Review Article

# Systematic review of cortical bone trajectory versus pedicle screw techniques for lumbosacral spine fusion

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**Abstract:** Fusion of the lumbosacral spine is a common surgical procedure to address a range of spinal pathologies. Fixation in lumbar fusion has traditionally been performed using pedicle screw (PS) augmentation. However, an alternative method of screw insertion via cortical bone trajectory (CBT) has been advocated as a less invasive approach which improves initial fixation and reduces neurovascular injury. There is a paucity of robust clinical evidence to support these claims, particularly in comparison to traditional pedicle screws. This study aims to review the available evidence to assess the merits of the CBT approach. Six electronic databases were searched for original published studies which compared CBT with traditional PS and their findings reviewed. Nine comparative studies were identified through a comprehensive literature search. Studies were classified as retrospective cohort, prospective cohort or case control studies with medium quality as assessed by the GRADE criteria. The available literature is not cohesive regarding outcomes and complications of CBT versus PT procedures. Most studies found no difference in operative time, but reported less blood loss during CBT. Radiological outcomes show no difference in slippage at one year although CBT is associated with greater bone-density compared to PT. Results for post-operative pain are inconclusive.

**Keywords:** Cortical bone trajectory (CBT); cortical screw; lumbosacral fusion; pedicle fixation; pedicle screw (PS)

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## Introduction

Fusion of the lumbosacral spine is a common surgical procedure to address spinal pathologies including degenerative disk disease, lumbar stenosis, deformities, trauma, and neoplasms (1-3). Fixation in lumbar fusion necessitates the insertion of screws into the vertebrae. Traditionally, this has been done via pedicle screw (PS) augmentation of the posterior lumbosacral spine as first described by Boucher in 1959 (4). However, advances in spine surgery and a more general trend towards the adoption of less invasive procedures have led to the development of new and innovative techniques, which aim to achieve spinal fixation while causing less damage to surrounding tissues (5,6).

 

One of these newer methodologies is screw insertion via a cortical bone trajectory (CBT), initially described in spinal trauma as the medio-latero-superior technique (MLST) and later reintroduced by Santoni *et al.* in 2009 (7-10) as CBT. CBT is thought to have improved initial fixation by optimizing contact of the screw with the cortical bone of the vertebrae (11). Furthermore, the medial entry of the screw in CBT allows for minimal soft tissue dissection in comparison to traditional pedicle screws, and may reduce the risk of neurovascular injury (12). As such, CBT theoretically offers increased bone purchase with reduced invasiveness.

Since the introduction of CBT, a number of morphometric and biomechanical studies have supported its viability for pedicle fixation (11-18). Nevertheless, there is limited clinical evidence available in the literature that directly compares outcomes and complications between CBT and the traditional PS technique (8,11,15,19-23).

## Methods

### *Purpose*

The objective of this review is to summarize the literature regarding clinical investigations comparing CBT to PS, in order to assess needs for future research and elucidate differences in both operative outcomes and complications. This will be achieved through a systematic review, following recommended guidelines (24,25).

### *Search strategy and study selection*

A comprehensive search of published reports was performed via six electronic databases; namely, Ovid Medline, PubMed, Cochrane Central Register of Controlled Trials, Cochran Database of Systematic Reviews, American College of Physicians Journal Club and Database of Abstracts of Review of Effectiveness from their date of inception to [INSERT DATE]. To maximise the sensitivity of the search strategy, the terms; "cortical bone", "cortical bone trajectory", "CBT", "medial-lateral superior trajectory", "spine", and "pedicle screw" were combined as either key words or MeSH terms. The reference lists of all retrieved articles were reviewed to identify additional potentially relevant studies.

Eligible studies for the present systematic review included those in which cohorts undergoing CBT and PS procedures were directly compared. Studies that did not provide direct comparison of CBT and PS, or that did not report data on outcomes or complications were excluded. Abstracts, case reports, conference presentations, editorials, reviews and expert opinions were excluded.

### *Quality assessment*

Studies were independently assessed for quality by two investigators (K Phan, RJ Mobbs) using the GRADE criteria (26). Discrepancies between the two reviewers were resolved by discussion and consensus.

## Results

### *Included studies and quality of evidence*

An extensive literature search identified nine relevant papers comparing CBT and PS methodologies for lumbosacral spine fusion (*Figure 1*) (27-35). All studies were classified as either retrospective cohort, prospective cohort, or case-control. The quality of evidence for all papers, using the GRADE criteria, was estimated to be low to medium based on the observational nature of the studies. More than half of the relevant studies had ≥40 patients with a third of all relevant studies exceeding 100 patients.

### *Baseline characteristics*

*Table 1* shows the baseline characteristics for each study that met inclusion criteria for comparison of CBT and PS including age, sex, diagnosis, vertebral level involvement, and average follow-up. Only one study, Chen *et al.*, identified that there was no statistically significant difference between CBT and PS groups based on smoking status (27). Additionally, both Chin *et al.* and Takenaka *et al.* identified no difference in CBT and PS groups based on body mass index (28,35).

### *Intraoperative & postoperative outcomes and complications*

*Figure 2* shows an overall analysis of intraoperative outcomes, postoperative outcomes, and complications analyzed by all papers included in the systematic review. It delineates the specific findings of each study specifically comparing CBT to PS and highlights the significant gap that is present in the literature for commonly reported outcomes and complications.

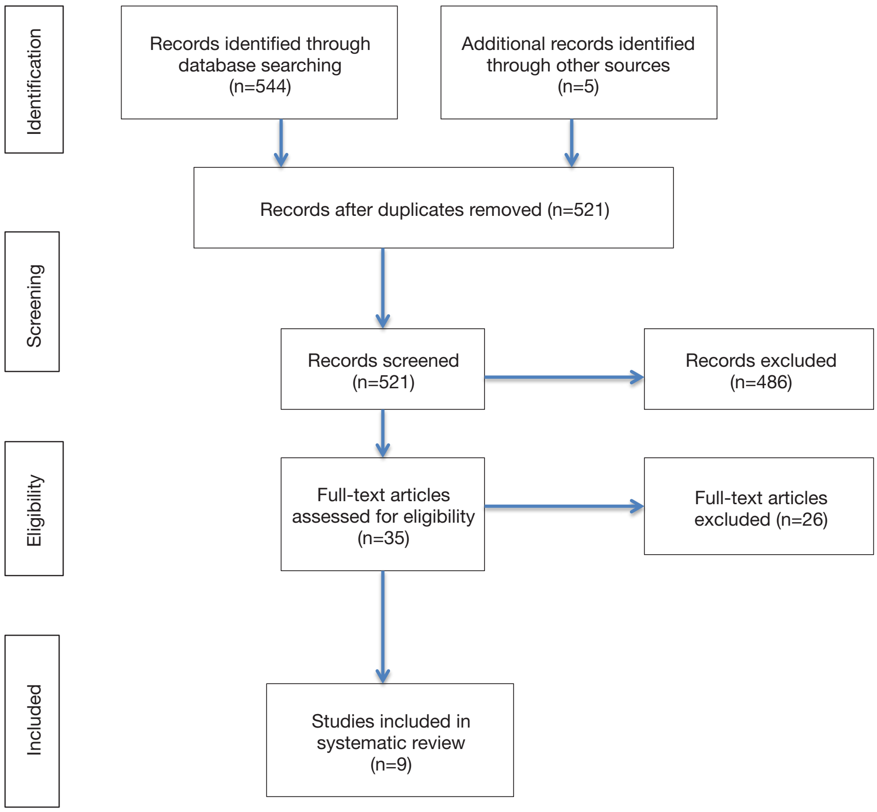


**Figure 1** PRISMA chart for search strategy of the present systematic review.

## Discussion

### *Previous studies*

Alternative cortical trajectories for pedicle fixation in lumbar fusion have been proposed in clinical practice for over a decade. Steel *et al.* reported applying a medio-lateral superior trajectory for monosegmental screw fixation in patients with a thoracolumbar burst facture (8). After the initial description of CBT by Santoni *et al.* in 2009, several biomechanical studies were performed to evaluate the stability of the technique relative to traditional PS (7,12,16-18) although clinical evidence remained limited (15,19-23).

These authors previously reviewed the literature on the biomechanical, morphometric and clinical outcomes of CBT, and concluded that the available data were too few to allow for a definite evaluation of its merits; though CBT appeared to offer several advantages over the traditional PS approach (9). Several clinical studies have since been conducted that compare complications and outcomes between CBT and PS. A further review of the evidence is therefore warranted.

### *Techniques for CBT versus PS*

The traditional PS approach to lumbosacral spine surgery, currently the standard of care, requires extensive lateral spinal dissection for screw placement. In contrast, the CBT procedure requires less soft tissue exposure as screws are placed medially to laterally with a starting point at the junction between the lateral pars interarticularis and superior articular process (1 mm inferior to the inferior border of the transverse process, which was projected to the 5 o'clock orientation in the left pedicle and the 7 o'clock orientation in the right pedicle). *Figure 3* shows the contrast in the trajectories of screw placement for both PS and CBT procedures in various planes (15). Recent trends have demonstrated a transition towards minimally invasive surgical approaches over traditional invasive approaches (16). Since CBT requires less dissection of the spine and smaller incisions than PS, it is considered to be the more minimally invasive of the two approaches.

**Table 1** Baseline characteristics of studies comparing CBT and PS

| First author | Total Pts | Average age (years) | | Sex (%) | | | Diagnosis | Level involvement | | | | | | | Avg F/U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Overall | P | Total (M) | Total (F) | P | | L1–L2 | L2–L3 | L3–L4 | L4–L5 | L4–S1 | L5–L6 | L5–S1 | |
| Chen | 33 | 56 | 0.12 | 39.4 | 60.6 | 0.01 | Lumbar degenerative disease | | | | | | | | Immediate (24–72 hrs)<br>Short-term (6–12 weeks)<br>Long-term (6–8 months) |
| Chin | 60 | 58 | 0.61 | 55 | 45 | 0.49 | Multi lumbar disk | | | | | | | | 2 years |
| Kasukawa | 26 | 67 | – | 11 | 15 | – | Spondylolisthesis | | | Y | Y | | | Y | CBT-TLIF 8 months<br>M-TLIF 16 months<br>P-TLIF 13 months |
| Kojima | 222 | 66 | – | 49.5 | 50.5 | – | Lumbar degenerative | | | | | | | | – |
| Mori | 32 | – | – | – | – | – | Spondylolisthesis | | | | | | | | Preoperative<br>Post-operative (1 month)<br>Latest F/U (24 months) |
| Ninomiya | 21 | – | 0.83 | – | – | 0.53 | Spondylolisthesis | | | Y | Y | | | | Preoperative<br>Immediately post-op<br>6 months<br>12 months |
| Orita | 40 | 63.6 | >0.05 | 57.5 | 42.5 | – | Spondylolisthesis | | | | Y | | | Y | CBT: 12.8+/-3.2 months<br>PS: 17.8+/-5.5 months |
| Sakaura | 177 | – | – | 46 | 54 | – | Spondylolisthesis | Y | Y | Y | Y | | Y | Y | CBT: 35 months<br>PS: 40 months |
| Takenaka | 119 | – | 0.997 | 49 | 70 | – | Spondylolisthesis | | Y | Y | Y | Y | Y | Y | 12 months |

CBT, cortical bone trajectory; PS, pedicle screw; Pts, patients; Avg F/U, average follow-up; Y, yes; TLIF, transforaminal lumbar interbody fusion.

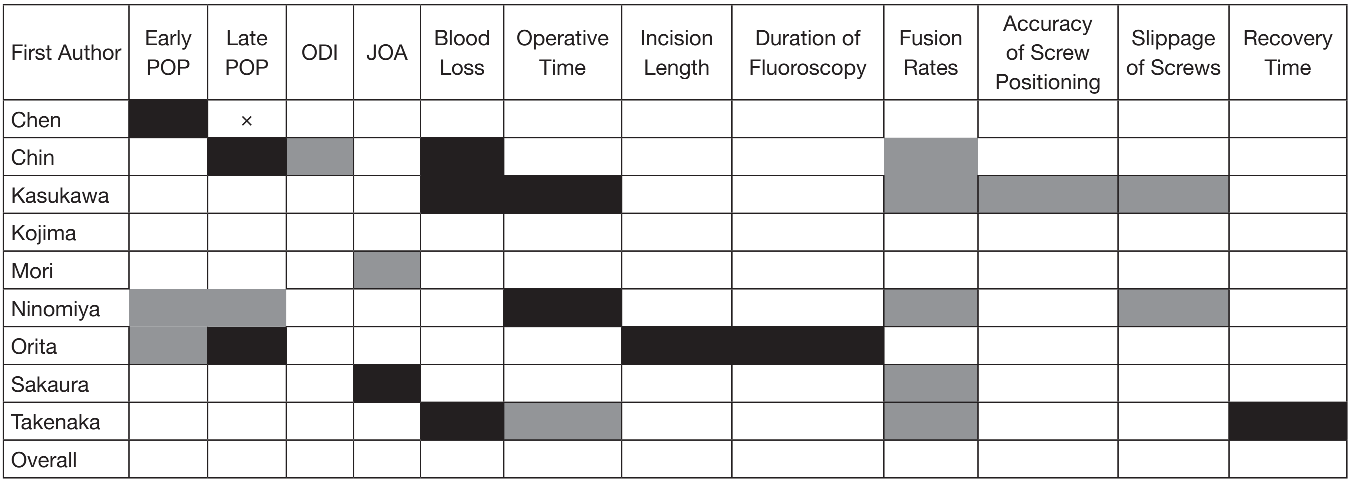


**Figure 2** Complications and outcomes from studies comparing CBT and PS. black, CBT > PS; grey, CBT = PS; ×, CBT < PS; white, no data. POP, postoperative pain; ODI, Oswestry Disability Index Score; JOA, Japanese Orthopedic Association Score; CBT, cortical bone trajectory; PS, pedicle screw.

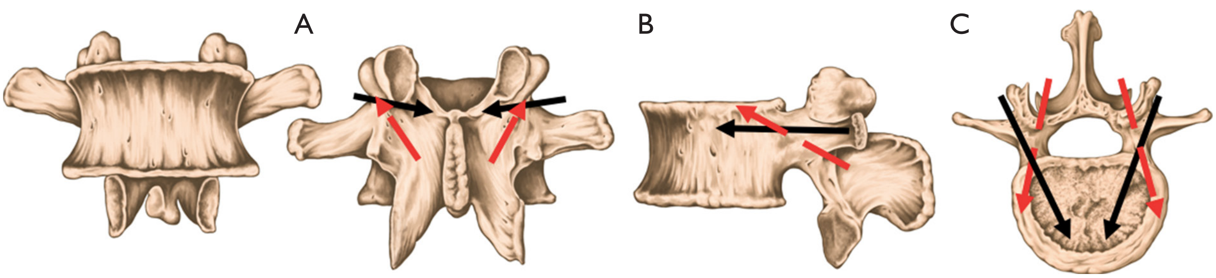


**Figure 3** Screw trajectories of traditional pedicle screw (PS, black arrows) trajectory and cortical bone trajectory (CBT, red broken arrows). (A) coronal plane; (B) sagittal plane; (C) axial plane.

### *Pain*

With the exception of Ninomiya et al, pain was evaluated utilizing the visual analog scale (VAS) Pain score (32). Chen *et al.*, Chin *et al.*, Orita *et al.*, Ninomiya *et al.*, and Takenaka *et al.* all reported no significant differences in preoperative back or leg pain among their subjects (P>0.05) (27,28,32,33,35). Orita *et al.* and Ninomiya *et al.* saw a decrease in pain among both CBT and PS cohorts postoperatively. However, there was no significant difference between the CBT and PS cohorts at the 1-, 3-, 6-, or 12-month follow-up (32,33). Chen *et al.* described no difference in postoperative back pain immediately after surgery between the two cohorts, but noted that the CBT cohort had a significantly higher VAS pain score at the final 8-month follow-up (6.14 *vs.* 3.8, P=0.02) (27). Chin *et al.* also described no differences in postoperative back pain immediately after surgery between the two cohorts, but noted that the PS cohort had a significantly higher VAS Pain score at two-year postoperative follow-up. Additionally, no difference was elicited in leg pain postoperatively between the CBT and PS cohorts (P=0.169) (28).

Overall, the majority of literature suggests that the CBT technique results in similar or decreased postoperative pain compared to the more traditional PS technique. Lee *et al.* suggested that the decrease in immediate postoperative period associated with CBT technique was due to the smaller incision size, decreased disruption of muscle attachments and soft-tissue dissections. In their study, Lee *et al.* found that cortical screws were associated with lower immediate postoperative pain (within one week of surgery) compared to pedicle screws. However, long-term pain was similar in both groups (36).

### *Oswestry Disability Index (ODI) score*

Disability was evaluated utilizing the ODI. Chin *et al.* reported no significant differences between the CBT and PS cohorts preoperatively (40.8 *vs.* 44.6, P=0.053). The CBT cohort was found to have a significant reduction in ODI score compared to the PS cohort postoperatively (28.7 *vs.* 32.5 respectively, P=0.027). This was attributed to the ability to preserve anatomy, decreased operative time, decreased dissection, intraoperative blood loss, and less postoperative pain (28).

### *Complications*

Complications were described extensively in Sakaura *et al.* and Takenaka *et al.* Intraoperatively, Sakaura *et al.* and Takenaka *et al.* described no significant differences in misplacement of screws among the two cohorts, with Sakaura *et al.* specifically reporting 2.1% in CBT placement and 3.7% in PS placement (34,35). It is likely that misplacement of screws is due more to surgical technique rather than approach. Kuo *et al.* showed that with the help of radiographic guidance, the accuracy of placement of lumbar screws was determined to be 94% before repositioning and 98.74% after repositioning (37).

Postoperatively, Sakaura *et al.* and Takenaka *et al.* described no significant differences with dural tears, symptomatic hematomas, superficial wound infections, or deep wound infections among the CBT and PS cohorts. Both saw increased incidence of dural tears among the PS group (3.7% and 2.1% respectively). However, this was not found to be statistically significant. With regards to the incidence of symptomatic hematoma, Takenaka *et al.* reported a higher incidence in the CBT cohort (2.4% *vs.* 0%) while Sakaura *et al.* reported similar incidences among both groups (1.1% *vs.* 1.2%). Both studies found the incidence of symptomatic hematoma to be similar between CBT and PS cohorts. With regards to rates of wound infection, both Sakaura *et al.* and Takenaka *et al.* found no significant differences between the rates of superficial or deep wound infections in either group (P>0.05). However, Sakaura *et al.* did notice a higher incidence of superficial wound infection in the CBT cohort (2.1% *vs.* 0%), and both papers noted a higher incidence of deep wound infection in the PS cohort (34,35). Hegde *et al.* suggests that rate of infection can be correlated to length and complexity of surgical procedures. The increased duration of surgery, dissection, and postoperative dead space are factors that may explain this finding (38).

### *Operative time*

Operative time is an important consideration in assessing different techniques as increased operative duration may result in higher rates of infection, post-operative complications, and intra-operative outcomes such as increased blood loss (39-41). Several studies have investigated operative time in lumbar fusion procedures utilizing CBT and PS techniques. Three studies (Chin *et al.*, Sakaura et al., and Takenaka *et al.*) directly compared operative times for CBT and PS procedures. Of these three studies, only Sakaura *et al.* demonstrated significant findings in that PS procedures were longer in duration (145±33 min) than lumbar fusions performed via CBT (123±16 min) (P<0.01). The other two studies, Chin *et al.* (P=0.084) and Takenaka *et al.* (P=0.672), showed no difference in operative time between the procedures (28,34,35). Orita *et al.* showed that percutaneously-performed CBT (147.3±23.3 min) and PS (144±19.2 min) did not vary in operative time (P=0.252) (33). Kasukawa *et al.* compared operative times of CBT (209±49 min) to PS inserted via conventional minimally invasive (198±51 min) or percutaneous methods (243±26 min). None of these values were statistically different when compared and the mean PS time between the two techniques was 214.9 minutes (29). Overall, operative times between the procedures did not vary significantly. In a wide variety of surgical fields, proper surgical technique has been associated with improved patient outcomes (42,43). This is true for spine surgery as well (44). As such, in deciding between CBT and PS, operative time may not be as important of a criterion in selection of an approach compared to a surgeon's comfort with the technique and other factors that may portend patient outcomes in the peri-operative period. *Figure 4* shows the complete comparison between intraoperative times of CBT and PS in five different studies.

### *Blood loss*

Blood loss is an important consideration in comparing different surgical techniques due to its impact on post-operative mortality (45). Analysis of the literature revealed four studies reporting blood loss for CBT and PS

 

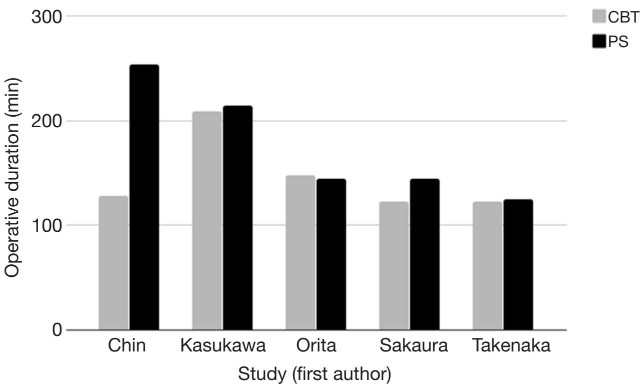


**Figure 4** Comparison of intraoperative time by study. CBT, cortical bone trajectory; PS, pedicle screw.

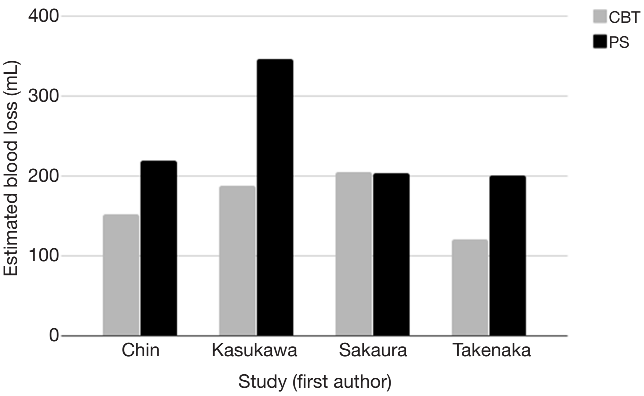


**Figure 5** Comparison of estimated blood loss by study. CBT, cortical bone trajectory; PS, pedicle screw.

procedures. Chin *et al.* demonstrated that CBT resulted in less blood loss (152 mL) compared to PS (219 mL) ($P<0.05$) (28). Similarly, Takenaka *et al.* showed that CBT (120 mL) had less blood loss than PS (201 mL) ($P<0.001$) (35). Kasukawa delineated blood loss in PS procedures by those performed percutaneously (210±114 mL) and those performed via conventional minimally invasive techniques (429±289 mL), the weighted mean of which is represented in *Figure 5*. Their investigation showed that intraoperative blood loss was significantly less with CBT (188±167) compared to the conventional minimally invasive PS approach (29). Sakaura *et al.* showed no difference between intraoperative blood loss in CBT (205 mL) and PS (204 mL) procedures (34). Overall, these findings show that the CBT approach may yield less blood loss than PS approaches and may be an important consideration in determining surgical approach to lumbar fusion in patients who are higher risk surgical candidates. Additionally, it may be of importance in patients which chronic medical conditions such as chronic kidney disease and cardiac failure in whom anemia is commonplace or hemodynamic stability precipitated by blood loss may lead to adverse post-operative outcomes (46).

### *Japanese Orthopedic Association (JOA) Score*

Some clinical research studies investigating lumbar fusion have utilized the JOA scale scoring system to assess the results of treatment for low-back pain. In the normal population, the total JOA score is a full 29 points. Specifically, the JOA evaluates symptoms, functionality, and clinical signs of low-back pain and may be used in pre- and post-operative evaluation of patients (47). Mori *et al.* showed that mean post-operative (25±2.0, $P<0.001$) and latest follow-up JOA scores (25±1.8, $P<0.001$) were significantly increased from mean pre-operative scores (12±4.9) in patients who underwent CBT (31). Sakaura *et al.* investigated JOA scores in patients who underwent CBT or PS. In the CBT cohort, pre-operative (13.7±4.6) and post-operative (23.3±4.71) JOA scores were significantly improved when compared ($P<0.001$). Similarly, in the group undergoing PS, pre-operative (14.4±3.9) and post-operative (22.7±3.71) JOA scores were improved significantly as well. While pre-operative scores between the cohorts were not significantly different, the recovery rate of JOA scores in the CBT group (64.4%±25.9%) was significantly higher than in the PS group (55.8%±26.4%) ($P<0.05$) (34).

Both CBT and PS greatly improve post-operative JOA scores, indicating improvement in patient overall quality of life from low-back pain. However, comparisons are lacking between CBT and PS to elucidate these techniques' impact on patients' self-reported outcomes. Prior low back pain research has revealed that patient-reported outcome indices such as the pain self-efficacy questionnaire (PSEQ) and the patient-specific functional scale (PSFS) are the most responsive scales in measuring changes in patients with chronic low back pain following a back class exercise regimen (48). By incorporating such scales in CBT and PS studies, self-reported patient outcomes may be better recorded. This may allow for enhanced selection of surgical technique based not only on quantitative surgical peri-operative measures, but also based on patient-reported measures which may be of equal importance.

### *Radiographic analysis of outcomes*

Radiographic analysis of outcomes of CBT and PS can be used to assess fixation and bone density at the sites of fusion, providing another methodology to assess outcomes in these procedures. Ninomiya *et al.* showed that both CBT and PS result in a statistically significant decrease in percentage slippage for patients with lumbar degenerative spondylolisthesis immediately post-operatively, 6 months post-operatively, and one year post-operatively (P<0.05). Additionally, there was no significant loss of slippage percentage in CBT and PS at 6- and 12-month follow-up. However, neither CBT nor PS changed lumbar lordosis significantly at one-year postoperative follow-up (32). These findings denote that both CBT and PS are highly effective in adequately addressing the slippage percentage in patients with lumbar spondylolisthesis. However, further research is required to address residual lordosis and corroborate findings.

In another radiologic analysis, Kojima *et al.* utilized computerized tomography (CT) to assess pedicle screw-cortical bone contact between CBT and PS implanted screws. The investigation had several findings. There is a statistically significant difference in the Hounsfield units (HU) (a CT number used as a measure of bone density) between individuals >70-year-old and <70-year-old for both CBT and PS (P<0.001) at L4 and L5. Additionally, males have higher HU than females at L4 and L5 at baseline. In comparing CBT performed at L4 (726.7±13.61) and L5 (711.4±20.58), there was no difference in HU. The same was found for PS performed at L4 (171.3±4.01) and L5 (173.3±4.88). However, there is a statistically significant difference in HU between CBT and PS at L4 (P<0.0001) and L5 (P<0.0001) (30). These findings suggest that CBT results in richer cortical bone at the site of screw placement, perhaps alluding to its utility for anchoring pedicle to the vertebrae. This is especially pertinent when performing procedures on older patients, who often have diminished bone density. In fact, the average age of the patient population undergoing lumbar fusion has been increasing, heightening the importance of considering techniques with increased cortical bone purchase (49).

## Conclusions

There is no widely accepted consensus regarding comparison of outcomes and complications between the CBT and PS procedures. Generally, indications for CBT and PS are similar between most studies, especially for common pathologies resulting in spondylolisthesis. In terms of intraoperative outcomes, most studies found no significant differences between operative time, but found that CBT has less blood loss than PS. Post-operative outcomes including pain have inconclusive results as some studies found more post-operative pain for CBT while others found more post-operative pain with PS. Radiologic studies show no difference in slippage within one-year of follow-up after CBT and PS, but there is a significant difference in resulting bone density post-procedure for CBT when compared to PS, which has tremendous implications on stability for lumbosacral spine surgeries in elderly patients. Future studies, including randomized controlled trials, would control for more confounding factors and offer stronger evidence towards choosing CBT versus PS. The current literature reveals significant gaps in measurement of both patient-reported outcomes and quality metrics that impact the decision of both patients and surgeons when evaluating the benefits and risks of both CBT and PS procedures.

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## Footnote

*Conflicts of Interest*: The authors have no conflicts of interest to declare.

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