studies assessing a hybrid approach that combines rigid thoracic fusion and motion-sparing lumbar AVBT.

In the growing spine, optimal treatment for idiopathic scoliosis must balance maximal curve correction and motion preservation. Thoracolumbar scoliosis corrected through rigid posterior fixation has been the standard treatment for over 60 years, with multidecade data showing the maintenance of curve correction as well as adequate control of pain and physical function following correction.[13,14] Despite providing reliable curve correction and preventing progression, PSF has limitations. The number of instrumented levels for a given curve has been widely debated,[9] and a more caudal lowest instrumented vertebra (LIV) has been associated with both adjacent disc degeneration and loss of spinal mobility.[15] To address this potential long-term sequela, surgeons have focused on minimizing the number of instrumented levels, with the goal of decreasing the possibility of adjacent segment disease and loss of mobility in the lumbosacral spine.

Anterior VBT offers a solution for motion preservation, which makes it an attractive option for both surgeons and patients. After receiving approval from the FDA as an alternative to PSF for AIS in 2019,[16] AVBT has recently grown in popularity as a growth-modulation alternative to rigid posterior fixation. Although PSF intentionally attempts to limit subsequent spine growth, AVBT involves thoracoscopic placement of a flexible cord (or tether) on the side of the convexity, leading to asymmetrical compression of the vertebral body growth plates and correction of the scoliosis as the child's spine grows through growth modulation.[5,6,17] In our experience using 3D motion capture technology, we showed that patients who had undergone AVBT experienced significantly less loss of motion in the lumbar spine than the PSF patients at 2 years after surgery.[9] In a recent meta-analysis comparing AVBT with PSF, Shin et al.[18] found that rates of deformity correction, clinical outcomes, and midterm

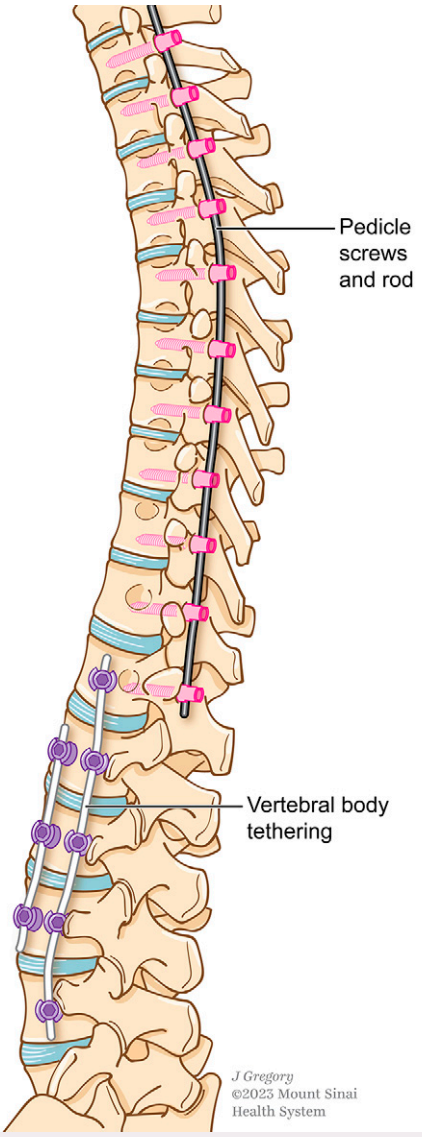

FIG. 1. Illustration of the hybrid fixation technique showing posterior spinal instrumentation with pedicle screws in the thoracic spine and AVBT in the lumbar spine.

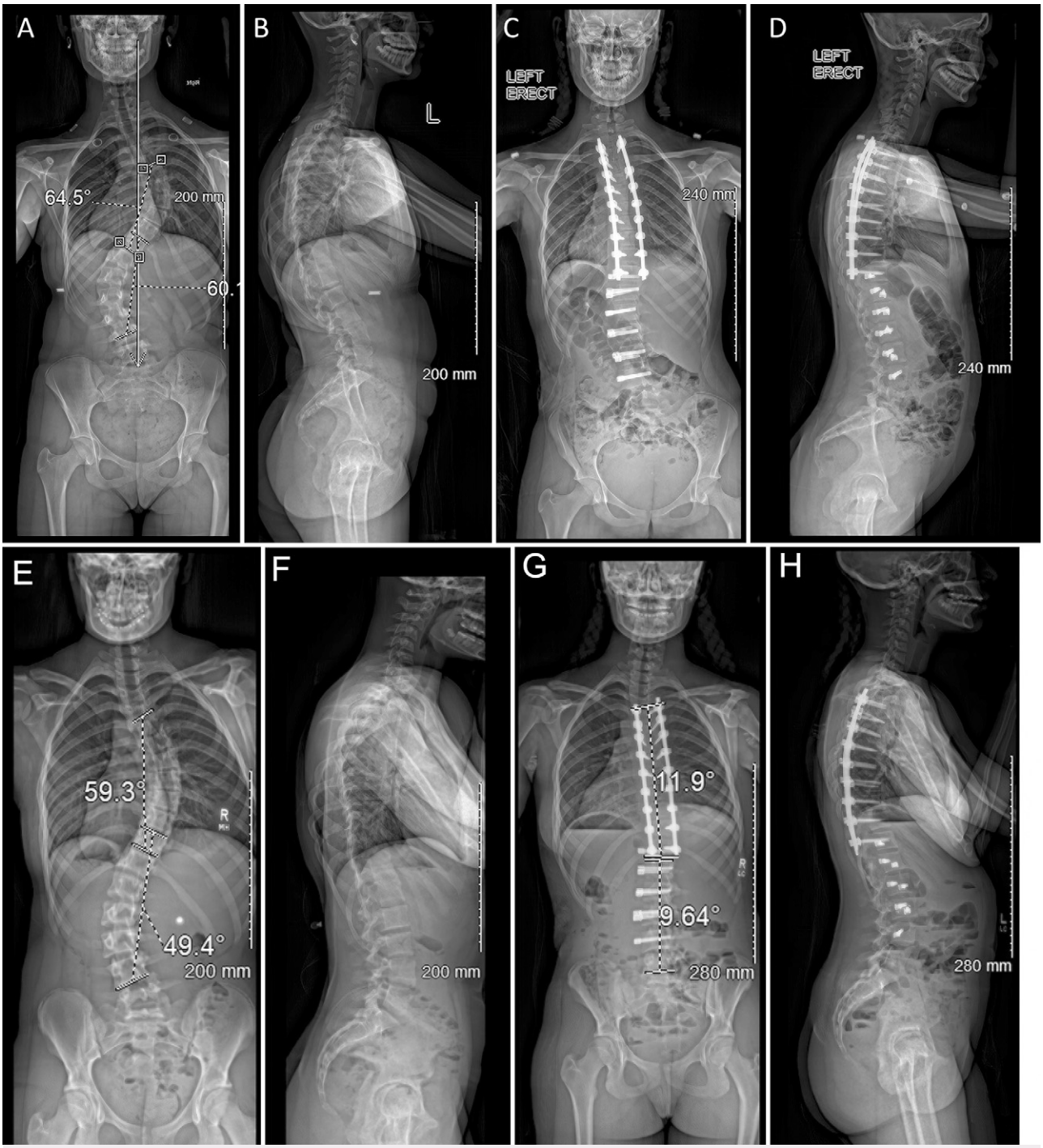

FIG. 2. Posteroanterior (PA; **A**) and lateral (**B**) radiographs obtained in a 14-year-old girl with AIS who presented with a Lenke 3C double major curve. PA (**C**) and lateral (**D**) radiographs obtained after the girl underwent a staged T3–11 PSF and T11–L4 AVBT. PA (**E**) and lateral (**F**) radiographs obtained in a 10-year-old girl with AIS who presented with a Lenke 3C double major curve. PA (**G**) and lateral (**H**) radiographs obtained after the girl underwent a staged T4–12 PSF and T12–L4 AVBT.

22-item Scoliosis Research Society scores were similar between groups. Despite these advantages, AVBT has its limitations and has been shown to have higher rates of complications and reoperations than PSF, with a pooled complication rate of 26% versus 2% in the PSF group.[18] AVBT's most common complications include tether breakages and overcorrection,[18,19] which are not relevant in the PSF group. Large curves, lumbar curves, and rigid curves all increase the risk of tether breakage.[20] While tethering technology continues to improve, surgeons must weigh the benefits of motion preservation with a potentially greater risk of complications and/or reoperation.

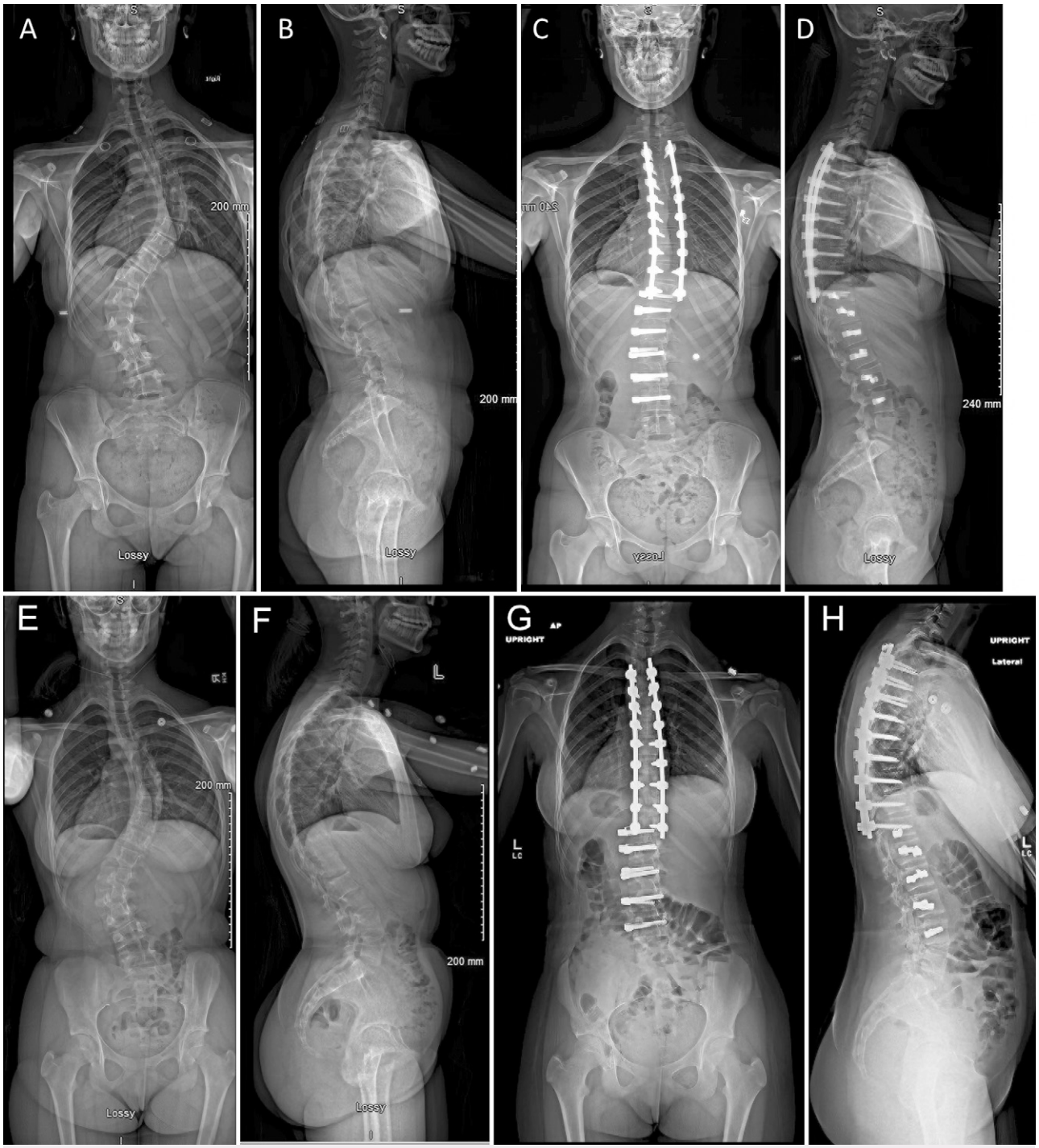

FIG. 3. A–H: Posteroanterior (PA; **A**) and lateral (**B**) radiographs obtained in a 14-year-old girl with AIS who presented with a Lenke 6C double major curve. PA (**C**) and lateral (**D**) radiographs after the girl underwent a staged T1–10 PSF and T10–L4 AVBT. PA (**E**) and lateral (**F**) radiographs obtained in a 14-year-old girl with AIS who presented with a Lenke 6C double major curve. PA (**G**) and lateral (**H**) radiographs obtained after the girl underwent a staged T3–11 PSF and T11–L4 AVBT.

Observations

Given the potential limitations of both PSF and AVBT, a combined approach may offer the benefits of both rigid fixation and motion preservation while minimizing the risk of complications and reoperation. In our series, all patients had PSF through the thoracic curve, with a double tether cord along the lumbar curve (Fig. 1). We overlapped our tether with the LIV of the thoracic PSF. Although traditionally patients with a double curve would undergo rigid

posterior fixation into their lumbar curve, the combined approach allows the use of AVBT for correction of the caudal levels (Figs. 2 and 3). Although tether surgery is aimed at motion preservation, the risk of complications (26% reported in the literature) may not justify the clinically insignificant degree of motion preservation gained in the thoracic spine compared with selective thoracic fusion.[18] However, the greatest loss of motion following curve correction with fusion is in the lumbosacral spine,[9] and, by using a motion-preserving technique throughout this region, the goal is to limit the loss of lumbar mobility while maintaining curve correction through both techniques. This hybrid technique with follow-up data has not been described in the literature; therefore, larger patient samples with longer-term follow-up data will be needed to assess the efficacy of this technique. Current questions remain, such as the impact of rigid fixation at cranial levels on preventing overcorrection of the caudal tethered levels and the degree of motion preservation of hybrid constructs compared with more traditional rigid constructs. We hope to address these issues in subsequent studies. Our current recommendations are to apply selective thoracic fusion level selection principles to the thoracic spine and tether the lumbar curve to the distal end vertebra.

Although our initial experience with this combined technique offers promise, there are limitations to the present study that warrant discussion. Its major limitation is the small sample size. Our institution has performed 20 hybrid approaches to idiopathic double curves over the past 2 years, which limits generalizability to the overall scoliosis population. Another major limitation is the short follow-up, with an average of just 8 months. Although there were no failures or revisions within this short time frame, longer follow-up and further assessment will provide better insight into potential complications or reasons for reoperation as a result of this treatment paradigm. Given the short follow-up, we have not yet answered the question whether the tether will be durable in this hybrid construct. We plan to continue to assess long-term outcomes in these patients as well as continue to explore this therapeutic modality to better understand the role of a combined approach in the treatment of AIS and juvenile idiopathic scoliosis.

Lessons

From our experience with AVBT, we have learned that for most patients with thoracic-only curves, fusion is a better option. Similarly, the preservation of lumbar motion likely has not only benefits with respect to activity but also less degeneration later in life. The combined hybrid procedure—thoracic fusion and lumbar VBT—combines the best of both procedures. With respect to the fusion, it is imperative to impart as much kyphosis as possible to allow the lumbar spine to maximally correct. When performing the lumbar VBT, one must not overtension the proximal or distal ends, because this may induce overcorrection.

In conclusion, the hybrid surgical treatment of idiopathic scoliosis in children is a novel combined technique of PSF in the thoracic spine and AVBT in the lumbar spine. It allows fixed correction of thoracic deformity while preserving motion in the lumbar spine. The initial experience was safe and well tolerated, but further longitudinal studies are warranted to assess the long-term effects of this treatment paradigm.

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Disclosures

Dr. Samdani reported personal fees for consulting from DePuy Synthes Spine, Ethicon, Globus Medical, Medical Device Business Services, Mirus, Orthofix, and Stryker; and personal fees for consulting and royalties from NuVasive and ZimVie outside the submitted work. Dr. Pahys reported personal fees for consulting from DePuy Synthes, NuVasive, and ZimVie outside the submitted work. Dr. Hwang reported shares from Auctus during the conduct of the study and outside the submitted work.

Author Contributions

Conception and design: Samdani, Cherian, Stein, Pahys, Hwang. Acquisition of data: Samdani, Cherian, Stein, Naseer, Nice. Analysis and interpretation of data: Samdani, Cherian, Schüpper, Stein, Naseer, Pahys. Drafting the article: Cherian, Schüpper, Stein, Naseer, Pahys, Nice. Critically revising the article: Samdani, Cherian, Stein, Pahys, Hwang. Reviewed submitted version of manuscript: Samdani, Cherian, Schüpper, Stein, Pahys, Hwang. Approved the final version of the manuscript on behalf of all authors: Samdani. Statistical analysis: Cherian, Schüpper. Study supervision: Samdani, Hwang.

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