Lumbar Spinal Fixation with Cortical Bone Trajectory Pedicle Screws in 79 Patients with Degenerative Disease: Perioperative Outcomes and Complications
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OBJECTIVE: Biomechanical studies demonstrate that cortical bone trajectory pedicle screws (CBTPS) have greater pullout strength than traditional pedicle screws with a lateral-medial trajectory. CBTPS start on the pars and angulate in a mediolateral-caudocranial direction. To our knowledge, no large series exists evaluating the perioperative outcomes and safety of CBTPS.

METHODS: We retrospectively reviewed all patients who received lumbar CBTPS at our institution. Data were collected regarding patient demographics, use of image guidance, operative blood loss, hospital stay, and postoperative complications.

RESULTS: A total of 79 patients undergoing CBTPS fusion for degenerative lumbosacral disease with back pain were included in the analysis (42 female, 37 male; October 2011–January 2015). Twenty patients (25.3%) had previous lumbar spine surgery, 39 (49.4%) had a smoking history, and mean body mass index was 28.7. Mean length of stay was 3.5 days, and mean operative blood loss was 306.3 mL. Image guidance was used in 69 (87.3%) cases. A total of 66 (83.5%) fusions were single level, and 54 (68.4%) fusions were single level without previous surgery. There were 9 complications in 7 (8.9%) patients; these included hardware failure, pseudarthrosis, deep vein thrombosis, pulmonary embolism, epidural hematoma, and wound infection. No complications were caused by misplaced screws. Mean follow-up was 13.2 months.

CONCLUSIONS: As CBTPS becomes increasingly popular among spine surgeons performing lumbar fusion, this report provides an important evaluation of technique safety and acceptable perioperative outcomes.

INTRODUCTION

Posterior lumbar screw-rod fixation and fusion is a well-accepted treatment for patients in whom conservative treatment has failed to adequately treat degenerative lumbosacral disease because of segmental instability. Minimally invasive surgery (MIS) techniques were developed to mitigate approach-related morbidity by decreasing tissue trauma during exposure, but many critics argue that this benefit is obtained at the cost of fusion augmentation using decortication and posterolateral arthrodesis compared with the open approach. In contrast, the recently described cortical bone trajectory pedicle screw (CBTPS) approach to lumbar fusion may offer a compromise: a minimally invasive approach with less tissue disruption, a robust fixation construct, and effective interbody fusion.

Biomechanical studies demonstrate superior pullout force for the CBTPS compared with traditional approaches. In addition, the entry point for the CBTPS requires less manipulation of the paravertebral musculature, which is thought to generate postoperative pain in conventional approaches. A diversity of constructs can be coupled with the CBTPS to augment fusion, including lateral lumbar interbody fusion (LLIF), transforminal...
lumbar interbody fusion (TLIF), posterior lumbar interbody fusion (PLIF), and anterior lumbar interbody fusion (ALIF).

Because of smaller incisions and reduced soft tissue dissection, mini—open surgery with CBTPS may be associated with reduced morbidity and expedited recovery compared with open surgery with traditional pedicle screws. To our knowledge, there are no perioperative clinical series that evaluate these purported advantages. Because our experience with the CBTPS approach has increased since 2011, we have expanded our indications for the approach beyond lumbar degenerative disease to traumatic fractures, infection, extension into the thoracic spine, and scoliotic deformities, and thus, we have sought to evaluate its safety. We present perioperative data, including complication rates, for 79 consecutive patients who underwent CBTPS for degenerative disease. The goal of this study is not to compare CBTPS outcomes with those for traditional pedicle screw techniques but rather to evaluate the feasibility and safety of the CBTPS constructs in a clinical population.

METHODS

We retrospectively reviewed data for all patients who received lumbar CBTPS at Barrow Neurological Institute, St. Joseph’s Hospital and Medical Center, Phoenix, Arizona, USA from 1 October 2011, to 31 January 2015. Preoperative clinic charts and radiographic imaging were reviewed to extract demographic data, symptoms, and clinical outcomes. Operative reports and inpatient hospital records were reviewed to collect information on use of image guidance, operative blood loss, complications, and length of stay. Clinic notes were reviewed to identify any patients who returned to clinic with complications. Complications were defined as hemorrhage, hematoma, seroma, infection, neurologic complications, thromboembolic complications (including deep venous thrombosis and pulmonary embolus), cardiac complications (including myocardial infarction), and urinary and renal complications (including acute renal failure), failure of hardware, and pseudarthrosis. Postoperative radiographic imaging was reviewed to confirm proper cortical screw placement. Time of last follow-up was defined as the last time the surgeon’s office had contact with the patient via either office visit or telephone call. GraphPad software (GraphPad Software Inc., La Jolla, California, USA) was used for statistical analysis. Means were compared using paired t tests, and P values of <0.05 were considered statistically significant. This study was approved by the St. Joseph’s Hospital and Medical Center institutional review board.

Surgical Approach

All patients underwent a CBTPS approach using the following method. A midline incision was tailored above the level of interest using preoperative fluoroscopy. Subperiosteal dissection was performed to expose the pars at the cranial level and the caudal level, but no farther. Only a portion of the transverse processes was exposed, if at all. The superior facet required minimal exposure, if at all. The entry point for the pedicle screw started at the pars at the junction of the center of the superior articular process, 1 mm inferior to the inferior border of the transverse process, angulating the screw in a mediolateral and caudocranial direction (Figures 1 and 2). Depending on surgeon comfort and patient anatomy, navigation was used to tailor the screw trajectory.

If the patient required decompression of the thecal sac or nerve roots via laminectomy, foraminotomy, or discectomy, the procedure was performed before or after placement of screws. Unilateral or bilateral facet removal was performed based on whether the surgeon preferred placement of a unilateral TLIF (Figure 1) or bilateral PLIF grafts. In select cases, posterior fixation and fusion using CBTPS was performed in a second-stage surgery the next day after a first-stage LLIF (Figure 2) or ALIF (Figure 3) had been performed. In cases with minimal disc degeneration or spondylolysis alone, no interbody graft was placed. When possible, additional arthrodesis was achieved by placing morselized local autograft and allograft bilaterally at exposed decorticated bone sites.

RESULTS

During the study period, 84 patients underwent CBTPS fusion at our institution. Four of these patients had thoracolumbar fusions for traumatic fractures and thus were excluded from the final analysis. One patient was excluded because of the use of CBTPS for thoracolumbar fixation after corpectomy for Pott disease. Seventy-nine patients underwent CBTPS for lumbar degenerative disease with back pain and were included in the final analysis. Thus, patients were excluded if they had CBTPS for indications other than lumbar degenerative disease with back pain or CBTPS placed in conjunction with thoracic screws.

Most of the cases in this series were those of the senior author (S.C.), who performs only CBTPS for his patients with degenerative lumbar disease. In degenerative cases, the significant facet hypertrophy allows autograft to be placed for fusion over the posterior elements. The senior author reserves traditional pedicle screws for cases of 1) trauma, although biomechanical laboratories are testing various uses for CBTPS in traumatic injuries; 2) revision surgery with significant bony removal that precludes a screw through the pars; and 3) tumor resection in which a more significant bony removal for decompression precludes placement of cortical screws. Most patients were female (n = 42, 52.6%), 20 patients (25.3%) had received previous lumbar spine surgery, and 39 (49.4%) had a history of smoking. The mean (standard deviation) body mass index (weight in kg/height in m²) was 28.7 ± 6.6 (range, 15.7–45.4). The most common preoperative comorbidities were hypertension (33, 41.8%) and obesity (28, 35.4%) (Table 1). Preoperative symptoms are summarized in Table 2.

Of the 79 patients undergoing CBTPS fusions, 54 (68.4%) received a single-level fusion without previous surgery (Table 3). Of all 79 patients, 10 (16.5%) had multiple-level instrumentation, ranging from 2 to 7 levels; of these 13 patients, 8 (61.5%) had received previous lumbar spine surgery. Mean length of stay after CBTPS fusion was 3.5 ± 2.2 days (range, 1–10) for all patients, and mean operative blood loss was 306.3 ± 254 mL (range, 50–1400 mL). Image guidance was used in 69 (87.3%) of the 79 cases. Implants included TLIF/PLIF (n = 46, 58.2%), LLIF (n = 11, 13.9%), ALIF (n = 6, 7.6%), and ALIF combined with LLIF (n = 1, 1.3%); 15 patients (19%) did not have an interbody device implanted. In a comparative
analysis, the patient population was subdivided into those with single-level without previous spinal surgery and all other patients (Table 3). There was a statistically significant difference in the estimated blood loss of 247.3 mL in single-level without previous spinal surgery compared with that of all other patients (434 mL; *P* < 0.01). There was also a statistically significant difference in the inpatient hospitalization days after CBTPS of 3.1 days in single-level without previous surgery compared with that of all other patients (4.4 days; *P* = 0.02).

The mean follow-up was 13.2 ± 7.9 months (range, 3–41 months). Nine complications were encountered in 7 (8.9%) of the 79 patients (Table 4). These included hardware failure (*n* = 2), pseudarthrosis (*n* = 2), thrombosis (pulmonary embolism or deep vein thrombosis) (*n* = 3), epidural hematoma (*n* = 1), and deep wound infection requiring surgical debridement (*n* = 1). No dural violation occurred as a result of the placement of screws. No nerve-root injury occurred and no misplaced screws were seen on immediate postoperative imaging.

**DISCUSSION**

In this experience, which to our knowledge is the largest series of patients undergoing CBTPS for treatment of degenerative disease, CBTPS was a safe alternative to traditional or MIS techniques for lumbar fixation in a diverse group of patients. In this cohort, perioperative complications were acceptable. Multicenter prospective trials are necessary to better elucidate the safety and efficacy of this approach compared with traditional methods.

**Biomechanical Considerations**

The number of pseudarthroses and hardware failures reported in the medical literature after pedicle screw fixation and fusion is variable. The biomechanical profile of cortical screws should lend itself to decreased hardware failure. Inceoglu et al. demonstrated a significantly higher pullout strength for cortical trajectory screws over traditional pedicle screws, but not higher pullout stiffness. Santoni et al. demonstrated that CBTPS incurred a 30% increase in uniaxial yield pullout load compared with traditional pedicle screws (*P* = 0.08). Mixed loading was equivalent between the 2 trajectories. In addition, there were no significant differences in construct stiffness or in failure moments between the 2 trajectories (*P* = 0.35). Another recent study by Perez-Orribo et al. evaluated standard nondestructive flexibility tests in cadaveric lumbar specimens. With LLIF support, there was no significant difference in stability between traditional pedicle screw-rod and cortical screw-rod fixation. With TLIF support, traditional pedicle screw-rod fixation was stiffer than CBTPS-rod fixation during lateral bending and axial bending, but CBTPS-rod fixation was stiffer than traditional pedicle screw-rod fixation in flexion and extension. These investigators concluded that bilateral CBTPS-rod fixation provided about the same stability in cadaveric specimens as traditional pedicle screw-rod fixation regardless of the presence of interbody or type of interbody support. The greater pullout strength of cortical bone trajectory screws may be because of the increased cortical bone purchase at the medial starting point of the screw as well as the smaller pitch of the threads, which may decrease the risk of

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**Figure 1.** A 35-year-old male patient presented with significant axial low-back pain after 2 previous microdiscectomies at L4-5 with (A) a new recurrent herniated lumbar disc evident on axial T2-weighted magnetic resonance imaging. He underwent an L4-5 transforaminal lumbar interbody fusion combined with an L4-L5 cortical screw fixation. (B) Lateral and (C) anteroposterior radiographs demonstrate a large interbody graft with a rigid posterior construct. (Used with permission from Barrow Neurological Institute, Phoenix, Arizona, USA.)
The risk of pseudarthrosis may be decreased by the extra stability provided by the cortical screws. Posterior fixation has been proved to enhance stability by relieving the load supported by the interbody graft, thus reducing the risk of subsidence and collapse of the intervertebral space. Cortical screws may provide this posterior fixation for anterior interbody graft. An additional benefit to the use of CBTPS with anterior constructs is that the CBTPS does not interfere with screws placed anteriorly, as demonstrated in Figure 3. Figure 3 illustrates the case of a 50-year-old male patient who presented...
with axial back pain, bilateral lower-extremity radicular pain, severe disc collapse, and spondylolisthesis at L5-S1. A large graft was placed anteriorly and cortical screws were placed posteriorly. Screws incorporated in the graft anteriorly do not collide with the CBTPS, which can occur with the traditional trajectory of posterior pedicle screws. Other groups have found success with CBTPS at the L5-S1 level, and some, such as Matsukawa et al.,25 have refined the trajectory of the technique to engage the dense bone at the S1 end plate.

Exposure-Related Trauma

Traditional pedicle screw trajectory requires a large incision with significant muscular dissection to provide the lateral to medial angulation of screws. This is often cited as the reason for significant postoperative spasm and incisional pain, with resultant increased postsurgical length of stay, postoperative narcotics, and time to recovery to preoperative functional status.16-19 With the CBTPS approach, the portions of the facet and transverse processes that are traditionally exposed do not need to be exposed for the screw entry points.26,27 Because only the pars needs to be exposed, there is significantly less muscular manipulation and blood loss. The medial to lateral angulation of screws (Figures 1 and 2) allows one to tailor a smaller incision to minimize unnecessary exposure.

The decreased amount of exposure required for CBTPS should translate into improved perioperative outcomes. The mean blood loss for all cases in our series of 79 patients was 306.3 mL (247.2 mL for the 54 first-time single-level surgery patients). Because of decreased trauma with less exposure, patients undergoing CBTPS should have a shorter hospitalization, because their pain should be easier to control. In our series, patients had a reasonable mean length of stay of 3.5 days, compared with longer stays previously reported. In a series of 42 patients with standard pedicle screw placement, Rivet et al.20 reported average blood loss of 507 mL in 1-level standard pedicle screw fusions and 800 mL in 2-level fusions, with a length of stay of 4.6 and 5.3 days, respectively. Similarly, a series by Kim et al.28 evaluated the risk of complications across 4588 patients receiving single-level fusions in the National Surgical Quality Improvement Program database. These investigators found increasing operative time to be associated with stepwise increases in risk for overall complications. Because CBTPS decreases the amount of exposure required, it may reduce the time required for a case and thus may also reduce complications.
Complication Avoidance

Several aspects of CBTPS beyond muscle trauma are amenable to complication avoidance. As previously mentioned, the pedicle screw trajectory in CBTPS is aimed from medial to lateral rather than the traditional lateral to medial. Thus, the surgeon aims the screw away from the spinal nerve roots and, at higher levels, the conus medullaris/spinal cord, potentially reducing the risk of catastrophic neurologic injury with nonideal screw placement. In our series, no nerve roots were injured with cortical screw placement and no dural violation occurred as a result of cortical screw placement. In addition, most spine surgeons are familiar with the midline spinal anatomy exposure necessary for the CBTPS approach as opposed to the MIS TLIF approach, in which the exposure starts laterally. The common exposure prevents struggling on the part of the surgeon or complications caused by unfamiliarity with lateral anatomy.

The use of navigational guidance in most of these cases as opposed to the traditional pedicle screw technique may also contribute to the safety of the technique. In our study, 69 of the 79 patients (87.3%) had CBTPS placed using navigational guidance. In our series, initial postoperative imaging after screw placement demonstrated no misplaced screws. The spinal literature has consistently demonstrated increased accuracy of screw placement with the use of wand guidance.29-32

A major limitation of the traditional pedicle screw open approach is the degree of disruption of the adjacent facet capsule upon exposure. The lateral to medial projection of these screws often requires partial disruption of the transverse process and facet capsule to identify the entry point. Even with a meticulous surgical technique, unroofing the facet can lead to inadvertent violation of the adjacent capsule or disruption of its vascular supply with a theoretical increase in the likelihood of proximal junctional kyphosis (PJK) throughout the lifetime of the patient.33 Advantages of the CBTPS technique are that it does not necessitate a wide exposure and the entry point for cortical screws is just shy of the superior facet. Since we have started using CBTPS for longer degenerative constructs, it is possible that reduced superior facet dissection/exposure and less disruption of the posterior tension band may serve to decrease the risk of adjacent-level disease compared with the open approach. An example of this can be seen in Figure 4. A 65-year-old male patient presented with significant lumbar back pain as well as sagittal and coronal deformities. Lateral transpsoas interbody fusions from L1 to L4 improved the coronal

| Table 1. Preoperative Comorbidities in 79 Patients with Degenerative Lumbosacral Disease |
|---------------------------------------------|-------|
| Disease                                  | Number (%) |
| Hypertension                              | 33 (41.8) |
| Obesity                                   | 28 (35.4) |
| Osteoarthritis                            | 17 (21.5) |
| Thyroid disease                           | 14 (17.7) |
| Diabetes mellitus type 2                  | 12 (15.2) |
| Heart disease                             | 8 (10.1) |
| Cancer                                    | 7 (8.9) |
| Lumbar degenerative disc disease          | 5 (6.3) |
| Other (chronic obstructive pulmonary disease, diabetic neuropathy, deep vein thrombosis, liver disease, multiple sclerosis, obstructive sleep apnea, osteoporosis, rheumatoid arthritis, systemic lupus erythematosus, thrombotic thrombocytopenic purpura)* | 21 (26.6) |

*Each “other” comorbidity was reported in <5% of patients.

| Table 2. Preoperative Symptoms of 79 Patients with Degenerative Lumbosacral Disease |
|---------------------------------------------|-------|
| Symptom                                    | Number (%) |
| Pain                                       | 79 (100) |
| Weakness                                   | 55 (68.6) |
| Sensory                                    | 46 (58.2) |
| Gait imbalance                             | 40 (50.6) |
| Incontinence                               | 6 (7.5) |
| Impotence                                  | 1 (1.3) |
deformity and indirectly decompressed the bilateral neural foramina. L1-L5 Ponte osteotomies and an L4-L5 TLIF, followed by CBTPS from the back, corrected the sagittal deformity. With this combination of treatments, the patient experienced improvement in back pain. Although our short-term data do not address the incidence of PJK with CBTPS, we will continue to report ongoing data among this cohort. The incidence of PJK will be especially important to evaluate as groups begin to extend CBTPS fusions into the thoracic spine for longer constructs.34

**Study Limitations**

The current study neither proves nor disproves any additional benefits of the CBTPS approach over the MIS TLIF or the traditional open approach, because the CBTPS approach was not compared directly with other approaches. The current study does not delineate which types of patients have the best outcomes with the CBTPS approach. However, we demonstrate here that CBTPS is a safe alternative to more traditional approaches, with acceptable perioperative outcomes and rates of complications. It is possible that the follow-up for complications for these patients is longer than presented here, because follow-up was defined as when the surgeon last had contact with the patient, and many patients do not follow-up when they are doing well. No conclusions can be made about functional or radiographic outcomes without a minimum of 1-year follow-up for all patients.

**CONCLUSIONS**

As CBTPS use becomes increasingly popular among spine surgeons performing lumbar fusion, this report provides an important evaluation of technique safety and acceptable perioperative outcomes. To our knowledge, this is the largest single-institution series to date evaluating CBTPS perioperative outcomes. This series illustrates how the technique, even with longer constructs, can be performed safely, with acceptable length of stay and blood loss. Randomized controlled trials are necessary to evaluate whether the technique results in improved functional and radiographic outcomes over traditional pedicle screw and MIS TLIF approaches.

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**Table 4. Complications and Management for 7 Patients Who Received a Cortical Bone Trajectory Pedicle Screw with 9 Total Complications**

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<tr>
<th>Case</th>
<th>Complication(s)</th>
<th>Initial Surgery</th>
<th>Description and Management</th>
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</table>
| 1    | DVT and PE      | L5-S1           | Immediately PO developed DVT complicated with PE  
Management: enoxaparin and warfarin  
Pseudarthrosis  
9 months PO developed pain; imaging confirmed pseudarthrosis  
Management: reintervention with hardware removal and replacement of new bilateral L5-S1 screws |
| 2    | PE              | L4-L5           | 1 month PO while in rehabilitation  
Management: enoxaparin |
| 3    | Epidural hematoma  
Hardware failure | L4-L5           | Hematoma suspected POD 3 and confirmed with imaging  
Loosened left L5 screw evident during imaging for hematoma  
Management: return to OR for postoperative evacuation of hematoma, L5 screw removal, and replacement with extension of construct to S1 |
| 4    | Hardware failure | L4-L5           | 3 month PO minimal posterior migration relative to the L5 end plate of interbody spacer without symptoms  
Management: none |
| 5    | DVT             | L2-L4           | 1 month PO  
Management: enoxaparin and warfarin |
| 6    | Pseudarthrosis  | L4-S1           | 15 month PO worsening pain, difficulty walking, conservative management failed  
Management: reintervention with hardware removal and replacement of screws and rods from L4-S1 |
| 7    | Wound infection | L1-S1           | 1 week PO deep wound infection, MRSA+  
Management: debridement and washout 14 days PO, vancomycin, and cefepime |

DVT, deep vein thrombosis; PE, pulmonary embolism; PO, postoperatively; POD, postoperative day; OR, operating room; MRSA+, methicillin-resistant *Staphylococcus aureus* positivity.
REFERENCES


12. Perez-Orribo L, Kalb S, Reyes PM, Chang SW, Crawford NR. Biomechanics of lumbar cortical

Figure 4. A 65-year-old male patient with severe axial low-back pain presented with both sagittal (A) and coronal (B) lumbar deformities with multilevel degenerative disc disease evident on radiographs. He underwent an L1-L4 lateral lumbar interbody fusion followed immediately by a posterior approach for L4-5 transforaminal lumbar interbody fusion, L1-L5 Ponte osteotomies, and L1-L5 cortical screw fixation. Postoperative sagittal (C) and anterior-posterior (D) radiographs demonstrate improvement of lumbar lordosis as well as sagittal and coronal deformity. (Used with permission from Barrow Neurological Institute, Phoenix, Arizona, USA.)


