Use of sub–transverse process polyester bands in pediatric spine surgery: a case series of 4 patients with a minimum of 12 months' follow-up

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OBJECTIVE In a previous study, the authors reported on their experience with the use of sublaminar polyester bands as part of segmental spinal constructs. However, the risk of neurological complications with sublaminar passage of instrumentation, such as spinal cord injury, limits the use of this technique. The present study reports the novel use of sub–transverse process polyester bands in posterior instrumented spinal fusions of the thoracic and lumbar spines and sacrum or ilium in 4 patients.

METHODS The authors retrospectively reviewed the demographic and procedural data of patients who had undergone posterior instrumented fusion using sub–transverse process polyester bands.

RESULTS Four patients, ranging in age from 11 to 22 years, underwent posterior instrumented fusion for neuromuscular scoliosis (3 patients) and thoracic hyperkyphosis (1 patient). There were 3 instances of transverse process fracture, with application and tensioning of the polyester band in 1 patient. Importantly, there was no instance of spinal cord injury with sub–transverse process passage of the polyester band. The lessons learned from this technique are discussed.

CONCLUSIONS This study has shown the “Eleghia” technique of passing sub–transverse process bands to be a technically straightforward and neurologically safe method of spinal fixation. Pedicle screws, laminar/pedicle/transverse process hooks, and sublaminar metal wires/bands have been incorporated into posterior spinal constructs; they have been widely reported and used in the thoracic and lumbar spines and sacrum or ilium with varying success. This report demonstrates the promising results of hybrid posterior spinal constructs that include the Eleghia technique of passing sub–transverse process polyester bands. This technique incorporates technical ease with minimal risk of neurological injury and biomechanical stability.

<http://thejns.org/doi/abs/10.3171/2015.6.PEDS15255>

KEY WORDS pediatric spine; spine surgery; spinal instrumentation; sub–transverse process polyester bands

LAMINAR hooks, pedicle screws, and sublaminar wires made of stainless steel, titanium alloys, or cobalt chromium alloys have been used to varying degrees of success as anchors, or fixation points, in the instrumented fusion of the pediatric spine. There are strengths and weaknesses to each of these modalities of fixation to bone. The ideal device should meld the technical ease of sublaminar

wires, the adaptability of hooks, and the biomechanical stability of screws, while remaining neurologically safe.

Apical sublaminar wires and pedicle screw instrumentation offer similar outcomes in terms of degree of deformity correction.³ When compared with sublaminar wire/hook constructs and hybrid wire/hook/screw constructs, an all-pedicle-screw construct did not have a significant

ABBREVIATIONS MEP = motor evoked potential; SSEP = somatosensory evoked potential.

SUBMITTED April 24, 2015. **ACCEPTED** June 17, 2015.

INCLUDE WHEN CITING Published online October 30, 2015; DOI: 10.3171/2015.6.PEDS15255.

advantage for enhancement of deformity correction.²² In weak or skeletally immature bone, laminar hooks demonstrated a better pull-out profile than pedicle screws⁵; moreover, not all patients are anatomically suited for hook or pedicle-screw implantation. Therefore, no one construct type has been shown to be superior to others.

We previously reported on the successful treatment of pediatric patients who had undergone posterior instrumented fusion with hybrid hook/screw/sublaminar polyester-band constructs.⁷ However, unacceptable neurological morbidity, such as spinal cord injury, limits the use of sublaminar instrumentation, including the polyester band.^{2,4,6,13,20,24}

An alternative technique is sub-transverse process passage of the spinal instrumentation, such as metal wires¹⁴ and polyester bands, which seems to be a technically straightforward and neurologically safe method. In this study, our aim was to demonstrate the advantages of sub-transverse process polyester bands over sublaminar polyester bands. Biomechanical and clinical studies in the literature that compare different types of sublaminar wiring and sub-transverse process wiring exist.^{1,8,9} However, to the best of our knowledge, no prior studies have described the “Eleghia” technique of sub-transverse process passage of polyester bands for spinal fixation.

Methods

Patient Population

We retrospectively reviewed the records of 4 consecutive patients who were taken to the operating room for posterior instrumented spinal fusions by the neuro-spine service at Texas Children’s Hospital between January and April 2014 (Table 1). Preoperative radiographs, CT scans, and MR images were obtained in all patients. Postoperative radiographs and CT scans of the spine were obtained in all patients at a minimum of 12 months of follow-up.

Surgical Technique

All patients were placed in the prone position after in-

tubation. Older patients (age 8 years or older) were placed on a Jackson operating table (Orthopedic Systems Inc.), whereas younger patients (age less than 8 years) were placed on a standard operating room table, with chest bolsters and a foam pillow. Neurophysiological monitoring was used for all cases; baseline parameters for motor evoked potentials (MEPs) and somatosensory evoked potentials (SSEPs) for the lower extremities were recorded prior to skin incision. The posterior thoracic and lumbar spines and sacrum or ilium were exposed in the usual manner. Entry points for pedicle screws were prepared. Pedicle screws and laminar hooks (Legacy, Medtronic Sofamor Danek) were implanted in the usual way.

Polyester bands (Universal Clamp, Zimmer Inc.) were used bilaterally in the thoracic spine (T1–12) via the Eleghia technique. The malleable metal end of the polyester band was shaped into a gentle curve for passage between the transverse process and the rib head (Fig. 1). The polyester band was placed under the transverse process by passing near the lateral end of the transverse process in the costovertebral junction. The tip of the band then was gripped with hemostats or forceps, and the rest of the passage followed a push-pull technique, drawing through the middle part between the transverse process and the rib head. The band should rest at the confluence of the transverse process, pedicle, lamina, and superior articulating process. If a transverse process was not strong enough to hold the polyester band (usually below T-10), then the level was omitted from the construct.

Sublaminar polyester bands were placed caudal to the level of the conus to L-5. There is a smaller risk of neurological injury in this region below the conus with sublaminar instrumentation.

Osteotomies, as required by the particular case and spinal deformity, were performed prior to securing the 5.5-mm-diameter titanium rods to the laminar hooks and pedicle screws. The sub-transverse process polyester band was attached to the contralateral rod with a titanium alloy clamp and locking screw (Fig. 2). The sublaminar polyester band was attached to the ipsilateral rod. Reduction ma-

TABLE 1. Summary of demographic and procedural data in 4 pediatric patients with hybrid spinal constructs using sub-transverse process polyester bands

Pt No.	Age (yrs), Sex	Etiology	Op	Anchors	Length of Op (hrs)	EBL (ml)	Complications	FU (mos)
1	11, F	Thoracic hyperkyphosis	T2–L1 pst instrumented fusion	Sublaminar hooks: T-2, T-3; subtransverse bands: T-4, T-8, T-9, T-10; pedicle screws: T-11, T-12, L-1	9.5	500	None	16
2	18, M	Neuromuscular scoliosis	T2–ilium pst instrumented fusion	Sublaminar hooks: T-2, T-3; subtransverse bands: T4–10; pedicle screws: T-11, T-12, L-1; iliac screws	8	700	T10–12 rt transverse process fracture	15
3	12, F	Neuromuscular scoliosis	C2–ilium pst instrumented fusion	Pars screws: C-2; lat mass screws: C3–6; subtransverse bands: T1–12; iliac screws	9	450	None	12
4	22, F	Neuromuscular scoliosis	T2–ilium instrumented fusion	Sublaminar hooks: T-2, T-3; subtransverse bands: T4–10; sublaminar bands: T-11, T-12, L-1, L-4, L-5; iliac screws	10	1200	None	12

EBL = estimated blood loss; FU = follow-up; pst = posterior; Pt = patient.

FIG. 1. Artist's illustration demonstrating the Eleghia technique of passage of a sub-transverse process polyester band. Copyright Katherine Relyea. Published with permission.

neurosurgeons starting at the apex on the concave side were performed by the sequential tightening of each band/clamp implant against the transverse process or lamina and rod with a tensioner supplied by the manufacturer. The tensioner has a ratchet-driven, spring-loaded shaft that puts tension on the polyester band. The band is formed into a loop and placed onto a stump on the reduction tool. The handle is pressed against the shaft, which ratchets up the distal portion of the cylinder and progressively sets the band tension. A scale on the side of the tensioner displays the polyester band tension. A torque of 6–12 inch-pounds is usually achieved, which is sufficient to attain reduction and stabilization.

Arthrodesis was performed with local autograft, morselized cancellous allograft, and bone morphogenetic protein in all cases (Infuse, Medtronic Sofamor Danek) after proper decortication. No bone harvest from other sites was performed.

This study received approval from the Baylor College of Medicine institutional review board.

Illustrative Case

History and Examination

Neurosurgery was consulted for a 12-year-old girl with a significant medical history of perinatal hypoxia-ischemia, static encephalopathy, global developmental delay, spasticity, and seizure disorder, who was found to have progressive neuromuscular scoliosis. The patient had pre-

FIG. 2. Intraoperative photograph showing the final configuration of the crossing sub-transverse process polyester attached to rods. Figure is available in color online only.

viously undergone surgery for vagus nerve stimulator and baclofen pump placement to address her intractable epilepsy and spasticity, respectively. Radiographs showed an S-shaped curve, with the thoracic curve toward the right with a Cobb angle of 75° and the lumbar curve toward the left with a Cobb angle of 86°. There was also a profound thoracic kyphosis with a Cobb angle of 106° (Fig. 3). Neurological examination demonstrated severe developmental delay. The patient was awake and alert, with limited interaction secondary to her developmental delay. She could occasionally vocalize but produced no recognizable words. She used a communication board for simple commands. The patient was nonambulatory and wheelchair bound but was able to reach with her right hand and exhibited a poor grasp.

No abnormalities were seen on CT, and MRI showed no abnormalities in the spinal cord. It was noted on preoperative CT scans that, although the transverse processes at T-10, T-11, and T-12 seemed to be smaller than thoracic transverse processes at more proximal levels, they appeared to be of sufficient size to accept placement of a polyester band. Furthermore, the baclofen pump catheter entered the thecal sac at the L3–4 interlaminar space. On preoperative MRI, the conus was positioned between the L-1 and L-2 levels. Therefore, after careful study of the preoperative imaging, we planned to place sublaminar bands at L-2 and L-5, below the level of the conus and avoiding the laminae (L-3 and L-4) adjacent to the baclofen pump catheter. Because of the patient's poor head and neck control and the subsequent high risk of proximal junction kyphosis if the spinal construct was prematurely stopped in the upper thoracic spine, the surgical plan called for a C2–ilium posterior instrumented fusion to stabilize and reduce her spinal deformity.

Operation

After proper identification procedures, the patient was positioned, given general anesthesia, and intubated. Somatosensory evoked responses and motor evoked re-

FIG. 3. Case 3. **A–B:** Upright preoperative anteroposterior (AP) scoliosis (A) radiograph and upright preoperative lateral scoliosis radiograph (B) demonstrating a 75° thoracic curvature, 86° lumbar curvature, and 106° thoracic kyphosis. **C–D:** Upright postoperative AP scoliosis radiograph (C) and upright postoperative lateral scoliosis radiograph (D) obtained 12 months after surgery showing modest improvement and reduction of the scoliosis (43° thoracic curvature and 73° lumbar curvature) and kyphosis (86° thoracic kyphosis). **E:** Parasagittal CT scan of the spine obtained 12 months after surgery demonstrating solid bony fusion.

spones were measured via needle electrodes placed in the upper and lower extremities. Baseline electrophysiological parameters were recorded; there were no reproducible signals from the lower extremities.

Exposure of bone of the posterior elements of the spinal column from C-2 to the ilium was achieved. Bilateral iliac screws were placed with fluoroscopy guidance. Laminae were created at L1–2, L2–3, L4–5, and L5–S1 for passage of sublaminar polyester bands. The L3–4 interlaminar space, where the baclofen pump catheter entered the thecal space, was avoided to prevent inadvertent dislodgement or injury to the catheter.

The space between the transverse process and rib head at each thoracic level was then developed with a curved instrument, such as a hook starter. Care was taken to avoid fracturing the transverse process and losing a segmental point of fixation by creating an intraosseous defect with the hook starter. Sub-transverse process bands were passed from caudal to rostral around the thoracic transverse processes.

C-2 pars screws and C-3, C-4, C-5, and C-6 lateral mass screws were placed bilaterally. The cervical screws were connected with a contoured 3.5-mm-diameter rod on each side, and the thoracic, lumbar, and iliac points of fixation were connected with a contoured 5.5-mm-diameter rod on each side. The adjacent 3.5- and 5.5-mm-diameter rods were secured together with a domino connector. Two cross-links were installed to create a rigid frame and countertraction against which tensioning of the polyester bands could be performed. This configuration of the spinal instrumentation allowed us to translate the curved spine toward the relatively straighter rods and effect a reduction of the spinal deformity. All connections were final tightened. Excess polyester band was truncated, leaving approximately 1 cm of material from the clamp/rod interface.

Bone graft material was placed over the exposed de-

corticated bone surfaces from C-2 to the ilium. Local autograft was harvested from the spinous processes from T-1 to L-5. This was supplemented with bone morphogenetic protein and 60 ml of morselized allograft mixed with demineralized bone matrix putty. Vancomycin powder and irrigation was used during closure, and a Hemovac drain was placed.

Postoperative Course

The patient had an unremarkable hospital course and was discharged 6 days after surgery. At 12 months after surgery, the patient continued to do well. There had been no change in neurological status. The parents had been pleased with her new posture and sitting balance. CT scan of the spine at 1 year after surgery demonstrated solid bony fusion with no evidence of loss of spinal alignment nor instrumentation failure (Figs. 3C–E).

Results

All 4 patients underwent operative treatment. No long-term complications have arisen in any of these 4 patients, and postoperative stability and alignment were maintained in long-term follow-up (mean 13.8 months, range 12–16 months). All patients underwent postoperative imaging during the follow-up period, consisting of spine radiographs and CT scans. There was no evidence of pseudarthrosis, instability, or hardware failure in any patient during follow-up, and fusion was achieved in these cases (Fig. 3).

Sixty polyester bands in 4 patients were passed around transverse processes. There were 3 instances of transverse process fracture in 1 patient with passage of the polyester band or overzealous tensioning of the polyester band against bone. These fractures occurred at or below T-10: at T-10 (1 fracture), T-11 (1 fracture), and T-12 (1 fracture).

Discussion

Polyester Bands

Sublaminar polyester bands, with a locking mechanism to provide rod coupling, were developed as an alternative to traditional anchors: wires, hooks, and screws.^{7,15,16} The material properties of polyester are characterized by its high tensile strength; high resistance to stretch, wet or dry; and resistance to degradation.¹⁹ Polyester is biocompatible without an exorbitant inflammatory reaction in surrounding tissue, including the dura. In Europe, polyester has been in use for more than 25 years in spinal implants (K. Mazda, personal communication, 2014). Abbot Spine (now Zimmer Inc.) developed the first modern interspinous device, the Wallis system, in 1986; it was in widespread use in Europe before interspinous spacers became popular in the United States. This device was used primarily for patients with recurrent disc herniation and was composed of a titanium spacer placed between spinous processes and secured with 2 polyester bands wrapped around the spinous processes.¹⁰

Polyester's woven fabric makes it gentle, and flexible polyester bands are an excellent alternative to implantation into the pediatric spine. This is most applicable when the anatomy either is too extraordinarily small to accept hooks or screws or is marked by significant congenital structural abnormalities. The polyester bands and locking mechanism to the rod may be placed at multiple levels, similar to wires, hooks, and screws, to effect segmental control, reduction, and fusion.

Biomechanical studies^{11,12} have compared the pull-out strength of the sublaminar polyester banding with sublaminar wiring, laminar hooks, interspinous spacers, and pedicle screws. The mean failure load of the pedicle screw group was significantly higher than that of the sublaminar banding, sublaminar wiring, laminar hooks, and interspinous spacers. Only the pedicle screw had a statistically higher failure load than the sublaminar polyester band technique. Therefore, sublaminar polyester banding compared favorably to the traditional methods of sublaminar wires and laminar hooks and, thus, should be considered as an alternative anchor in the spine.

Nevertheless, high risk of neurological injuries limits the use of this technique—even a single case of neurological injury from sublaminar instrumentation is one too many. Neurological complications may occur intraoperatively during passage of the sublaminar polyester band or postoperatively because of spinal cord edema, peridural fibrosis, and epidural hematoma caused by disruption of the epidural venous plexus; the complications rate is 1%–15%.^{1,2,13,24} Thompson et al. found more neurological injuries than expected in their series of patients with sublaminar wiring methods, and, reportedly, the main reason was inexperience.²¹ Many intraoperative complications have been seen with the use of sublaminar wires, including dural laceration, CSF leak, and epidural, subdural, or intramedullary hemorrhage.¹ Peridural fibrosis, migration secondary to wire breakage, and difficulties in removing sublaminar wires due to epidural scarring and fibrosis under the lamina are examples of reported postoperative complications.¹ Transient dysesthesia syndrome was re-

ported as a frequent complication in the postoperative period for patients who had undergone sublaminar wiring.^{1,18} This complication has also been documented in our series of sublaminar polyester-band patients, as seen in our case illustration and our previous report.⁷ Reames et al. found that anterior screw and wire-only constructs were associated with significantly higher rates of new neurological injury, as compared with pedicle screw-only and hook-only constructs.¹⁷

The Eleghia Technique

Because of the high risk of neurological complications with use of the sublaminar polyester band technique, we studied an alternative method for segmental spinal instrumentation—the Eleghia technique—for sub-transverse process polyester bands. The Eleghia technique was named after a patient who changed the way we approach spine surgery. In this index case, our 14-year-old patient with cerebral palsy and progressive neuromuscular scoliosis had undergone a hybrid spinal construct from T-3 to the ilium to reduce and stabilize her spinal deformity. During passage of a sublaminar polyester band at T-11, there was a loss of intraoperative electrophysiological potentials. The surgery was aborted when there was no return in MEP and SSEP. Immediately after surgery, the patient demonstrated clonus, hyperreflexia, and lack of movement or grimace in response to painful stimuli in the bilateral lower extremities.

In our case series, we present 4 surgical cases that used the Eleghia technique (Table 1). The patient in Case 1 underwent a T2–L1 posterior instrumented fusion with sub-transverse process bands at T-4 and T8–10 for thoracic hyperkyphosis. At 16 months' follow-up, the patient was grossly neurologically intact without back or neck pain, leg weakness, or bowel or bladder dysfunction. The patient in Case 2 underwent T2–ilium posterior instrumented fusion with sub-transverse process bands at T4–10 for neuromuscular scoliosis. During the operation, right T-10 through T-12 transverse processes fractures occurred due to osteoporosis and the small size of these transverse processes, which are typically seen at the caudal end of the thoracic spine. At 15 months' follow-up, he was grossly at his neurological baseline. The patient in Case 3 underwent C-2–ilium posterior instrumented fusion for neuromuscular scoliosis with sub-transverse process bands at T1–12. At 12 months' follow-up, she was grossly at her neurological baseline without any complaints. The patient in Case 4 underwent T2–ilium instrumented fusion for neuromuscular scoliosis with transverse bands at T4–10. At 12 months' follow-up, she was grossly at her neurological baseline without any complaints.

In a study by Wenger et al.,²³ the strength of fixation points in the instrumented vertebrae was examined, and they found that resistance to failure was greatest in intact lamina, followed by decorticated lamina, the transverse process, and the spinous process. Kemal Us et al.¹⁴ reported no neurological complications in the early results of scoliotic patients treated with the sub-transverse process wiring method. Akmeşe and Kemal Us showed similar results in a cohort of patients with main thoracic adolescent idiopathic scoliosis who were operated on using

a sub-transverse process wiring technique.¹ Overall, the evidence suggests that sub-transverse process wiring is a safe technique, and we adapted this technique to use with polyester bands. Transverse processes are not only stronger than spinous processes, but also safer than operating in the sublaminar space.

Lessons Learned

Care must be taken not to overtighten the bands, which can cause the bands to pull through or fracture a weak or skeletally immature lamina, as occurred in one of our cases. Aggressive decortication in preparing the bony bed for arthrodesis, likewise, may decrease transverse process strength and increase the risk of transverse process fracture in the follow-up period.

The ligamentous structures between the rib head and transverse process may pose a unique challenge to the neurosurgeon during passage of the wire. The use of a curved starting instrument may help disrupt the costotransverse ligament, making passage of the sub-transverse process easier. Because the space between the transverse process and rib head is devoid of critical neurovascular structures, the bands can be drawn through by applying more force than what would be acceptable for sublaminar passage.

Conclusions

Sub-transverse process passage of polyester bands is biomechanically sound, resulting in maintenance of post-operative spinal alignment and the development of bony fusion. Because sub-transverse process polyester bands are located away from the spinal canal, this technique may be safer and more technically straightforward than traditional methods of fixation. More follow-up studies with a greater number of patients are needed to determine long-term safety and efficacy, as well as the effects and outcomes in the maintenance of deformity correction of posterior spinal fusions with hybrid hook/screw/sub-transverse process polyester band constructs in pediatric spinal deformities.

Posterior instrumented spinal fusions in patients with small or abnormal anatomy from congenital or acquired deformities represent technically challenging cases. Placement of pedicle screws in these patients is difficult, even in the best of hands. Sublaminar instrumentation carries an unacceptably high risk of spinal cord injury. A direct comparison of outcomes between sublaminar and sub-transverse process cohorts may prove helpful.

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Disclosure

The authors report no conflicts of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Jea. Acquisition of data: Sayama, Briceño. Analysis and interpretation of data: Sayama, Briceño. Drafting the article: Jea, Strickland. Critically revising the article: Jea, Lam, Luerssen. Reviewed submitted version of manuscript: Jea. Administrative/technical/material support: Luerssen. Study supervision: Jea.

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