The Era of Cortical Bone Trajectory Screws in Spine Surgery: A Qualitative Review with Rating of Evidence

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Key words
- Biomechanics
- Cortical bone trajectory
- Cortical screws
- Posterior fixation
- Spine surgery
- Surgical technique

Abbreviations and Acronyms
3D: Three-dimensional
CBT: Cortical bone trajectory
CT: Computed tomography
MIS: Minimally invasive surgery
PLF: Posterolateral fusion
PLIF: Posterior lumbar interbody fusion
PT: Pedicle trajectory
TLIF: Transforaminal lumbar interbody fusion

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Citation: World Neurosurg. (2020) 134:14-24.
https://doi.org/10.1016/j.wneu.2019.10.079

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

The use of cortical bone trajectory (CBT) pedicle screws for posterior fixation and fusion seems to constitute a viable alternative for spinal procedures, with the potential to mitigate risks, be minimally invasive, and cause less tissue damage than the traditional technique. This review analyzes the literature regarding CBT according to the rate of evidence of articles and their main focus. CBT has proved to be a safe and viable option for screw fixation in spine surgery. Given the denser bone interception, high-quality biomechanics studies show equal or even better properties compared with classic pedicle screw fixation, depending on several factors such as screw size and length. Through the years, surgical technique has improved to gain a longer and safer trajectory than first described. Level 2 and 3 clinical studies suggest equal clinical and radiologic outcomes compared with pedicle trajectory fixation, but high-quality, level 1, randomized controlled trials are needed to confirm these results.

INTRODUCTION

The use of cortical bone trajectory (CBT) pedicle screws for posterior fixation and fusion seems to constitute a viable alternative for spinal procedures, with the potential to mitigate risks, be minimally invasive, and cause less tissue damage than the traditional technique. Its use is spreading among spine surgeons, so that the number of reports and publications dealing with this topic in the English literature has increased beyond measure. Still few prospective series have investigated clinical or radiologic outcomes of CBT fixations with a long-term follow-up, and the surgical technique along with its technological developments and the understanding of variations of biomechanics have been further improved and documented. The aim of this review was to analyze the state of the art of the technique and to examine the medical evidence published on this topic.

METHODS

Selection criteria and references for this review were identified by searching PubMed, using the terms "cortical bone trajectory," "cortical bone trajectory screws," "cortical pedicle screws," and "cortical screws." Only articles published in English, until June 10, 2019 were reviewed. Inclusion of the references was based on the scope of this review, according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines[1] (**Figure 1**). Studies were then analyzed according to their main focus and divided into groups: "biomechanics investigation," "surgical technique," "clinical/radiological studies." Each article was classified according to its evidence rate using the modified Sackett grading system proposed by the *Journal of Bone and Joint Surgery, American Volume*.[2] Descriptive clinical or radiologic studies were all included in level IV. Some studies did not satisfy the grading system, which was not applicable in those cases.

BIOMECHANICS INVESTIGATIONS

Biomechanical properties were studied in most cases with cadaveric tests and computational analysis. Only few in vivo evaluations exist. Santoni et al.[3] first reported a description of CBT technique and showed the equivalent pullout and toggle characteristics compared with the traditional convergent pedicle trajectory (PT) in a human cadaveric biomechanics study. Although other studies confirmed these findings,[4,5] Baluch et al.[6] found no differences in axial pullout strength between the 2 techniques but showed superior resistance in toggling of CBT screws. Other studies showed no differences in mechanic tests using CBT with smaller screws, suggesting considerations about the superior quality of intercepted bones,[7,8] as confirmed by radiologic studies.[9-11] Perez-Orribo et al.[12] performed standard nondestructive flexibility tests comparing PT and CBT, confirming the same stability regardless of the presence and the type of an interbody support.

Matsukawa et al.[13] first highlighted in an in vivo study that the insertional torque of the CBT technique was higher than in the PT technique. Subsequently, in a study with the finite element

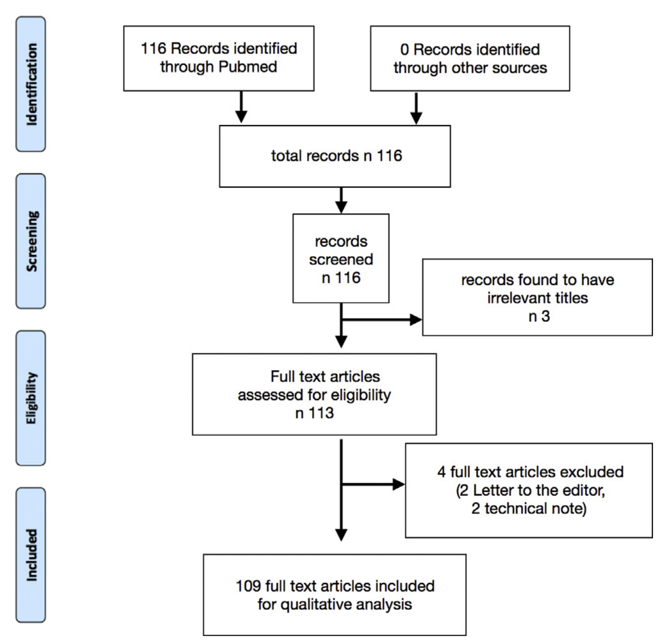

Figure 1. PRISMA flowchart.

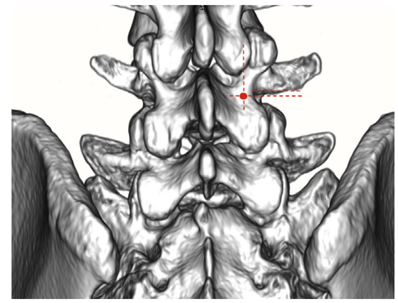

Figure 2. Standard ideal entry point described by Matsukawa et al.[31]: junction of an ideal vertical line traced through the center of the superior articular process and an ideal horizontal line traced 1 mm inferior to the inferior border of the transverse process.

method,[14] these investigators showed superior fixation strength for each individual CBT screw compared with PT (mean pullout strength and mean stiffness during cephalocaudal and mediolateral loading) along with higher resistance to flexion and extension loading, but with lower resistance to lateral bending and axial rotation. Mechanical data were shown to vary depending on technical factors of screw placement, bone quality,[15] and, above all, screw size and length,[16] factors that were later confirmed after other cadaveric tests.[17,18] The use of longer screws with bigger size was shown to be related to best biomechanical properties compared with PT fixations.[13,14] Some investigators described modified trajectories in an attempt to strengthen fixation: Matsukawa et al.[19] described the satisfactory cross-trajectory, whereas Sakaura et al.[20] presented worse results in lumbosacral fixation with an articular entry point. Grigoryan et al.[21] evaluated a feasible S1 trajectory according to the CBT technique to achieve more stability.

Few studies evaluated the biomechanics of CBT in spondylolisthesis. Some investigators found no differences in the range of motion after fixation of cadaveric spine (Cheng et al.[22]) and in radiologic reduction evaluation (Ninomiya et al.[23]) in low-grade spondylolisthesis between CBT and PT screws. In isthmic spondylolisthesis, PT was shown to have a better biomechanical profile but further studies are needed.[24] An in vivo study by Ninomiya et al.[25] recommended extreme caution with the CBT technique in patients with lysis who are aged ≥75 years. Bone quality seems to be a key point. A study focused on this topic[26] and showed that Hounsfield unit values could be a strong predictor of both primary and long-term screw fixation in vivo. Only 1 study described a better fatigue performance of PT screws compared with CBT screws in vertebrae with compromised bone quality.[27]

The general consensus, as confirmed by this review and others in the past,[28,29] is that CBT fixation seems to have at least equal biomechanical properties compared with PT fixations. The denser bone intercepted could justify the results, even with the use of smaller screws because of the shorter corridor. Screw size and length seem to play a key role in reaching a real advantage over PT technique. In low-grade spondylolisthesis, the CBT technique proved to be equally effective. No evidence supports the use of CBT for isthmic spondylolisthesis.

SURGICAL TECHNIQUE

Standard Technique and Morphometric Measurements

Santoni et al.[3] first presented the new cortical trajectory in 2009 describing summarily a path with a caudocephalad direction in the sagittal plane and a mediolateral direction in the transverse plane in the transverse plane. Mobbs[30] first described a standard sequence for the procedure, choosing a starting point medially on the pars and proceeding with a 2-mm high-speed round burr drill, to minimize the risk of fracture in the pars. In the caudocephalad path, the target seemed to reach the posterior third of the upper end plate whereas the mediolateral trajectory was not specified. Matsukawa et al.[31] first identified in 2013 the ideal entry point, in a radiologic study of 100 adults, with the aim of investigating lumbar pedicles and ideal CBTs: the entry point was described to be at the junction of an ideal vertical line traced through the center of the superior articular process and an ideal horizontal line traced 1 mm inferior to the inferior border of the transverse process (Figure 2). Regarding the mediolateral and caudocephalad directions, the trajectory seemed to vary according to the lumbar level but was described to be about 25° for the cephalad angle and 9° for the lateral angle, trying to follow

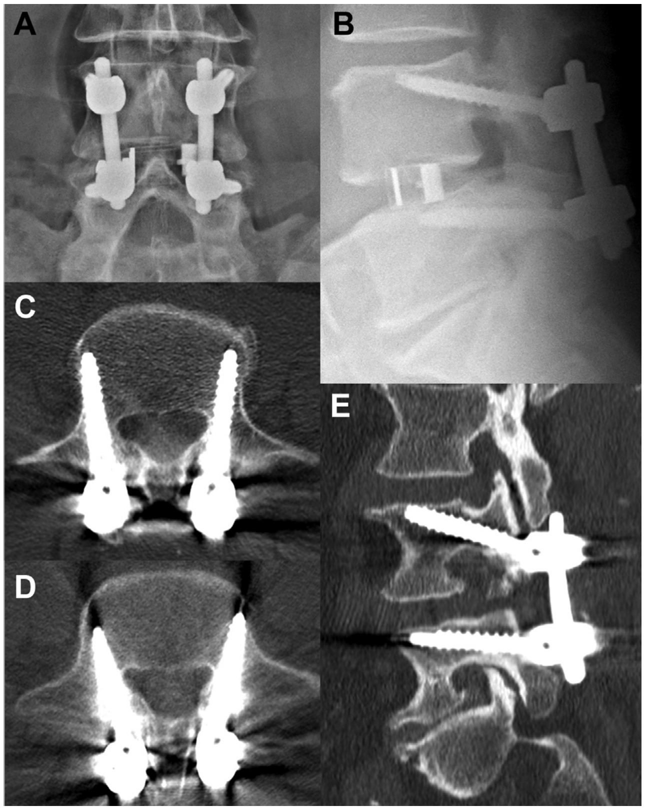

Figure 3. Postoperative radiographs of an L4-L5 transforaminal lumbar interbody fusion performed with cortical bone trajectory screws (**A, B**). The most high-density bone is reached through the divergent and caudocephalad path of the screws as shown on a postoperative computed tomography scan (**C**–**E**).

Mobbs technique and in accordance with other studies in that period.[32,33]

Matsukawa et al.[34] also described the sacral CBT in a radiologic study, with the entry point at the junction of the center of the superior articular process of S1 and approximately 3 mm inferior to the most inferior border of the inferior articular process of L5. The direction was straight forward in the axial plane without convergence, angulated cranially in the sagittal plane, penetrating the middle of the sacral end plate. The mean cephalad angle was found to be about 30°. The sacral end plate penetrating screw seemed to gain more stability against loosening and higher pullout force, as confirmed by Grigoryan et al.[21]

Regarding size, the mean length was in a range of 36.8–39.8 mm investigating all lumbar pedicles and 31.5 ± 3.5 mm for S1.[31] Zhang et al.[35] identified in a radiologic study the maximum theoretic screw diameters from L1 to S1 to be about 4.8, 5.1, 6.1, 6.8, 7.8, and 6.1 mm, respectively, thus further confirming previous reports by Matsukawa et al.[31]

Modified Trajectories and Different Applications

Early landmark studies were followed by other studies describing modified trajectories: more or less pronounced cephalad or lateral angles have been proposed, as have hybrid constructions, even for different application after anecdotal reports of clinical complications.[32,36-44] First reviewed experiences[45-47] encouraged the use of this technique also for trauma and deformity surgery. Goldstein et al.[48] described the use of CBT screws to treat a single-level spondylolysis fracture. Mijakoshi et al.[49] successfully treated an L2 flexion-distraction fracture. Dual trajectories and fixations have been proposed as an option in osteoporotic patients or in patients with adjacent segment disease, who underwent previous pedicle instrumentation, or in spinal deformity surgery.[50-53]

The use of CBT screws has been proposed and described also for thoracic spine fixation, with promising technical results, both in adults and pediatric patients, analyzing the feasibility of the technique together with different angles of trajectory, length, and size of the screws.[54-61] Orita et al.[62] described a percutaneous CBT fixation on 20 patients and compared it against percutaneous pedicle screw fixation, with comparable outcomes and safety.

Given the reduced visual exposure and the peculiarity of the technique, the use of neuromonitoring has been added and described as an important tool to avoid damage to nervous structures.[63,64] For the same reason, modular head screws have been developed to widen surgical exposure, easing decompression maneuvers given the medial entry point, and a study[65] showed a significantly lower fracture rate of modular than of preassembled head screws.

Shifting to a New Paradigm in Surgical Trajectory

After years of anatomic studies and trying to identify the optimal entry point and angulation, a new way of conceiving CBT arose. The need for a customized trajectory for the anatomy of the single patient gained importance, to reach a concrete biomechanical advantage on PT screws. Given that most CBT arthrodeses come from degenerative disease, investigators started to notice that the degenerative process does not always allow for easy and perfect identification of the isthmus. Furthermore, every patient's vertebrae present slight differences from one another, making it difficult to standardize the perfect trajectory. For this reason, many of the articles outlined earlier described the trajectory with similar but different ranges of angulation. Matsukawa et al.[15] first underlined the need for varying CBT screw fixation according to patient anatomy, particularly in terms of bone mineral density. In this view, trajectory measurements could be used only as a guide in clinical practice.[66] Senoglu et al.[67] gave a comprehensive analysis of anatomic variations with a radiologic study, suggesting a detailed computed tomography (CT) scan examination before the procedure to determine the ideal fixation.

With technological advancements, new tools have contributed to facing this challenge. Neuronavigation and robot-assisted techniques are considered more accurate and safer techniques than freehand fluoroscopy-aided placements, according to recent studies in CBT fixation.[68] First conceived for deformity surgery, three-dimensional (3D) printed patient-matched drill guides have been described for CBT screw placement, with encouraging results in terms of accuracy in cadaveric studies.[69-71] Marengo et al.[72] described for the first time the promising results of a clinical study investigating the accuracy of 3D guides in a series of 11 patients. Questions still remain about the use of navigation and guides, considering radiation exposure for the patient, costs, and availability in common spine centers. 3D printed guides could represent a promising strategy in selected cases of important anatomic degeneration, thus sustaining lower costs compared with CT-based neuronavigation. However, they require time for planning and a learning curve for surgery. A real in-between strategy could involve accurate CT planning with 3D reconstruction for a visual aid during procedures, as described by the experience of Penner et al.[73]

CLINICAL/RADIOLOGIC STUDIES

The first articles describing clinical and radiologic outcomes of CBT fixation analyzed small case series with conflicting conclusions: whereas some of them highlighted the safety of the technique and experienced satisfactory results,[33,74-77] showing less blood loss and a shorter operative duration against PT fixation with similar rates of bone union,[75] conversely, others focused on complications, which occurred after surgery. Glennie et al.[78] revised 2 of 8 patients with frank screw loosening. Patel et al.[79] described 22 cases, and among them 2 patients developed early screw loosening, 1 developed an intraoperative pars fracture, and 1 patient developed both a pedicle fracture as well as early screw loosening.

These opposing reports, among other reasons, were likely to the result of the small size of the studies and as a result of the necessary learning curve, as confirmed by the changes in the surgical technique strategy outlined earlier. The first comparison between CBT and PT fusion was reported in 2015 by Lee et al.[80] in a prospective randomized noninferiority trial. Seventy-nine eligible patients were randomly assigned to either CBT or PT fusion. The primary study end point was to measure the fusion rate. Secondary end points included intensity of lower back pain and pain radiating to the leg using visual analog scales, and also functional status using the Oswestry Disability Index, surgical morbidity, and additional outcomes such as pedicle fracture and mechanical failure. At 6 and 12 months follow-up, similar fusion rates were observed in both groups ($P = 0.81$ and 0.61, respectively). As for clinical outcome, CBT fusions provided similar improvements in pain amelioration and functional status compared with PT. In addition, CBT fusion also resulted in significantly shorter incision length, quicker operative time, and less blood loss, compared with PT fusion. Therefore, CBT screws in posterior lumbar interbody fusion (PLIF) provided similar clinical and radiologic outcomes compared with PT screws in PLIF.

A large series of CBT fixations was reported by Snyder et al. in 2016.[81] A total of

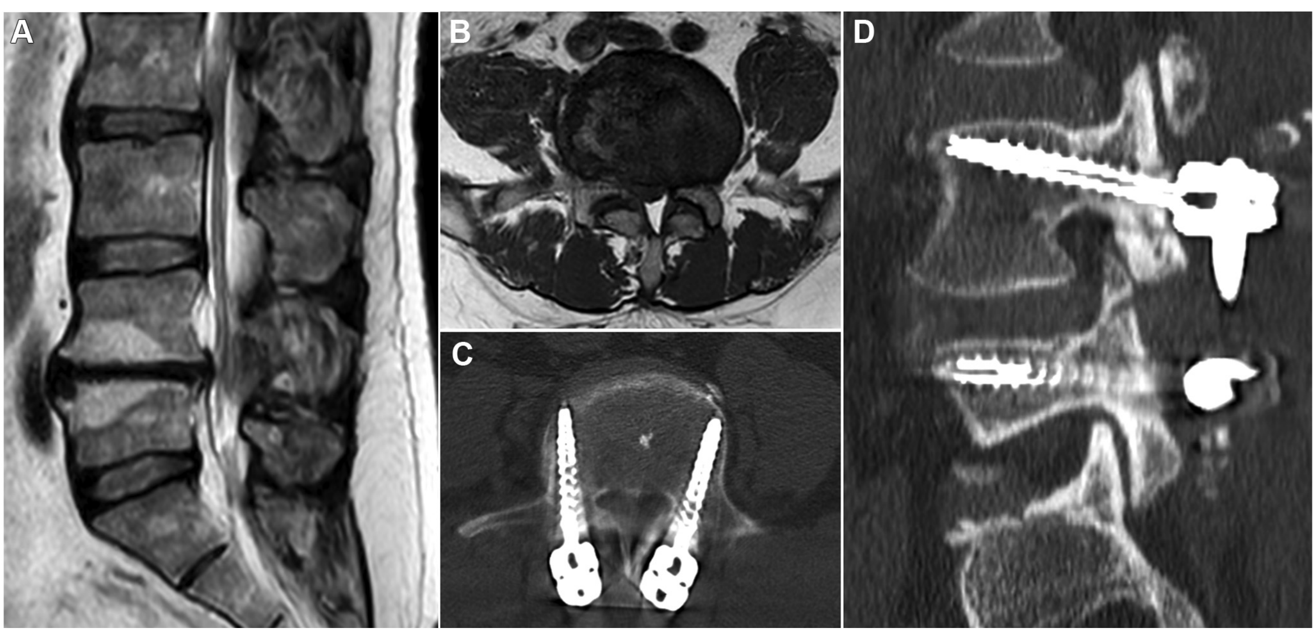

Figure 4. L4-L5 advanced discopathy in a patient with bilateral sciatalgia and back pain (**A, B**). A cortical bone trajectory—transforaminal lumbar interbody fusion was performed et al. (**C, D**).

Table 1. Cortical Bone Trajectory Biomechanics Studies

Study Number	Reference	Evidence Rate
1	Santoni et al., 2009[3]	2
2	Perez-Orribo et al., 2013[12]	2
3	Matsukawa et al., 2014[13]	2
4	Baluch et al., 2014[6]	Not available
5	Ueno et al., 2015[4]	4
6	Wray et al., 2015[7]	2
7	Kojima et al., 2015[9]	2
8	Matsukawa et al., 2015[14]	2
9	Matsukawa et al., 2015[15]	2
10	Oshino et al., 2015[5]	2
11	Phan et al., 2015[47]	2/3
12	Cheng et al., 2015[22]	2
13	Matsukawa et al., 2015[19]	4
14	Ninomiya et al., 2015[11]	3
15	Akpolat et al., 2016[27]	2
16	Mai et al., 2016[10]	4
17	Matsukawa et al., 2016[16]	4
18	Matsukawa et al., 2016[24]	4
19	Ninomiya et al., 2016[23]	3
20	Sansur et al., 2016[17]	2
21	Mobbs et al., 2016[108]	N/A
22	Sakaura et al., 2016[20]	4
23	Ninomiya et al., 2016[25]	3
24	Matsukawa et al., 2017[8]	4
25	Delgado-Fernandez et al., 2017[28]	2/3
26	Phan et al., 2017[29]	2/3
27	Matsukawa et al., 2018[26]	3
28	Grygorian et al., 2019[21]	2

79 patients were included in a retrospective analysis between October 2011 and January 2015. Mean length of hospital stay was 3.5 days, and mean operative blood loss was 306.3 mL. Image guidance was used in 69 cases (87.3%). A total of 66 fusions (83.5%) were single level and 54 fusions (68.4%) were single level without previous surgery. There were 9 complications in 7 patients (8.9%), which included hardware failure, pseudarthrosis, deep vein thrombosis, pulmonary embolisms, epidural hematoma, and wound infections. No complications were caused by misplaced screws. Mean follow-up was 13.2 months. No conclusions were made about functional or radiographic outcomes, because of the lack of a minimum follow-up for all patients (12 months).

Khanna et al.[82] presented the retrospective results of a multicenter study describing preliminary complications and treatment results of CBT fixation. Of the 138 patients identified, 61% were treated for degenerative spondylolisthesis at 167 levels, most commonly at L4-5 (62%). Mean total operative time was 135 minutes, with an average of 236 mL of blood loss. Mean total postoperative length of hospital stays was 2.6 days, with 25% of the patients being discharged on the same day or within 23 hours of surgery. The total perioperative complication rate in 138 patients was 10.1% (14/138), with 3 related reoperations. Intraoperative complications included 5 instances (3.6%) of incidental durotomy, without any progression to persistent cerebrospinal fluid leaks. Nine postoperative complications (6.5%) occurred; none was directly related to the technique. Three reoperations (2.2%) were performed, 1 for revision of an L5 vertebral body fracture, and 2 for wound debridement. No instances of postoperative radiculitis or neurologic injury were observed.

Hung et al.[83] found no differences compared with conventional PT fixations with respect to short-term clinical outcomes but reported less multifidus muscle damage in a series of 32 patients. In a prospective series by Dabbous et al.[84] with 25 patients, results were compared with previous studies reported on PT fixation, finding shorter operative time and quicker discharges but preserving the same safety and efficacy. Other comparative studies confirmed the same efficacy of CBT against PT fusions, with a limited trend of better outcomes in the short-term.[85-91] Furthermore, a larger comparative study by Sakaura et al.[92] (95 patients who underwent CBT fixation and PLIF vs. 82 PT-PLIF) showed that PLIF with CBT screw fixation for degenerative spondylolisthesis provided comparable improvement of clinical symptoms with PLIF using traditional PT fixation. Takenaka et al.[93] compared 42 patients who underwent CBT-PLIF and 77 who underwent conventional PT-PLIF. These procedures were comparable in terms of clinical outcomes and fusion rates, but CBT-PLIF showed additional benefits in terms of less blood loss, less intraoperative muscle damage, less perioperative pain, and earlier recovery of normal activities.

In 2018, Lee et al.[80] reported the 2-year follow-up of their prospective randomized study reported in 2015. The results confirmed no significant differences in both groups within 2 years postoperatively considering clinical outcomes, radiologic outcomes, and related complications.[94] Sakaura et al.[95] reported the results of a comparison of surgical outcomes in the treatment of 2-level degenerative spondylolisthesis between CBT and PT fusion. CBT procedures proved to be a valid alternative for fusion, with comparable rates of bony fusion and clinical outcomes considering PT fixations, with shorter significant operative durations and less blood loss, although in this case, the differences were not significant.

Our group presented in 2018 the largest available single-center experience study regarding CBT for circumferential arthrodesis.[96] In a retrospective cohort study, a total of 101 patients who underwent CBT arthrodesis for degenerative lumbosacral disease were reviewed (**Figures 3** and **4**). Mean procedural time was 187 minutes. Mean operative blood loss and X-ray dose per procedure was 383 mL and 1.60 mg/cm², respectively. Mean hospital stay was 3.47 days. Mean follow-up was 18.23 months. Mean lordosis increment at the treated level was 4.2°. When follow-up was longer than 12 months (53% of patients), fusion was obtained in 94% of cases. Mean Oswestry Disability Index and visual analog scale index improved with statistical significance. The results highlighted the safety and efficacy of this technique.

Concerning muscular damage, our group also provided evidence, through a

Table 2. Cortical Bone Trajectory Literature About Surgical Technique

Study Number	Reference	Evidence Rate	Study Number	Reference	Evidence Rate
1	Santoni et al., 2009[3]	2	30	Senoglu et al., 2017[67]	4
2	Perez-Orribo et al., 2013[12]	2	31	Matsukawa et al., 2017[57]	4
3	Mobbs et al., 2013[30]	N/A	32	Kaye et al., 2017[47]	2/3
4	Matsukawa et al., 2013[31]	N/A	33	Karsy et al., 2017[59]	
5	Ueno et al., 2013[32]	4	34	Delgado-Fernandez et al., 2017[28]	2/3
6	Rodriguez et al., 2014[33]	3	35	Phan et al., 2017[29]	2/3
7	Matsukawa et al., 2014[34]	N/A	36	Cheng et al., 2018[65]	2
8	Iwatsuki et al., 2014[36]	3	37	Sellin et al., 2018[58]	3
9	Takata et al., 2014[37]	3	38	Chen et al., 2018[53]	3
10	Song et al., 2014[38]	3	39	Cofano et al., 2019[63]	2/3
11	Ueno et al., 2015[4]	4	40	Bohl et al., 2018[41]	N/A
12	Pacione et al., 2015[39]	N/A	41	Goel et al., 2018[109]	N/A
13	Gautschi et al., 2015[45]	N/A	42	Asamoto et al., 2018[42]	3
14	Matsukawa et al., 2015[15]	2	43	Gao et al., 2018[66]	2
15	Phan et al., 2015[46]	2/3	44	Xuan et al., 2018[60]	2
16	Cheng et al., 2015[22]	2	45	Miyakoshi et al., 2018[49]	N/A
17	Matsukawa et al., 2015[19]	4	46	Kaito et al., 2018[69]	4
18	Zhang et al., 2016[35]	4	47	Ashayeri et al., 2018[64]	3
19	Cheng et al., 2016[40]	2	48	Le et al., 2018[68]	3
20	Matsukawa et al., 2016[44]	3	49	Rexiti et al., 2018[43]	2
21	Orita et al., 2016[62]	2	50	Kim et al., 2018[70]	N/A
22	Goldstein et al., 2016[49]	4	51	Kim et al., 2018[71]	N/A
23	Mullin et al., 2016[50]	N/A	52	Mendenhall et al., 2019[61]	3
24	Xuan et al., 2016[56]	4	53	Grigoryan et al., 2019[21]	2
25	Sakaura et al., 2016[20]	4	54	Wang et al., 2019[72]	N/A
26	Sheng et al., 2016[55]	4	55	Zhang et al., 2019[51]	2/3
27	Tortolani et al., 2016[110]	2/3	56	Penner et al., 2019[73]	3
28	Ashayeri et al., 2016[52]	N/A	57	Marengo et al., 2019[72]	3
29	Xuan et al., 2017[54]	4			

N/A, not available.

prospective study comparing CBT fusion with the traditional open technique, that radiologic muscular damage (evaluated with the multifidus cross-sectional area and the T2 multifidus/psoas ratio) was reduced, as well as surgical morbidity (blood loss). However, no substantial differences were noticed in clinical and radiologic outcomes with PT fusion.[97]

Lee et al.[98] described in a retrospective study the comparison between CBT and conventional PT technique in the treatment of proximal adjacent segment disease. The CBT technique was shown again to be a valid alternative for lumbar fusion. Fusion at 1 year postoperatively was achieved by 90% and 91% of patients, respectively, in PT and CBT fixations ($P > 0.99$). Patient satisfaction at 1 month after surgery ($P = 0.03$) and pain intensity within 1 month after surgery ($P = 0.04$) were significantly better in the CBT group compared with PT. Regarding surgical morbidity, blood loss was significantly less, operation time and length of hospital stay were remarkably shorter, and the incision was notably smaller in the CBT group. Clinical parameters and outcomes were similar.

Other comparative studies contributed to proving comparable results between CBT fusion and other classic minimally invasive surgery (MIS) techniques such as microendoscopic laminotomy,[99] MIS—posterolateral fusion (PLF), or MIS—transforaminal lumbar interbody fusion (TLIF) with Wiltse/percutaneous approach.[100] In the study by Elmekaty et al.,[100] CBT-TLIF fusions showed a considerable shorter surgery duration (111 minutes), less bleeding (112.5 mL), and lower values of C-reactive protein and creatine kinase than the other 2 techniques. There was no significant difference in the overall function outcome of the 3 groups. CBT-TLIF fusions provided a greater increase in the lumbar lordosis angle and in the segmental disc angle. CBT and MIS-TLIF resulted in a significant increase in the middle disc height compared with MIS-PLF. The fusion rate was 100% in CBT and MIS-TLIF groups and 90% in the MIS-PLF group. Screw loosening occurred in 10% of the MIS-PLF cases, 7.14% of the MIS-TLIF cases, and 4.76% of the CBT-TLIF cases.

Table 3. Cortical Bone Trajectory Clinical Studies

Study Number	Reference	Evidence Rate	Study Number	Reference	Evidence Rate
1	Rodriguez et al., 2014[33]	3	22	Feng et al., 2017[106] (ongoing trial)	1
2	Mizuno et al., 2014[74]	3	23	Chin et al., 2017[87]	3
3	Glennie et al., 2015[78]	3	24	Lee et al., 2018[94]	2
4	Kasukawa et al., 2015[77]	3	25	Sakaura et al., 2018[95]	3
5	Phan et al., 2015[47]	2/3	26	Hussain et al., 2018[91]	3
6	Ohkawa et al., 2015[76]	3	27	Phan et al., 2018[90]	N/A
7	Lee et al., 2015[80]	2	28	Marengo et al., 2018[96]	4
8	Snyder et al., 2016[81]	4	29	Marengo et al., 2018[97]	2
9	Khanna et al., 2016[82]	4	30	Shi et al., 2018[101]	3
10	Hung et al., 2016[83]	3	31	Lee et al., 2018[98]	3
11	Patel et al., 2016[79]	3	32	Hayashi et al., 2018[99]	2
12	Dabbous et al., 2016[84]	2	33	Wochna et al., 2018[102]	3
13	Chen et al., 2016[85]	2	34	Elmekaty et al., 2018[100]	3
14	Sakaura et al., 2016[92]	3	35	Huang et al., 2018[111]	3
15	Bielecki et al., 2016[86]	3	36	Kotheeranurak et al., 2018[112]	N/A
16	Mori et al., 2016[77]	3	37	Dayani et al., 2018[104]	2
17	Takenaka et al., 2017[93]	3	38	Sakaura et al., 2018[113]	3
18	Keorochana et al., 2017[88]	2	39	Chen et al., 2018[103]	4
19	Bruzzo et al., 2017[89]	3	40	Tschugg et al., 2018[107] (ongoing trial)	1
20	Delgado-Fernandez et al., 2017[28]	2/3	41	Hoffman et al., 2019[114]	3
21	Phan et al., 2017[29]	2/3	42	Wang et al., 2019[105]	2

N/A, not available.

Recently, other investigators have exploited little known applications of the technique. Shi et al.[101] investigated the efficacy of CBT fixations in the treatment of elderly patients with lumbar tuberculosis, with comparable results to PT screws. Wochna et al.[102] reported a retrospective study analyzing the differences in the treatment of thoracolumbar fractures with CBT against the PT technique, finding noninferior results in terms of clinical and radiologic outcomes.

Recent studies have continued to confirm satisfactory outcomes in clinical, technical, and radiologic results.[103,104] In June 2019, Wang et al.[105] reported a systematic review and meta-analysis comparing the clinical efficacy and safety of CBT and PT technique. These investigators found that both achieve similar fusion and revision surgery rates. CBT was superior, with lower incidence of complications, shorter operation time, less blood loss, shorter incision length, and shorter hospital stay. Given these results, the need for high-quality randomized controlled trials seems to emerge to better clarify the effectiveness of the CBT technique against traditional open fixation with pedicle screws. Two trials investigating the comparison of CBT versus PT technique are ongoing. Feng et al.[106] will evaluate patients until 24 months postoperatively. A total of 254 participants with lumbar disc degenerative disease who are candidates for TLIF surgery will be randomly allocated to either the CBT-TLIF group or the PT-TLIF group at a ratio of 1:1. The primary clinical outcome measures will be the incidence of adjacent cranial facet joint violation, fusion rate, and the screw loosening rate. Secondary clinical outcome measures will be the visual analog scale for back and leg pain, Oswestry Disability Index, operative time, intraoperative blood loss, and complications. These parameters will be evaluated on a regular follow-up at day 3, and at 1, 3, 6, 12, and 24 months postoperatively. Tschugg et al.[107] will evaluate a total of 154 adults allocated in a ratio of 1:1 in a single-center randomize, controlled parallel-group superiority trial. The primary outcome parameter is the Oswestry Disability Index up to 5 years after surgery. Secondary outcome parameters are the EuroQoL 5-Dimension questionnaire, the Beck Depression Inventory, the painDETECT questionnaire, and the timed-up-and-go test, together with radiologic and health economic outcomes.

These trials (level 1) will certainly help to strengthen the mounting evidence of the medium-quality studies (level 2—3), suggesting that the CBT technique constitutes a safe and viable alternative in respect to traditional open PT arthrodesis, with a limited trend of reduced surgical morbidity.

Limits of Evidence and Disadvantages of the Technique

CBT seems to represent a valid alternative to traditional PT fixations but an effective number of prospective series with long-term follow-up is lacking. Selection bias in retrospective studies could have interfered with clinical results. The necessary learning curve to face a different entry point and trajectory is not well quantified, because many surgeons have tended to exclude from this technique patients with advanced degeneration of the anatomy of the lumbar spine; however, the progressive spread of CBT and the use of technological tools such as navigation or 3D printed guides is progressively overcoming this issue.[66-69,72,73,96,97,105]

S1 screwing with CBT is still an open topic, although the first reported case series with medium-term follow-up involving sacral fixation showed encouraging clinical and radiologic results.[105]

Although thoracic CBT fixation has been described, no real clinical or radiologic advantages over PT technique have been shown.[58-60] In the thoracic spine, the isthmic entry point is very close to the traditional one, and usually, fixations involve more than a single level. This situation probably decreases or nullifies the advantages of a reduced mediolateral exposure and of muscular preservation. For the same reason, clinical studies highlighting the lower incidence of perioperative complications and the lower burden of postoperative hospital stay in lumbar spine surgery are usually based on single-level or double-level fixations.[94-97] For >2-level fixations, no sufficient data exist to hypothesize better perioperative outcomes.

A contraindication seems to emerge for isthmic spondylolisthesis, and few data support the use of CBT for open reduction of fractures in traumatic spine surgery.[24,25,102]

Studies about biomechanics, surgical technique, and clinical outcomes are summarized in **Tables 1-3**.

CONCLUSIONS

CBT has proved to be a safe and valuable option for screw fixation in spine surgery. Given the denser bone intercepted, high-quality biomechanical studies have shown equal or even better properties compared with PT fixation depending on several factors such as screw size and length. Surgical techniques have improved to gain a longer and safer trajectory than first described. Moreover, level 2 and 3 clinical studies suggest equal clinical and radiologic outcomes with a lower incidence of perioperative complications compared with PT fixation, but high-quality, level 1, randomized controlled trials are needed to confirm these results.

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Conflict of interest statement: This study was supported by Ministero dell'Istruzione, dell'Università e della Ricerca—MIUR project "Dipartimenti di eccellenza 2018—2022".

Received 14 August 2019; accepted 13 October 2019

Citation: World Neurosurg. (2020) 134:14-24.
https://doi.org/10.1016/j.wneu.2019.10.079

Journal homepage: ***www.journals.elsevier.com/world-neurosurgery***

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