Feasibility and safety of using thoracic and lumbar cortical bone trajectory pedicle screws in spinal constructs in children: technical note

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Thoracic and lumbar cortical bone trajectory pedicle screws have been described in adult spine surgery. They have likewise been described in pediatric CT-based morphometric studies; however, clinical experience in the pediatric age group is limited. The authors here describe the use of cortical bone trajectory pedicle screws in posterior instrumented spinal fusions from the upper thoracic to the lumbar spine in 12 children. This dedicated study represents the initial use of cortical screws in pediatric spine surgery.

The authors retrospectively reviewed the demographics and procedural data of patients who had undergone posterior instrumented fusion using thoracic, lumbar, and sacral cortical screws in children for the following indications: spondylolysis and/or spondylolisthesis (5 patients), unstable thoracolumbar spine trauma (3 patients), scoliosis (2 patients), and tumor (2 patients).

Twelve pediatric patients, ranging in age from 11 to 18 years (mean 15.4 years), underwent posterior instrumented fusion. Seventy-six cortical bone trajectory pedicle screws were placed. There were 33 thoracic screws and 43 lumbar screws. Patients underwent surgery between April 29, 2015, and February 1, 2016. Seven (70%) of 10 patients with available imaging achieved a solid fusion, as assessed by CT. Mean follow-up time was 16.8 months (range 13–22 months). There were no intraoperative complications directly related to the cortical bone trajectory screws. One patient required hardware revision for caudal instrumentation failure and screw-head fracture at 3 months after surgery.

Mean surgical time was 277 minutes (range 120–542 minutes). Nine of the 12 patients received either a 12- or 24-mg dose of recombinant human bone morphogenetic protein 2. Average estimated blood loss was 283 ml (range 25–1100 ml).

In our preliminary experience, the cortical bone trajectory pedicle screw technique seems to be a reasonable alternative to the traditional trajectory pedicle screw placement in children. Cortical screws seem to offer satisfactory clinical and radiographic outcomes, with a low complication profile.

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KEY WORDS pediatric spine; spine surgery; spinal instrumentation; pedicle screws; cortical bone trajectory pedicle screws; surgical technique

MIDLINE posterior spinal fusions using cortical bone trajectory pedicle screws are an alternative to posterolateral spinal fusions using traditional trajectory pedicle screws.² The entry point located on the pars interarticularis is more medial than the standard entry point at the junction between the transverse process and

superior articulating facet process. The cortical bone trajectory screw technique utilizes more “stout” screws; that is, the screws are shorter but may have a larger diameter. The trajectory for cortical pedicle screws is inferomedial to superolateral, capturing the denser cortical layer of bone along its path. The medial starting point may decrease the

ABBREVIATIONS BMP = bone morphogenetic protein; rh = recombinant human; SSEP = somatosensory evoked potential.

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length of the incision, operative time, and estimated blood loss and may avoid the need for muscle retraction and dissection lateral to the facets. These technical advantages may be even more important in fragile young children with a smaller circulating blood volume than their adult counterparts. The medial-to-lateral trajectory away from the spinal canal may avoid other screw placement–associated morbidity such as neurological injury from breaching the spinal canal and its contents. Similarly, the inferior-to-superior vector of the trajectory avoids the neural foramina.

Thus far, biomechanical studies suggest that cortical bone trajectory pedicle screws possess equivalent to even higher pullout strength than conventional trajectory pedicle screws.²⁰ However, literature demonstrating the clinical effectiveness of this technique is sparse, especially in the pediatric age group. We present our preliminary experience with the use of cortical bone trajectory pedicle screws in 12 children.

Methods

Patient Population

We retrospectively reviewed the records of 12 consecutive patients ≤ 18 years old who had undergone posterior instrumented spinal fusions. Cortical bone trajectory pedicle screws were used exclusively by the Neurospine Service at Texas Children's Hospital between April 29, 2015, and February 1, 2016, in this series of patients (Table 1). The senior author regarded the cortical trajectory pedicle screw technique as an appropriate alternative to traditional trajectory pedicle screw placement because of the decreased muscle dissection required to expose the screw entry points for the medial-to-lateral trajectory, as well as the potential decreases in blood loss and operative time. The same patients who were considered reasonable candidates for traditional trajectory pedicle screws were also deemed suitable for cortical trajectory pedicle screws; that is, cortical trajectory pedicle screws substituted for traditional trajectory pedicle screws in the study patients. Preoperative 36-inch radiographs of the spine, CT scans, and MR images were obtained in all patients. Immediate postoperative 36-inch radiographs of the spine in the upright position were obtained in all patients. Postoperative full-spine radiographs and CT scans were obtained in the follow-up to document fusion. Thereafter, radiographic follow-up with full-spine radiographs was performed at 6- to 12-month intervals; clinical follow-up in person or via telephone interview was also conducted at 6- to 12-month intervals.

Surgical Technique

All patients were positioned prone after intubation. Neurophysiological monitoring was used for all cases; motor evoked potential and somatosensory evoked potential (SSEP) baseline parameters for the lower extremities were obtained prior to skin incision. The posterior thoracic and lumbar spine, sacrum, and posterior superior iliac spine were exposed in the usual manner, as needed. Notably though, lateral bony landmarks such as the transverse processes and sacral alae were not exposed. Subperiosteal

muscle dissection was performed along the spinous processes and over the laminae up to the lateral border of the pars interarticularis and medial facet joints. Entry points for the cortical bone trajectory pedicle screws were prepared using intraoperative spinal navigation in all patients (StealthStation and O-arm systems, Medtronic Sofamor Danek). The starting points, located on the pars interarticularis just medial to its lateral border and at the confluence of the pars interarticularis with the superior articular process of the facet joint, mark the mediocaudal entry point into the pedicle (Fig. 1). The screw path was drilled and tapped using frameless stereotactic neuronavigation. A tap one size smaller than the planned diameter of the final screw placement was used. Importantly, the entire length of the screw path was tapped because of the hardness of the cortical bone. After a safe screw trajectory was confirmed via palpation of the bony channel with a ball-tipped probe to rule out breaches, cortical pedicle screws were placed (screw diameter range 4.5–6.5 mm, screw length range 25–45 mm; Solera, Medtronic Sofamor Danek) (Fig. 2). In longer constructs, iliac bolts, laminar hooks, and sublaminar and/or subtransverse process bands were then implanted in the usual way,⁹ as needed. Motor evoked potentials and SSEPs were obtained after each passage of the components of the spinal construct.

Osteotomies, primarily Smith-Peterson osteotomies used to loosen a fixed deformity, as required by the particular case and spinal deformity, were performed at the apex of the deformity prior to securing the 5.5-mm-diameter titanium or cobalt-chromium rods to the laminar hooks, polyester bands, and pedicle screws. Our surgical technique at the apex of a spinal deformity or in the middle of a long-segment fusion typically involves the placement of sublaminar and/or subtransverse process bands for fixation, rather than pedicle screws. Hence, we did not have occasion to juxtapose posterior osteotomies with cortical trajectory pedicle screws. Nonetheless, the starting point for cortical trajectory pedicle screws overlies the inferomedial edge of the pedicle and should not be a barrier to the completion of the Smith-Peterson osteotomy, which avoids resecting any portion of the pedicle.

Arthrodesis was performed with local autograft or morselized cancellous allograft in all cases, and bone morphogenetic protein (BMP) was used in 9 of 12 cases (Infuse, Medtronic Sofamor Danek) after proper decortication. Iliac crest and rib autograft harvest were employed in 2 patients, respectively.

Characteristics of Pseudarthrosis

The criteria used to detect pseudarthroses were as follows: 1) loss of fixation, such as implant breakage, dislodgement of rods or hooks, or halo around a pedicle screw (halo around an iliac screw is an expected finding from preservation and motion of the sacroiliac joint); 2) significant progression of deformity with or without pain; 3) subsequent disc space collapse observed from the first postoperative visit to the most recent visit in which pseudarthrosis was determined; and 4) lucency across the fusion mass on postoperative CT imaging. Fusion rate was assessed independently by a board-certified fellowship-trained pediatric neuroradiologist and graded on a previ-

TABLE 1. Perioperative data in 12 patients who underwent cortical bone trajectory pedicle screw placement

Case No.	Age at Op (yrs), Sex	Comorbidities	Indications for Op	Posterior Instrumented Fusion	No. of Levels Fused	Location & Dimensions (in mm) of Cortical Screws	BMP Dose (mg)	Graft	EBL (ml)	Op Time (mins)	CT FU (mos)	CT Grade at Last FU† (mos)	Clinical FU (mos)
1	17, M		L-5 spondylolysis; intrac-table back pain	L5-S1	2	L-5 & 6.5 × 30	NA	Iliac crest auto, allo	75	180	2	3	19
2	17, F		L-5 spondylolysis; intrac-table back pain	L4-S1	3	Lt L-4 & 5.5 × 30; rt L-4 & 5.5 × 25; lt L-5 & 6.5 × 25; rt L-5 & 6.5 × 30	12	Local auto, allo	75	186	2	4-	19
3	11, F		Unstable L-1 seatbelt injury	T10-L3	6	T-10 & 4.5 × 25; T-11 & 5.5 × 25; T-12 & 5.5 × 25; L-2 & 4.5 × 30; L-3 & 5.5 × 30	12	Local auto, allo	50	191	NA	NA	19
4	18, F		L-5 spondylolysis; intrac-table back pain	L5-S2	3	L-5 & 6.5 × 30	12	Allo	300	202	2	4-	18
5	12, F	Chiari malformation; holocord syrinx; cystic fibrosis	Progressive neuromuscular scoliosis	T3-L3	10	L-1 & 4.5 × 35; L-2 & 4.5 × 35; L-3 & 4.5 × 35	24	Local auto, allo	500	422	1	4	17
6	18, M	Stuve-Wiedemann syndrome; dystrophic myopathy	Progressive neuromuscular scoliosis	C6-S2	21	L-3 & 6.5 × 30; L-4 & 6.5 × 30; L-5 & 6.5 × 30	24	Local auto, allo	570	500	NA	NA	16
7*	18, M	Prior L4-5 interspinous fusion; pseudarthrosis	Failed back syndrome	L4-5	2	L-4 & 6.5 × 35; L-5 & 6.5 × 30	12	Allo	25	141	3	4-	15
8	12, F	Liver laceration; small bowel perforation	Unstable T-12 seatbelt injury	T10-L3	6	T-10 & 5.5 × 25; T-11 & 5.5 × 25; T-12 & 5.5 × 25; L-2 & 5.5 × 35; L-3 & 6.5 × 30	12	Local auto, allo	100	170	2	4-	15
9	17, F	Malignant meningioma	Lat extracavitary approach for tumor resection	T7-L3	7	T-7 & 4.5 × 30; T-8 & 5.5 × 30; T-9 & 5.5 × 30; T-10 & 5.5 × 30; L-1 & 5.5 × 35; L-2 & 5.5 × 35; L-3 6.5 × 35	NA	Rib auto, allo	50	542	3	4-	15
10	14, F		L-5 spondylolysis; intrac-table back pain	L5-S1	2	L-5 & 6.5 × 30	12	Local auto, allo	50	120	2	3-	14
11*	16, F		Unstable T-12 burst fracture (1st admission); hardware failure (2nd failure)	T9-L2	6	T-9 & 4.5 × 40; T-10 & 4.5 × 40; T-11 & 5.5 × 40; L-1 & 4.5 × 45; rt L-2 & 4.5 × 45	12	Local auto, allo	500	248	10	3-	22
12	15, M	En plaque spinal meningioma	Lat extracavitary approach for tumor resection	T1-5	5	T-1 & 4.5 × 25; rt T-2 & 4.5 × 30; rt T-3 & 4.5 × 25; rt T-4 & 4.5 × 30; T-5 & 4.5 × 30	NA	Local auto, allo	1100	421	2	4-	13

Allo = allograft; auto = autograft; EBL = estimated blood loss; FU = follow-up; NA = not applicable.

None of the patients had a postoperative orthosis.

* Patient with revision surgery.

† CT-based grading scale for fusion assessment (see Table 2).

FIG. 1. Artist's illustration of the starting point for cortical bone trajectory pedicle screws on the pars interarticularis and its spatial relationship with the lateral border of the pars, the superior articulating process, and the facet joint (*inset* on right). Axial (**A**) and sagittal (**B**) trajectories of traditional pedicle screws are compared with those (**C and D**) of cortical pedicle screws. Copyright Christopher Brown. Published with permission. Figure is available in color online only.

ously validated scale that was modified for the purposes of the present study (Table 2).⁸

Statistical Analysis

Clinical, operative, and radiographic parameters were collected. Frequency distributions and summary statistics were calculated for these data.

Results

Clinical and Operative Data

The mean age of our patients at the time of surgery was 15.4 years (range 11–18 years). Five patients had a diagnosis of spondylolysis and/or spondylolisthesis, 3 patients had a diagnosis following trauma and unstable thoracolumbar fracture, 2 patients had a diagnosis of scoliosis, and 2 patients underwent destabilizing approaches (that is, lateral extracavitary approaches) to the spine for resection of en plaque meningiomas.

All patients were assessed preoperatively with MRI, CT, and upright 36-inch scoliosis radiographs. Arthrodesis to the pelvis was performed using bilateral iliac screw fixation and posterolateral fusion with allograft and/or local autograft and recombinant human (rh)–BMP-2. Nine of the 12 patients received either a 12-mg or a 24-mg dose of rh-BMP-2. Seventy-six cortical bone trajectory pedicle screws were placed: 33 thoracic screws and 43 lumbar

screws. Mean estimated blood loss was 283 ml (25–1100 ml), and mean operative time was 277 minutes (range 120–542 minutes).

Patients were followed up in person or via telephone for a mean of 16.8 months (range 13–22 months). No patient had significant loss of spinal alignment after surgery.

One patient (Case 11) developed caudal instrumentation failure with cortical bone trajectory pedicle screw head fracture, a complication that required surgical revision. The patient was a 16-year-old girl with an unstable T-12 burst fracture; she had undergone a T-9 to L-2 posterior instrumented fusion with cortical bone trajectory pedicle screws. The isthmus of the left L-2 pedicle was thin; therefore, a pedicle screw was omitted. Three months after surgery, the patient presented with a fracture of the right L-2 cortical bone trajectory pedicle screw, at the junction between the head and the shank of the screw.

Fusion Rate

Follow-up CT imaging was available in 10 of 12 patients. The average CT fusion grade for this patient cohort was 4, indicating solid fusion in the majority of our study group. A solid fusion mass (Grade 4– or 4) was found after 7 (70%) of 10 procedures, based on CT performed at a mean of 3 months after surgery. Three (25%) of 12 patients underwent single-level fusion. There were no cases of sig-

FIG. 2. Case 2. Axial (left) and sagittal (right) CT scans of the spine obtained 19 months after surgery, showing the medial-to-lateral and caudal-to-rostral trajectory of cortical bone trajectory pedicle screws, respectively, away from the spinal canal and neural foramina, respectively. The images also show a solid fusion spanning the spinal construct from L-4 to S-1 in the intermediate-term follow-up, without any evidence of instrumentation failure.

nificant graft resorption. As mentioned above, 1 patient (Case 11) required reoperation for hardware failure, which is considered a surrogate for pseudarthrosis; this patient's fusion was Grade 3– at 10 months after the initial surgery.

Surgical Complications

There were no complications in our series, including pedicle fractures, as a direct result of cortical bone trajectory pedicle screws.

Discussion

We report on our early experience using the cortical bone trajectory pedicle screw technique in pediatric thoracolumbar fusions. Our preliminary experience suggests that this technique is a reasonable, feasible, and safe alternative to conventional trajectory pedicle screw placement in short- or long-segment spinal fusions.

The concept of the cortical bone trajectory pedicle screw for the lumbar spine was introduced in 2009 by Santoni et al.²⁰ These authors analyzed the biomechanical properties of cortical bone trajectory pedicle screws in a cadaveric model, comparing the screws to conventional trajectory pedicle screws. They found that the cortical bone trajectory pedicle screws had higher resistance to uniaxial pullout forces. The biomechanical superiority of the cortical bone trajectory pedicle screws has been suggested by subsequent biomechanical studies.^{11,19,24,25}

However, one biomechanical analysis utilizing finite element modeling in adult isthmic spondylolisthesis showed cortical bone trajectory pedicle screws to be less optimal for stabilizing vertebra with isthmic spondylolisthesis because of their lower fixation strength compared with that of traditional trajectory pedicle screws.¹² A second biomechanical cadaveric study¹ revealed that standard trajectory pedicle screws had better fatigue performance in osteoporotic bone than the cortical bone trajectory pedicle screws. Therefore, data from experimental studies are conflicting.

In clinical practice, adults with degenerative lumbar

spondylolisthesis treated with cortical bone trajectory pedicle screws or conventional trajectory pedicle screws attained statistically equivalent patient-reported outcomes and fusion rates.¹⁸ Insertional torque was found to be almost twice as high for the cortical bone trajectory pedicle screws than for traditional trajectory pedicle screws.¹³ In another study²³ of 79 adults with degenerative lumbosacral disease, the authors demonstrated that the use of cortical bone trajectory pedicle screws was associated with acceptable operative outcomes with a low complication rate. There were no complications directly related to screw placement except for pars and pedicle fractures and early screw loosening.^{3,15} Mean estimated blood loss for the procedure was 306.3 ml; mean hospital stay was 3.5 days. Unfortunately, there is a lack of data regarding mid- and long-term clinical and radiographic outcomes.

Some authors of cadaveric and CT morphometric studies have demonstrated the feasibility of the cortical bone trajectory in the thoracic spine.^{10,22,27} Most adult thoracic pedicles and pedicle rib units might accommodate cortical screws with a width of 5.0 mm and a length ranging from 25 to 35 mm.

TABLE 2. Numerical CT-based grading scale for fusion assessment

Grade	Description
0	Clinically significant pseudarthrosis necessitating immediate revision surgery
1	Complete graft resorption
2–	Unilat bridging bone w/ focal areas of graft resorption
2	Unilat bridging bone
3–	Bilat bridging bone w/ focal areas of graft resorption
3	Bilat bridging bone
4–	Evidence of bony fusion w/ focal areas of incomplete incorporation into fusion mass
4	Solid bony fusion mass

In a published CT morphometric abstract, Patel et al. outlined the feasibility of cortical bone trajectory pedicle screws in the pediatric lumbar spine.¹⁶ Xuan et al.²⁶ performed a similar CT analysis of the pediatric lower thoracic spine (T9–12) and established the feasibility of placing 4.5- to 5.5-mm cortical bone trajectory screws via the pedicle or pedicle rib unit. These screw dimensions are comparable to those of the adult cortical bone trajectory thoracic pedicle screws.

Our early experience in 12 pediatric patients with this modified pedicle screw technique in the thoracic and lumbar spine seems to indicate satisfactory outcomes. A battery of patient-reported outcomes documented results comparable to age-equivalent norms at the last follow-up. The solid fusion rate (Grades 4+ and 4), based on CT as a gold standard, was high (70%) in the early postoperative period. The procedure is straightforward with the availability of intraoperative navigation. The medial-to-lateral angulation is about 10°, whereas the caudal-to-rostral angulation is about 20° targeting the posterior half of the superior endplate of the respective vertebral body, according to CT morphometric studies and our own experience. Estimated blood loss (mean 283 ml) was similar to that found in adults who received cortical bone trajectory pedicle screws. Our patients did not experience any evident pars or pedicle fractures during insertion of the pedicle screws; otherwise healthy children may have better cortical bone density than osteoporotic adult counterparts, making them more resistant to iatrogenic fracture during cortical screw placement.

Computed tomography–guided frameless stereotactic neuronavigation was used in all cases. Much like traditional trajectory pedicle screws, cortical trajectory pedicle screws can be placed freehand, with the use of fluoroscopy, or with the aid of intraoperative navigation. The advent of spinal neuronavigation, however, has changed the practice of many spine surgeons. While some debate remains, recent systematic reviews have shown that the use of intraoperative navigation increases the accuracy of pedicle screw placement, with reported accuracy as high as 100% in some series.⁷ Given that the senior author was learning a new technique for placing cortical trajectory pedicle screws that was not intuitive, the additional information provided by intraoperative neuronavigation was believed to be advantageous to minimize technical errors.

Overall, the patients in our series with at least 12 months' follow-up (mean 15 months) demonstrated improvement in their preoperative symptoms. Our series included 1 screw failure out of the 76 screws placed, which represents a failure rate of 1.3% in the intermediate-term follow-up. Published rates for transpedicular screw fracture range from 2.6% to as high as 60%.^{4–6,21} No direct surgical complications were observed. Specifically, no neurological injuries were observed due to misplaced pedicle screws. The deliberate trajectory of cortical screws may, in fact, decrease the risk of neurological injury, with its medial-to-lateral trajectory aimed away from the spinal canal and its inferior-to-superior trajectory directed away from the neural foramen and exiting nerve root. While reports on clinical outcomes using cortical trajectory screw-based constructs are sparse in the adult literature (and absent in the pediatric litera-

ture), 2 small series recently published in the peer-reviewed literature document no instances of neurological complication during or after surgery.^{14,17}

Study Limitations

There are several limitations to our study. The biggest drawback is that our study is based on a retrospective chart review of surgical cases performed by a single surgeon at a single institution. It is therefore subject to inherent selection bias, and the general applicability of these results is in question. Patient diagnoses and surgical indications were heterogeneous, making it difficult to draw definitive conclusions.

Moreover, 3D intraoperative spinal navigation was used exclusively in this small series of patients. Other popular techniques for screw insertion—freehand and 2D fluoroscopy guidance—were not analyzed. Another significant limitation of our study is the absence of an age- or disease-matched control group (traditional trajectory pedicle screws) with which to compare outcomes in our cohort, except for the historical adult data previously published in the literature.

Finally, our small patient population precludes more rigorous statistical analysis.

Conclusions

As cortical bone trajectory pedicle screws become more popular among pediatric spine surgeons, our report serves as an important evaluation of the safety and feasibility of this technique. In our early experience, the cortical bone trajectory pedicle screw technique seems to be a reasonable, feasible, and safe alternative to conventional trajectory pedicle screw placement in short- or long-segment spinal fusions in the pediatric age group. Our initial clinical and radiographic outcomes are presented—the absence of surgical complications, low intraoperative blood loss, and high fusion rate. Nonetheless, even longer-term follow-up is necessary in a larger group of patients and institutions, as are case-matched controls and comparisons with traditional pedicle screw placement to establish the durability and validity of our initial results prior to the widespread adoption of this technique at the exclusion of traditional trajectory pedicle screws.

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Disclosures

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

Author Contributions

Conception and design: Jea, Sellin, Raskin. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Jea, Sellin, Raskin. Critically revising the article: Jea, Sellin, Raskin, Moreno. Reviewed submitted version of manuscript: Jea, Sellin, Raskin, Staggars, Brayton, Briceño. Approved the final version of the manuscript on behalf of all authors: Jea. Statistical analysis: Briceño, Moreno. Administrative/technical/material support: all authors. Study supervision: all authors.

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