Characterizing Anesthetic Management and Perioperative Outcomes Associated with a Novel, Fusionless Scoliosis Surgery in Adolescents

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Anterior vertebral tethering (AVT) is a novel “fusionless” surgical approach to correct scoliosis. This study aims to characterize the anesthetic management and perioperative outcomes of AVT and traditional posterior spinal fusion (PSF) after establishing the technique at our institution. Scoliosis correction procedures performed in patients aged 10 to 21 years between January 2014 and August 2017 were identified in the electronic medical record. Patient characteristics and perioperative data about anesthetic use and pain management were extracted. Descriptive statistics were generated. Thirty-five patients undergoing AVT and 40 patients undergoing PSF met inclusion criteria. Preoperative fluoroscopy-guided epidural placement was used only in the AVT group (86%). The worst pain score on postoperative day (POD) 1 after AVT was a mean (SD) of 5.6 (2.3), with average pain scores on subsequent days ranging from 2.9 (1.2) to 3.6 (1.7). Total in-hospital opioid consumption in morphine milligram equivalents was 70 (76.6) for AVT and 193.4 (137.2) for PSF (P < .01). Discharge occurred on POD 4.4 (1.4) for AVT and POD 6.2 (1.9) for PSF (P < .01). The worst pain score on POD 1 for PSF was 6.6 (2.1), and average pain scores ranged from 3.7 (1.8) to 4.2 (1.8). These results help inform about the expected recovery profile and narcotic requirement after AVT and PSF.

Keywords: Adolescent idiopathic scoliosis, anterior vertebral tethering, pediatric anesthesia, perioperative management, posterior spinal fusion.

adolescent idiopathic scoliosis (AIS) is a progressive lateral curvature and axial rotational deformity of the spine that can lead to substantial morbidity for those affected. It arises in otherwise healthy children around the time of puberty. Epidemiologic studies have shown that AIS affects 1% to 3% of the at-risk adolescent population between ages 10 and 16 years, but only 10% progress to exhibit substantial spinal curvature that requires treatment.1 Left untreated, AIS has been associated with progressive back pain and, if severe, a potential for cardiovascular and pulmonary limitations that affect functionality and self-esteem, especially as individuals age.2-4 If AIS reaches a curvature greater than 40° to 45°, it is commonly treated surgically with the goals of arresting progression and permanent multidimensional curve correction. The most commonly performed procedure, posterior spinal fusion (PSF), is considered major surgery with considerable postoperative pain and a protracted in-hospital recovery course (averaging 4-7 days), delayed return to school, and a prolonged period of restricted physical activity (about 6 weeks).5-8 For both patients and their families, postoperative pain has been reported as the predominant concern voiced before scoliosis surgery.9 The major patient burden associated with PSF for correction of AIS merits further innovation in surgical and perioperative management, with several recent publications reporting improvements in pain scores or hospital length of stay with the use of multimodal analgesic regimens.10,11

Anterior vertebral tethering (AVT) is a newer, fusionless surgical approach developed as an alternative to traditional PSF for curve correction that has demonstrated efficacy and the promise for an improved recovery profile.12-16 The procedure uses small flank incisions, endoscopy, and a synthetic anterior “ligament” fixated to the spine under tension, thereby exerting traction force to correct the scoliotic curve and axial rotation. The underlying principle is to redirect the inherent spinal growth in adolescents with scoliosis, to achieve correction, and to halt progression of the scoliotic deformity.17 Although long-term surgical outcomes are currently pending evaluation, early outcomes have been promising.15,16 There is, to date, a paucity of literature addressing the immediate and early postoperative recovery profile of this novel technique. A recent publication is the first to detail a single-institution experience with
perioperative management of AVT, reporting in detail the authors’ use of a multimodal analgesia protocol to achieve adequate pain control.13 Because of the novelty of the procedure, however, it is unclear how this experience compares with both the experience at other institutions and the conventional surgical alternative of PSF.

At our institution, the same spine surgeon (J.T.B.) routinely performs PSF and AVT procedures, offering a unique opportunity to study management and outcomes of the 2 approaches side-by-side. However, AVT is a novel procedure and thus less likely to be offered to more complicated surgical candidates. The purpose of this study is to describe the perioperative characteristics of patients undergoing AVT and PSF at our institution (aim 1) and to evaluate short-term outcomes (length of stay, in-hospital opioid consumption, postoperative pain) after each procedure (aim 2). We hope that by reporting both AVT and PSF outcomes, we can provide a familiar context for providers unfamiliar with AVT.

Materials and Methods

This retrospective cohort study was approved by the institutional review board of Dartmouth-Hitchcock Medical Center, Lebanon, New Hampshire (STUDY00030212). Informed consent for study data collection was waived because of the study's retrospective nature and minimal risk to participants.

- **Anterior Vertebral Tethering Technique.** For AVT at our institution, patients are placed in a lateral decubitus position to allow access to the convexity of the scoliotic curve. The chest is entered endoscopically, typically with lung isolation and deflation of the ipsilateral lung via a double-lumen endotracheal tube or endobronchial blocker (Arndt Endobronchial Blocker, Cook Medical Inc), facilitating anterior surgical access to the spine. For thoracolumbar and lumbar curves, a small flank incision is made for retroperitoneal access. A synthetic ligament (Dynesys Dynamic Stabilization System, Zimmer Spine) is then secured to each of the affected vertebrae with vertebral body screws using fluoroscopic guidance. The ligament is attached to the screws and then tensioned between pairs of screws to achieve correctional force.

- **Patient Allocation, Anesthetic Care, and Pain Management.** Allocation to AVT was performed by the spine surgeon (J.T.B.) after careful consideration of candidacy for the novel technique in conjunction with patients and families. Factors considered included skeletal maturity and complexity of the scoliotic curve. Patients and families had the right to decline the novel procedure. In practice, some patients presented to our institution hoping to be candidates for the novel technique.

  Perioperative management of patients undergoing AVT routinely included fluoroscopic-guided epidural placement using an epidural catheter (21G Portex Nylon Epidural Catheter, Smiths Medical), general anesthesia with a total intravenous anesthesia (TIVA) regimen, and endotracheal intubation with a double-lumen tube for cases requiring lung isolation during the procedure. Arterial access was not routinely obtained. Somatosensory and motor evoked potential monitoring was conducted for every procedure. Adequate blood pressure was maintained with fluid administration and vasopressor (phenylephrine) infusion at the discretion of the anesthesia care team. The epidural infusion was started during wound closure, after completion of motor evoked potential monitoring. Postoperatively, the acute pain service managed the epidural infusion with a local anesthetic-opioid solution.

  Patients undergoing PSF were also managed with TIVA, but postoperative pain control usually was achieved with opioid patient-controlled anesthesia because of the difficulty of obtaining reliable epidural analgesia in this patient population18,19 and the surgeon's preference to avoid epidural analgesia for these patients. For both groups, adjuncts such as scheduled acetaminophen and ketorolac, and as needed medications such as diazepam or methocarbamol, were used.

- **Data Collection.** All patients aged 10 to 21 years having undergone scoliosis surgery at our institution by the same spine surgeon (J.T.B.) between January 1, 2014, and August 31, 2017, were identified. Because the novel surgical technique described in this study does not have a designated Current Procedural Terminology (CPT) code, we conducted a search by CPT code for spinal instrumentation (22840, 22841, 22842, 22843, 22844, 22845, 22846, 22847), osteotomy (22206, 22207, 22212), arthrodesis (22800, 22802, 22804, 22806, 22808, 22812), anterior or anterolateral approach of thoracic and lumbar spine (22556, 22528), and other procedures on the spine (22899). Patients who did not undergo either AVT or PSF were excluded from data collected. The excluded cohort received predominantly anterior fusions, combined anterior-posterior fusions, revision surgery, or hardware removal. Hybrid procedures with anterior tethering for the thoracic levels and posterior fusion for the lumbar levels were also excluded.

  For all remaining patients, the following demographic and clinical patient characteristics were collected from the electronic medical record: age, weight, height, gender, race/ethnicity, comorbidities as defined in the Elixhauser Comorbidity Index,20 and ASA physical status classification. Surgical and scoliosis data extracted consisted of procedure type, number of segments fused or tethered, preoperative Cobb angle, chest tube placement, complications, and discharge day. Data were also collected related to the anesthetic and postoperative pain management (maintenance agents, anesthesia duration, lung isolation technique, fluid balance, transfusion of blood products, agents used for anesthetic maintenance, epidural medications, length of postoperative epidural...
infusion, total postoperative systemic opioid requirement, and treatment of nausea and vomiting. Pain scores were recorded by nurses with an alphanumeric visual analog scale ranging from 0 to 10 and with the Face, Legs, Activity, Cry, Consolability (FLACC) score when appropriate. Per our institutional protocol, pain scores were documented at intervals every shift, each time a nurse was called for pain, and after interventions were administered to address pain. For data analysis, consideration was given to the highest pain score for postoperative day (POD) 0 and POD 1 because management of “worst pain” is important to the patient experience, and to average reported pain scores for POD 1 to 4.

**Data Analysis.** Perioperative management and early outcomes of AVT and PSF surgery were described by reporting intraoperative and postoperative data. These metrics included estimated blood loss, highest postoperative pain score on the day of the operation (POD 0) and POD 1; average pain scores on POD 1 through 4; antiemetic medication administration as an indicator of nausea and vomiting; postoperative fluid bolus administration as a marker of clinically relevant hypotension; discharge day; total in-hospital opioid consumption; and postoperative complications. Complications were composite outcome of surgical site infection, perioperative skin injury due to pressure or burn, need for revision surgery within 30 days, persistent intraoperative neurologic deficit, postoperative neurologic deficit, severe atelectasis, and other. The total opioid consumption was calculated by converting all postoperatively administered intravenous and oral opioids to morphine milligram equivalents and adding the total morphine milligram equivalents for the first 5 postoperative hospital days.

Data in this study were summarized and analyzed using statistical software (Stata Release 15, StataCorp). Categorical data were summarized as proportions, and continuous data as mean with standard deviation (SD). Categorical and binary measures were compared using $\chi^2$ analyses, whereas continuous measures were compared using 2-sample Student $t$ test.

**Results**

For both groups, patient characteristics are summarized in Table 1, and Table 2 displays intraoperative data as well as postoperative pain ratings and opioid requirements.

**Anterior Vertebral Tethering.** During the study period, 35 patients underwent AVT surgery. Intraoperative anesthetic maintenance was achieved with propofol/
remifentanil TIVA for all patients. Lung isolation was performed for 21 (60%) of the patients with a double-lumen tube, and with a bronchial blocker for 1 (2.9%). Vasopressor infusion (phenylephrine) was necessary in 16 patients (46%) to maintain adequate blood pressure. Thirty patients (86%) had a magnetic resonance imaging (MRI)-compatible epidural catheter placed preoperatively under fluoroscopic guidance. Catheter placement was attempted but aborted in 1 patient because of an inability to achieve correct epidural placement on imaging. The epidural infusion was started before skin closure in 26 patients (87%) and postoperatively in the remaining 4 patients (13%). Bupivacaine (0.125%) with clonidine, 1 μg/mL, and fentanyl, 2 μg/mL, was the most commonly used regimen and was administered to 20 (67%) of the patients with epidural anesthesia. The next most common regimen was 0.125% bupivacaine with fentanyl, 2 μg/mL, which was administered to 8 patients (27%); other regimens were used in 2 patients (6%).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>AVT (N = 35)</th>
<th>PSF (N = 40)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal segments tethered, mean No. (SD)</td>
<td>6.8 (2.0)</td>
<td>11.6 (2.2)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Anesthesia duration, mean (SD), min</td>
<td>409 (110)</td>
<td>546.5 (78.6)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>TIVA technique, No. (%)</td>
<td>35 (100)</td>
<td>40 (100)</td>
<td>.563</td>
</tr>
<tr>
<td>Lung isolation, No. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-lumen tube</td>
<td>21 (60)</td>
<td>0 (0)</td>
<td>.070</td>
</tr>
<tr>
<td>Bronchial blocker</td>
<td>1 (2.9)</td>
<td>0 (0)</td>
<td>.563</td>
</tr>
<tr>
<td>Estimated blood loss, mean (SD), mL</td>
<td>141 (118)</td>
<td>758.6 (253.5)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Crystalloid administered, mean (SD), mL</td>
<td>2,379 (1,092)</td>
<td>4,002.5 (1,379.1)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Colloid administered, mean (SD), mL</td>
<td>71.4 (378)</td>
<td>71.4 (239)</td>
<td>.070</td>
</tr>
<tr>
<td>Heterologous blood transfusion, No. (%)</td>
<td>0 (0)</td>
<td>5 (12.5)</td>
<td>NA</td>
</tr>
<tr>
<td>Surgical complication, No. (%)</td>
<td>7 (16)</td>
<td>9 (22.5)</td>
<td>.563</td>
</tr>
<tr>
<td>Epidural catheter placed, No. (%)</td>
<td>30 (86)</td>
<td>0 (0)</td>
<td>NA</td>
</tr>
<tr>
<td>Postoperative analgesic adjunct, No. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetaminophen</td>
<td>34 (97)</td>
<td>38 (95)</td>
<td>.637</td>
</tr>
<tr>
<td>Ketorolac</td>
<td>24 (69)</td>
<td>4 (10)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Benzodiazepine</td>
<td>13 (37)</td>
<td>33 (82.5)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Gabapentin</td>
<td>3 (9)</td>
<td>2 (5)</td>
<td>.383</td>
</tr>
<tr>
<td>Postoperative antiemetic, No. (%)</td>
<td>27 (77)</td>
<td>33 (82.5)</td>
<td>.563</td>
</tr>
<tr>
<td>Worst pain, mean (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On POD 0</td>
<td>6.5 (2.3)</td>
<td>6.7 (2.5)</td>
<td>.766</td>
</tr>
<tr>
<td>On POD 1</td>
<td>5.6 (2.3)</td>
<td>6.6 (2.1)</td>
<td>.052</td>
</tr>
<tr>
<td>Average pain, mean (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On POD 0</td>
<td>6.5 (2.3)</td>
<td>6.7 (2.5)</td>
<td>.766</td>
</tr>
<tr>
<td>On POD 1</td>
<td>5.6 (2.3)</td>
<td>6.6 (2.1)</td>
<td>.052</td>
</tr>
<tr>
<td>On POD 2</td>
<td>3.9 (1.2)</td>
<td>4.2 (1.8)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>On POD 3</td>
<td>3.5 (1.2)</td>
<td>3.8 (1.8)</td>
<td>.309</td>
</tr>
<tr>
<td>On POD 4</td>
<td>3.6 (1.7)</td>
<td>4.1 (1.8)</td>
<td>.204</td>
</tr>
<tr>
<td>Total in-hospital opioid consumption in morphine equivalents, mean (SD), mg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge on POD, mean (SD)</td>
<td>4.4 (1.4)</td>
<td>6.2 (1.9)</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Table 2. Operative and Postoperative Characteristics of Patients Undergoing Anterior Vertebral Tethering or Posterior Spinal Fusion

Abbreviations: AVT, anterior vertebral tethering; NA, not applicable; POD, postoperative day; PSF, posterior spinal fusion; TIVA, total intravenous anesthesia.

aCategorical data were summarized as proportions, and continuous data as mean with standard deviation (SD). Categorical and binary measures were compared using χ² analyses, and continuous measures were compared using 2-sample Student t test.

bComposite outcome of surgical site infection, perioperative skin injury due to pressure or burn, need for revision surgery within 30 days, persistent intraoperative neurologic deficit, postoperative neurologic deficit, severe atelectasis, and other.
was 70 (77) mg. Hospital discharge occurred on POD 4.4 (1.4), on average.

• Posterior Spinal Fusion. During the study period, PSF was performed in 40 patients. This patient cohort was similar to the AVT cohort in most measures. However, patients undergoing PSF exhibited a higher Elixhauser Comorbidity Index (0.9 vs 0.4, \(P = .006\)). Despite this, the ASA physical status was similar between study groups (\(P = .524\)). All patients undergoing PSF received TIVA. Neuraxial analgesia and lung isolation were not used. As shown in Table 2, patients undergoing PSF underwent longer procedures involving more spinal segments, which were associated with larger blood loss and more fluid administration.

Reported worst pain scores were 6.7 (2.5) and 6.6 (2.1) on POD 0 and 1, respectively. Average postoperative pain scores during the hospital stay ranged from 3.7 (1.8) on POD 1 to 4.2 (1.8) on POD3 (see Figure). Total postoperative opioid consumption was 193 (137) mg for PSF and 70 (77) mg for AVT (\(P < .001\)). Discharge from the hospital occurred on POD 6.2 (1.9) in the PSF group vs 4.4 (1.4) in the AVT group (\(P < .001\)).

Discussion

This case series details the perioperative course of adolescents undergoing either a novel, fusionless scoliosis operation (AVT) or traditional PSF at the same institution. We documented adequate pain control in both groups, with AVT patients requiring significantly less total opioid and exhibiting a shorter hospital length of stay. Differences in anesthetic and surgical factors exist between the AVT and PSF cohorts in the present retrospective study. Compared with patients undergoing traditional PSF, the novel surgery was performed in slightly healthier patients undergoing less extensive corrections. It was therefore not surprising that we found longer procedure duration, larger blood loss, and higher fluid administration for the PSF cohort. In addition, the use of neuraxial analgesia for just the AVT cohort is a crucial difference. These factors likely confounded our main outcomes of interest, including postoperative pain control, opioid consumption, and length of stay. Unfortunately, the low case numbers at this time preclude multivariate analyses to adjust for confounders. Moreover, prospective multicenter trials powered by large sample size to adequately control for confounders are difficult to carry out because of limited case numbers and differences in operative technique and postoperative management between institutions. Despite these limitations, the 3-fold difference in opioid consumption between AVT and patients undergoing PSF in the present study is striking. Reducing opioid use in adolescents is in itself a desirable goal, and the present case series documents adequate pain control with relatively little opioid use in our patients after AVT procedures.

The present study adds to the growing body of literature on AVT as a novel technique for the treatment of scoliosis. Anterior vertebral tethering allows for avoidance of rod instrumentation and fusion by using small incisions and endoscopy-assisted placement of a synthetic ligamentous “spinal tether.” Results of the available published studies consistently report shorter postoperative in-hospital length of stay and lower postoperative pain, but considerable variation exists in patient populations, surgical techniques, and analgesic regimens. A 2017 study by Gal et al10 describes, in great detail the perioperative multimodal analgesia protocol used at the authors’ institution, which consists of an opioid solution delivered via epidural catheter; perioperative gabapentin, acetaminophen, nonsteroidal anti-inflammatory agents, intraoperative methadone and ketamine; and injection of liposomal bupivacaine around the thoracic incisions. Reported postoperative pain scores were globally lower for their patients compared with the study population in the present study. However, total opioid consumption was not reported. Hospital discharge in their study population (mean and SD) occurred after 5.28 (1.82) days for unilateral AVT and 6.38 (1.60) days for bilateral AVT, in both cases longer than the average length of postoperative stay found with AVT in the present study. Another important differentiating factor between respective AVT populations is the present study’s use of fluoroscopically-guided, MRI-compatible epidural placement with local anesthetic/opioid infusion postoperatively, which may have contributed to findings of relatively shorter clinical recovery periods and earlier discharge. The comparatively higher pain scores reported in the present study may be partially attributed to variations in institutional culture.
and practice in pain score reporting by nursing staff and patient expectations. It should also be noted that published pain scores after scoliosis surgery have been shown to vary widely between institutions. Although beyond the scope of this retrospective study, it is possible that development of a multimodal analgesic protocol for patients undergoing PSF and AVT could further improve pain control at our institution.

In summary, this case series describes anesthesia and postoperative management for AIS at a single institution that performs 2 distinctly different interventions for surgical correction. The data presented suggest that patients undergoing AVT with neuraxial analgesia require less opioid administration than patients undergoing PSF and may be discharged sooner. Although limited by several differences between the cohorts, our findings can inform both spine surgeons and their patients about the expected recovery profile and the likely decreased postoperative opioid requirement associated with AVT and serve as a baseline for future adjustments to perioperative care.

REFERENCES


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