Asian Spine Journal
Review Article
Asian Spine J 2017;11(5):817-831 • https://doi.org/10.4184/asj.2017.11.5.817

Review of Cortical Bone Trajectory: Evidence of a New Technique

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This article summarizes recent evidence on the cortical bone trajectory (CBT) obtained from published anatomical, biomechanical, and clinical studies. CBT was proposed by Santoni in 2009 as a new trajectory that can improve the fixation of pedicle screws in response to screw loosening in osteoporotic patients. Recently, research interest has been growing with increasing numbers of published series and frequent reports of new applications. We performed an online database search using the terms "cortical bone trajectory," "pedicle screw," "CBT spine," "CBT fixation," "MISS CBT," and "traditional trajectory." The search included the PubMed, Ovid MEDLINE, Cochrane, and Google Scholar databases, resulting in an analysis of 42 articles in total. These covered three aspects of CBT research: anatomical studies, biomechanical parameters, and clinical cases or series. Compared to the traditional trajectory, CBT improves pullout strength, provides greater stiffness in cephalocaudal and mediolateral loading, and shows superior resistance to flexion/extension; however, it is inferior in lateral bending and axial rotation. CBT seems to provide better immediate implant stability. In clinical studies, CBT has shown better perioperative results for blood loss, length of stay in hospital, and surgery time; similar or better clinical postoperative scores; and similar comorbidity, without any major fixation system complications due to instrumentation failure or screw misplacement. In addition, advantages such as less lateral exposure allow it to be used as a minimally invasive technique. However, most of the clinical studies were retrospective case series or case-control studies; prospective evidence on this technique is scarce, making a definitive comparison with the traditional trajectory difficult. Nevertheless, we can conclude that CBT is a safe technique that offers good clinical results with similar biomechanical and perioperative parameters to those of the traditional trajectory. In addition, new applications can improve its results and make it useful for additional pathologies.

Keywords: Cortical bone trajectory; Traditional trajectory; Pedicle screw; CBT biomechanics; CBT anatomy; CBT complications

Introduction

Pedicle screw fixation is a standard procedure in spine surgery and the main technique for maintaining spinal stability and biomechanical features in spinal disease. Pedicle screws have been successfully used with good results for multiple pathologies, such as spinal deformities, degenerative diseases, or fractures. However, some complications have been associated with this procedure, with system failure being one of the most important. Incidence of screw loosening has been estimated to range from 1% to 15% in non-osteoporotic patients and exceed 60% in patients with osteoporotic bones [1]; however, the actual incidence of this problem has not yet been confirmed

Received Nov 15, 2016; Revised Feb 6, 2017; Accepted Mar 1, 2017
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Asian Spine Journal • pISSN 1976-1902 eISSN 1976-7846 • www.asianspinejournal.org

[2]. Obtaining a more solid internal fixation is therefore an important issue for spinal surgeons, and various approaches, including changing the screw trajectory, have been proposed with the aim of improving longevity and avoiding such complications [3,4].

In 2009, Santoni et al. [3] proposed a new insertional pathway in place of the traditional trajectory (TT), referred to as the cortical bone trajectory (CBT). The traditional insertional pathway runs through the pedicle axis with a lateral-to-medial trajectory starting at the junction between the transverse process and the lateral wall of the facet and ending at the vertebral body. In contrast, CBT involves a medial-to-lateral direction and a caudocephalad path with the objective of maximizing thread contact with higher-density bone. The aims of this track are to improve the adhesion of the screws in osteoporotic vertebrae and to prevent instrumentation failure [3].

This paper summarizes the biomechanical and clinical studies of CBT published to date and evaluates its possible advantages for daily clinical practice.

Materials and Methods

A literature search was performed in the PubMed, Ovid Medline, Cochrane, and Google Scholar databases using the search terms "cortical bone trajectory," "CBT spine," "CBT fixation," "MISS CBT," "traditional trajectory," and "pedicle screw." The search included papers published up to May 2016. All retrieved abstracts were analyzed to determine whether they presented relevant information about anatomical, biomechanical, or radiological results in either clinical or cadaveric studies. For those that did, complications, clinical results, and technical and surgical features were recovered from the associated papers for subsequent review. In addition, the reference lists of the identified publications were checked to determine further relevant articles that should be incorporated in the analysis.

Results

Finally, 42 articles were included in the analysis. These covered three aspects of CBT: anatomical studies, biomechanical parameters, and clinical cases or series. Six of the articles considered anatomical landmarks of CBT with regard to previous citations or possible complications in CBT procedures. Biomechanical parameters were discussed in 13 articles, which considered physical parameters that could show how CBT resulted in improved biomechanical properties compared to TT. Finally, 20 articles and two communications to meetings were analyzed for clinical series and cases. These 42 articles comprised all eligible reports published up to the date the review was finished. No previous review studies were included in the present narrative review.

1. Biomechanical and anatomical studies

In 2007, Sterba et al. [5] published a cadaveric study showing that straight screw insertion provided a more stable pedicle screw construct than the pathway parallel to the sagittal plane, because the angled trajectory resulted in lower average total fatigue damage. Previously, Roy-Camille et al. [6] had proposed that a vertical trajectory through the pedicle would increase thread contact with the cortical bone at the end point. In this context, Santoni et al. [3] proposed CBT as a way to avoid screw system failure in osteoporotic patients and demonstrated that this trajectory increased resistance in a uniaxial pullout test when compared to traditional screws. Some previous anatomic studies about the limitations of pedicle screw insertion should be considered. Li et al. [7] reviewed 41 computed tomography scans that focused on the height, width, and isthmus inclination of the pedicle, concluding that width was the most important factor for screw placement. They also found that the cortical thickness of the superior and medial walls was generally greater than 2 mm. This could explain why pedicles are more likely to break laterally. This demonstrated that the CBT technique could result in enhanced screw purchase and greater interface strength independent of the trabecular bone mineral density (BMD), because the screws have four points of fixation: between the dorsal cortex and the site of insertion, on the posteromedial and anterolateral pedicle walls, and on the marginal region of the vertebral body wall (Fig. 1) [4,8]. Thus, although CBT screws are shorter in length and smaller in diameter than those used with TT, they are in contact with bone surface of higher density. In fact, Mai et al. [9] conducted an observational study that measured BMD (in Hounsfield units) at the theoretical end point in CBT and TT, demonstrating greater density for CBT, especially in the osteoporotic cohort (Table 1).

Since the introduction of CBT, studies have been conducted to determine its biomechanical characteristics.

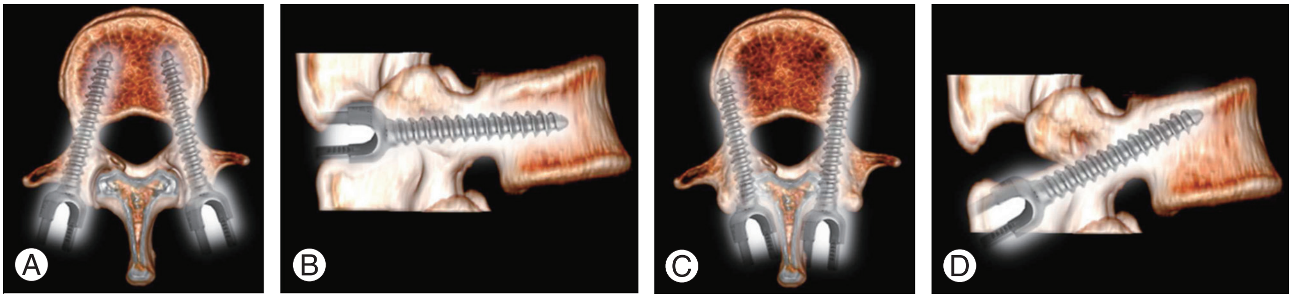

Fig. 1. Comparison of the traditional trajectory **(A, B)** and cortical bone trajectory **(C, D)**. **(A, B)** Axial and sagittal views of the traditional trajectory following the pedicle axis in a lateral-to-medial trajectory parallel to the superior and inferior endplates. **(C, D)** Axial and sagittal views of the cortical bone trajectory with a medial-to-lateral disposition and a 25°–30° cranial direction along the inferior border of the pedicle.

Table 1. Summary of anatomical studies for CBT fixation

Author	Type and nature of study	No. of subjects	Study design	Parameters	Conclusions
Li et al., 2004 [7]	Radiological morphometric study Cohort study LE: 4	41 Patients	Ultra high-speed spiral CT scans of lumbar spine	Isthmus width, height, area, isthmus endosteal, isthmus cortical thickness, inclination, and pedicle length	Pedicle isthmus is the narrowest section of the pedicle and especially the isthmus endosteal is the most important parameter for transpedicular procedures.
Matsukawa et al., 2013 [10]	Radiological morphometric study Cohort study LE: 4	100 Patients, 470 vertebrae	A morphometric measurement of CBT for the lumbar pedicle screw insertion using CT	Diameter, length, lateral angle to the vertebral sagittal plane, and cephalad angle to the vertebral horizontal plane of the trajectory	The morphology of the pedicle, such as shape and pedicle axis angle, differed over the lumbar levels. There were no differences between each level of the lateral and cephalad angles.
Matsukawa et al., 2014 [11]	Radiological morphometric and clinical study Cohort study LE: 4	CT from 50 patients; 19 patients were operated.	CT scans of 50 adults were studied for morphometric measurement of sacral trajectory.	Cephalad angle to the sacral endplate, length of trajectory	The penetrating S-1 endplate technique through the medial entry point is suitable for the connection of lumbar CBT.
Matsukawa et al., 2017 [12]	Radiological morphometric and human cadaveric study Case-control study LE: 4	CT from 50 patients; 24 cadaveric thoracic vertebrae	50 CT scans from lower thoracic vertebrae were analysed. Insertional torque was compared in cadaveric vertebrae between CBT and TT.	Diameter, length and cephalad angle. Insertional torque of fixation system.	All morphometric parameters increased from T9–T12. The insertional torque using thoracic CBT was 53.8% higher than TT.
Mai et al., 2016 [9]	Observational anatomic study Observational case-control study LE: 3	180 Patients	HU from CT images were used as a metric for bone mineral density.	Hounsfield units were measured at end fixation point for CBT or TT.	Bone mineral density measured by HU values for the fixation point of the CBT screw is higher than that of the TT. This difference is even more pronounced when comparing osteoporotic and elderly patients.
Zhang et al., 2016 [13]	Radiological morphometric study Cohort study LE: 4	86 Patients	3D-CT lumbosacral spines.	Distances from insertion starting point to inferior, lateral and medial border of inferior facet of the cephalad level and angles formed between screw trajectory and sagittal plane, superior endplate (CA1) and posterior margin of pars interarticularis (CA2).	A decrease in CA1 (26.7° to 22.9°) and CA2 (38.7° to 35.1°) is observed from L1 to L5. CA2 in S1 is increased. Maximum screw diameters from L1 to S1 varies from 4.8 to 7.8 mm. Maximum length 25 mm is safe for CBT. Inferior facet of the cephalad level is an attractive bone landmark for CBT.

CBT, cortical bone trajectory; LE, level of evidence; CT, computed tomography; TT, traditional trajectory; HU, Hounsfield unit; 3D, three dimensional.

Perez-Orribo et al. [14] published a cadaveric study using screws that were oriented more sagittally and cranially; they did not observe differences in stability compared to traditional pedicle screws, although this orientation gave worse results under axial rotation. Matsukawa et al. [15] showed that CBT provided greater pullout strength, stronger stiffness during cephalocaudal and mediolateral loading, and superior resistance to flexion/extension compared with TT, but that it was inferior with regard to lateral bending and axial rotation. However, different results were obtained when testing spondylolytic vertebrae; CBT showed worse results for all these parameters, making it unsuitable for fixation in these cases [16]. However, as discussed later, CBT has been applied to spondylolytic cases with good outcomes in other series and case-control studies. Range of motion has been compared between CBT and TT in animal [17] and human [14,18] cadaveric studies, finding no differences for flexion/extension, lateral bending, or axial rotation. Calvert et al. [19] used CBT with rescue screws after instrumentation failure; this provided adequate stiffness in flexion/extension and axial rotation. Insertional torque has been previously correlated with pedicle screw pullout strength [20] and Matsukawa et al. [21] investigated how it changed during implant positioning, as an indirect measure of implant stability, founding that it is 1.7 times higher with CBT than with TT. These authors determined, in a multiple regression analysis, that BMD of the femoral neck, screw length within the lamina, and cephalad angle were significant independent factors affecting the torque [21,22]. However, in contradiction to previous articles, Akpolat et al. [23] published in 2016 the results of a cadaveric study which concluded that implantation via TT required more cycles for screw loosening and showed better resistance to pullout. Finally, Sansur et al. [24] compared CBT and TT in destabilized cadaveric lumbar spines with osteoporosis, showing that CBT gave better results in the lower spine because of an increase in cancellous bone limit fixation with TT (Table 2) [3,14-19,21-26].

2. Clinical trials

Many biomechanical studies have been published since Santoni et al. [3] first proposed CBT, but clinical evidence is still lacking, with no systematic reviews that can provide clear indications for its use. In 2004, Steel et al. [27] were the first to propose mediolateral fixation at a single thoracic level. They described 18 patients with thoracolumbar fractures who underwent operations without major complications. All achieved stable fusion after 6 weeks, without deformity, system failure, or neurological deficit, except for one patient with non-union after 12 months. The authors concluded that this trajectory was safe and effective for fixation and stabilization, and that it was less invasive than anterior or lateral approaches. In 2013, Ueno et al. [28] published a case report of a patient with degenerative scoliosis and osteoporosis who was operated on with a double-trajectory technique (CBT combined with TT at each level), with good morphometric results, no complications, and improvement in daily-life activities 14 months after surgery. Biomechanical studies demonstrated that this technique resulted in greater strength than the TT or CBT constructs for flexion, extension, lateral bending, and axial rotation [26]. Gonchar et al. [29] presented two series at a meeting of the Society for Minimally Invasive Spine Surgery (data not published), one of which compared 100 CBT versus 63 TT patients with pathologies such as degenerative diseases, osteoporosis, trauma, or deformities. CBT showed similar clinical results to TT for visual analogue scale (VAS), Oswestry disability index (ODI), Japanese Orthopedic Association Score (JOA), and surgical time, but superior results for blood loss, screw loosening, and pseudarthrosis. The authors reported two cases of screw breakage in CBT that were not repeated with the use of screws of a larger diameter (5.5 mm instead of 4.75 mm). Furthermore, in a prospective study of 60 patients with spondylolisthesis (30 CBT and 30 TT with minimally invasive spine surgery), the CBT patients showed a significantly lower rate of screw loosening and loss of correction, and CBT was shown to be less invasive than TT, as measured by creatine phosphokinase (CPK) values [29].

Iwatsuki et al. [8] proposed an isthmus-guided approach for CBT (IGCBT) to avoid the complications associated with this pathway and compared it with CBT. No complications occurred and only one screw was misplaced with the IGCBT technique compared to four misplaced screws with the traditional CBT. Ohkawa et al. [30] subsequently used this procedure and compared CPK levels between the original CBT and IGCBT, showing improved results with the latter. They reported 4% screw misplacement in 12 patients (22%), without major complications.

Mizuno et al. [31] investigated patients with spondylolisthesis and CBT fixation with posterior lumbar inter-

Table 2. Summary of biomechanical studies for CBT fixation

Author	Type and nature of study	No. of subjects	Methods	Conclusions
Santoni et al., 2009 [3]	Human cadaveric biomechanical study Case-control study LE: 4	14 Vertebral bodies for pullout and 10 for screw toggle testing	Pullout and toggle testing was performed in CBT and traditional screw after insertion in the vertebral bodies in contralateral sides.	CBT has equivalent pullout and toggle characteristics compared with the traditional trajectory. CBT presents a 30% increase in uniaxial yield pullout. There were no differences between construct stiffness, but there was positive correlation between bone density (qCT) and trajectory and pullout force for both pedicles.
Perez-Orribo et al., 2013 [14]	Cadaveric lumbar specimens Case-control study LE: 4	28 Specimens in 7 groups	Flexibility test to assess spinal stability, range of motion, lax and stiff zone at L3–L4	CBT provided the same stability as TT, except during axial rotation, regardless of interbody support.
Radcliff et al., 2014 [18]	Cadaveric lumbar spines Case-control study LE: 4	8 Specimens	Range of motion was measured for flexo-extension, lateral bending and axial rotation before and after fatigue loading for L3–L4 and L4–L5 with CBT and TT	Average relative motion between L3–L5 increased slightly with fatigue loading, the largest being flexo-extension in the TT group (ΔFE: 3.68±3.15%) and only lateral bending decreased slightly in the TT group (ΔLB: –0.59±1.36%). However, all modes of motion were statistically equivalent between the screw groups. CBT screws provided statistically equivalent biomechanical stabilization as compared to TT screws.
Matsukawa et al., 2015 [21]	*In vivo* biomechanical study Cohort study LE: 2	48 Patients	162 CBT screws and 36 TT screws were compared. In 8 patients, the side-by-side comparison of 2 different insertional techniques for each vertebra were performed. Insertional torque was measured.	The mean maximum insertional torque was 2.49±0.99 Nm CBT vs. 1.24±0.54 Nm TT. The CBT screws showed 2.01 times higher torque and the difference was significant. In the side-by-side group, the insertional torque was 2.71±1.36 Nm in the CBT screws and 1.58±0.44 Nm in the TT screws. The CBT screws demonstrated 1.71 times higher torque and statistical significance.
Matsukawa et al., 2014 [22]	*In vivo* biomechanical study Cohort study LE: 2	72 Patients	Evaluate postoperative position of 268 screws with CT scan to identify factors contributing insertional torque.	Bone mineral density of the femoral neck, screw length within the lamina, and cephalad angle were significant independent factors affecting torque. The ideal trajectory was directed 25° to 30° cranially along the inferior border of the pedicle so as to obtain maximum contact with the lamina and sufficient length within the vertebral body.
Baluch et al., 2014 [25]	Human cadaveric biomechanical study Cohort study LE: 4	17 Vertebral levels	Resistance to toggle testing after progressive increasing of cycling craniocaudal toggling	CBT screws have superior resistance to craniocaudal toggling compared with TT pedicle screws.
Oshino et al., 2015 [17]	Animal cadaveric study Cohort study LE: 5	20 Lumbar spines specimens	Range of motion was measured for bending and rotational test for CBT and TT construct.	No significant differences between the CBT and TT groups were shown with regard to the mean ROMs. Intervertebral stability after CBT fixation was similar to that after TT fixation.

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Table 2. Continued

Author	Type and nature of study	No. of subjects	Methods	Conclusions
Calvert et al., 2015 [19]	Human cadaveric study Cohort study LE: 4	10 Fresh-frozen human lumbar spines	Spines were instrumented (5 CBT vs. 5 TT) at L3–4. L-3 screw pullout strength was tested to failure and salvaged with screws of the opposite trajectory.	CBT used as a rescue construct, provided stiffness in flexion/extension and axial rotation similar to that provided by the initial pedicle screw construct prior to failure. In pullout testing, there were small differences between pullout strength retained by the fixation (CBT 60% vs. TT 65%). CBT could be used as a rescue option in the setting of a failed or compromised TT screw in the lumbar spine.
Matsukawa et al., 2015 [15]	Finite element study Cohort study LE: 4	30 Models of L4 vertebrae	Models were computationally created and pedicle screws were placed using TT and CBT. Fixation strength was compared by axial pullout and multidirectional loading tests, and afterwards construct was examined by simulating flexion, extension, lateral bending and axial rotation.	CBT demonstrated a 26.4% greater mean pullout strength (p=0.003) than TT, and also showed a mean 27.8% stronger stiffness (p<0.05) during cephalocaudal loading and 140.2% stronger stiffness (p<0.001) during mediolateral loading. The CBT construct had superior resistance to flexion and extension loading and inferior resistance to lateral bending and axial rotation.
Matsukawa et al., 2015 [26]	Finite element study Cohort study LE: 4	30 Models of L4 osteoporotic vertebrae	Models were computationally created and bilateral TT, CBT o both screws (cross trajectory) were implanted. Vertebral fixation strength was examined in flexion, extension, lateral bending, and axial rotation.	Fixation strength using cross trajectory was the highest among the three different techniques. The cross trajectory demonstrated 320% higher strength in flexion, 293% in extension, 102% in lateral bending, and 40% in axial rotation than TT. Similarly, the cross trajectory showed 268% higher strength in flexion, 269% in extension, 210% in lateral bending, and 178% in axial rotation than CBT.
Matsukawa et al., 2016 [16]	Finite element study Cohort study LE: 4	Vertebral models from normal or spondylolytic vertebrae	Vertebral models of normal or spondylolytic vertebrae from CT patients were computationally created and pedicle screws were implanted using CBT or TT technique.	CBT in spondylolytic vertebrae show significant decrease in pullout strength (21.4%), flexion (44.1%), extension (40.9%), lateral bending (38.3%), and axial rotation (28.1%) compared with CBT in the normal vertebrae. In spondylolytic vertebrae, CBT construct showed lower vertebral fixation strength in flexion (39.0%), extension (35.6%), lateral bending (50.7%), and axial rotation (59.3%) compared with the TT construct. CBT screws are less optimal for stabilizing the spondylolytic vertebra due to their lower fixation strength compared with TT screws.
Akpolat et al., 2016 [23]	Cadaveric biomechanical study Cohort study LE: 4	12 Vertebrae from 6 cadaveric lumbar spines.	CBT or TT constructs were loaded for 100 cycles or until 6° of loosening was observed. After fatigue testing, the screws were pulled out axially.	TT showed better results in resistance against cycle loading (6.98°±4.88° TT vs. 15.28°±5.58° CBT), cycles to critical loosening (3,592±4,564 cycles TT vs. 84±24 cycles CBT) and postfatigue pullout (776±370 N TT vs. 302±232 N CBT).

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Table 2. Continued

Author	Type and nature of study	No. of subjects	Methods	Conclusions
Sansur et al., 2016 [24]	Cadaveric biomechanical study Cohort study LE: 4	8 Osteoporotic fresh-frozen human spino-pelvic specimens	Osteoporotic spines (T-score less than 2.5) were destabilized and later CBT or TT fixation was made. Finally fatigue and pull out testing was performed.	CBT screws improved fixation at lower lumbar vertebrae while TT resulted in greater pullout strength at higher lumbar vertebrae. CBT is a viable alternative to TT, particularly for patients suffering from significant osteoporosis in the lower lumbar spine.

CBT, cortical bone trajectory; LE, level of evidence; qCT, quantitative computer tomography; TT, traditional trajectory; CT, computed tomography; ROM, range of motion.

body fusion (PLIF) or transforaminal lumbar interbody fusion. This revealed one intraoperative complication due to a cortical bone fracture, but this was not associated with neurological deficit. At 20 months' follow-up, there were no signs of screw loosening, although four screws (8.3%) had perforated the pedicle wall without clinically adverse effects. Okudaira et al. compared PLIF versus mid-line lumbar fusion with CBT and showed significant benefits with CBT in surgical time and blood loss, with similar clinical outcomes. There were no complications associated with CBT, whereas in the PLIF group, there was one wound infection with neural injury. The authors concluded that CBT was less invasive, requiring less exposure, and that recovery was faster (data not published).

Rodriguez et al. [32] proposed a double-fixation system in patients with adjacent-segment lumbar disease using CBT without removing the previous screws. No complications and good clinical outcomes were recorded at 6 months' follow-up, with clinical improvement and radiographic fusion. Like Ueno et al. [28] and Rodriguez et al. [32], Takata et al. [33] also presented a hybrid technique in which TT was used for caudal segments and CBT for cranial vertebrae. They showed that this hybrid technique was less invasive than TT because it reduced muscular retraction in the upper level.

Pacione et al. [34] published a case report of an 83-year-old woman with osteoporotic L4 compression treated with kyphoplasty, L4 decompression, and CBT fixation on L3 and L5 that needed to be rescued 3 months later with kyphoplasty after L3 compression with the standard technique, because CBT enabled the usual pedicle pathway without complications. Glennie et al. [35] were the first to report complications with CBT after a 1-year follow-up. Eight patients underwent operations with CBT; at 1-year follow-up, two had undergone revision surgery, five showed screw loosening, and four failed to maintain reduction on radiographic control. The authors concluded that CBT should be evaluated at medium- or long-term clinical follow-up to validate outcome measures and check for complications. Other series have reported similar complication incidences: Patel et al. [36] reported complications in five out of 22 patients (13.6%) and Cheng et al. [37] reported two pars and pedicle fractures and two instances of early screw loosening in 22 patients. A subsequent cadaveric study by these authors revealed the proportions of pars and pedicle fractures to be 2.7% and 16.2%, deviations which resulted in gross loosening. These results were similar to those of the study by Ninomiya et al. [38], which evaluated screw loosening with and without the presence of a clear zone around the screws in patients with CBT fixation. Clear zones were observed around six screws (5.5%) in five patients (26.3%), showing better results than those of previous studies. This group also compared radiological results of slippage correction and lordosis change 1 year after surgery, with significant improvement compared with preoperative values, unlike with TT [39]. Snyder et al. [40] reported a study with 79 patients that had CBT screws with or without other fixation techniques; they observed only 10 complications in seven patients: two hardware failures, two cases of pseudoarthrosis, two pulmonary embolisms, two deep vein thromboses, a wound infection, and an epidural hematoma. Surgical intervention was required for both pseudoarthroses, the wound infection, and the epidural hematoma. Mori et al. [41] reported one-year follow-up data for CBT procedures, showing good morphometric and clinical results after surgery without major complications; however, the follow-up revealed apparent non-union in 9.4% (three) of the patients, which was a higher rate than that for TT [42,43]. Dabbous et al. [44] also found good results with CBT procedures for intraoperative time and blood loss, good recovery in terms of ODI score and walking distance without medication, and a reduction in analgesic medication, with 44% of patients ceasing medication. They found no major complications; minor complications were a durotomy, a pedicle fracture, and a cage migration, with only the former related to the technique due to the space limitations imposed by minimally invasive surgery (MIS). Hung et al. [45] measured fat infiltration after CBT or TT fixation by postoperative magnetic resonance imaging; they found no significant differences in clinical outcome or perioperative parameters, although minor postoperative blood loss, operative time, and hospital stay were reduced with CBT. Fat infiltration was higher with TT (Table 3) [27-41,44-48].

New articles about CBT have been published in the last few months. Orita et al. [46] described percutaneous CBT with better results measured with a VAS at 6 months compared to percutaneous TT, with a shorter time of fluoroscopy and skin incision. Ashayeri et al. [47] used a hybrid technique for congenital multilevel spinal non-segmentation, concluding that CBT could improve pedicle screw fixation when bone quality was suboptimal or pedicle anatomy was distorted. Sakaura et al. [48] compared CBT with PLIF versus TT with PLIF and concluded that the JOA were significantly better in the CBT group and that there were fewer cases of symptomatic adjacent-segment disease (three [3.2%] with CBT vs. nine [11%] with TT, $p<0.05$), with no differences in solid spinal fusion.

Discussion

In 1986, Roy-Camille et al. [6] proposed a vertical trajectory that did not follow the pedicle axis and contacted a greater proportion of cortical bone at its end point. However, until Sterba et al. [5] reported on its improved biomechanical properties, the vertical straight pathway was not used as a conventional technique. Anatomical studies have demonstrated that CBT enhanced screw purchase and interface strength through increasing thread contact with cortical bone [4,7-9]. Although CBT uses shorter and smaller-diameter screws compared to TT, it has shown better results in biomechanical studies for pullout strength, insertional torque, greater stiffness during cephalocaudal and mediolateral loading, and a superior resistance to flexion/extension; conversely, it is inferior with regard to lateral bending and axial rotation [3,14,15,18,21,27]. The benefits were especially important in patients with osteoporosis or in lower lumbar vertebrae where cancellous bone is more important [3,24]. Biomechanical studies have also demonstrated greater immediate stability with CBT screws due to the higher insertional torque [21]. However, other studies have shown worse results with CBT in terms of resistance to cycling loading [23] and decreased pullout strength, flexion, extension, lateral bending, and axial rotation compared to the TT construct in spondylolytic vertebrae [16]. However, clinical evidence does not support this negative conclusion from Matsukawa et al. [16], and instead shows good outcomes without major complications [8,29-33,35,38,39,41,44-46,48]. Biomechanical studies provide poor evidence in support of clinical outcomes, providing only indirect information which suggests that CBT is associated with less screw loosening and improved fixation after surgery, with the vast majority of these studies seeming to agree with its biomechanical advantages.

Prior to Santoni et al.'s proposal for CBT [3], clinical evidence for mediolateral fixation was described by Steel et al. [27] for thoracolumbar fractures, with good results. Since 2009, 22 clinical series or case reports have been reported and interest in CBT is growing. The majority of these showed favorable clinical results, with good clinical

Table 3. Summary of clinical series published with CBT fixation

Author	No. of patients	Type of study and follow-up	Pathology	Technique	Results	Complications
Steel et al., 2014 [27]	18	Case series LE: 4 6 mo	Thoracolumbar fractures (T10–L2)	Single level fixation with "medio-lateral superior trajectory"	Early mobilisation in all patient and stable fusion at 6 weeks	One wound infection. One no-union at 12 months. No patient experienced neurological deficit or have developed a delayed kyphotic deformity.
Ueno et al., 2013 [28]	1	Case series LE: 4 14 mo	Degenerative scoliosis and osteoporosis	Double trajectory: TT+CBT	Good morphometric results. Improvement in daily living activities	No complications reported.
Gonchar et al., 2014 (data not published)	100 CBT vs. 63 TT	Case series LE: 4 Not reported	Degenerative, osteoporotic, trauma or deformity	CBT or TT. In cases of deformity could include MISS-PLIF or TLIF.	No differences in clinical outcomes. CBT better results in blood loss (177 mL CBT vs. 334 mL TT), screw loosening (1 CBT vs. 16 TT) and pseudarthrosis (1 CBT vs. 6 TT).	2 Cases of screw breakage in CBT, both obtain good fusion in follow-up.
Gonchar et al., 2014 [29]	30 CBT vs. 30 TT+PLIF	Prospective clinical comparative study LE: 4 6 mo	L3–L5 spondylolisthesis	MISS PLIF and CBT or TT	No differences in clinical outcomes. Lower rate of screw loosening (1 CBT vs. 6 TT), lower loss of correction, lower blood loss (118 mL CBT vs. 280 mL TT) and surgical time (120 mL CBT vs. 137 mL TT) for CBT.	3 Cases on no-union on TT and none in CBT. Percentage slip loss of correction was significantly higher in TT (2.3% vs. 10.4%). Slip angle loss of correction was significantly higher in TT (2.3° vs. 5.2°)
Iwatsuki et al., 2014 [8]	8 (4 IGCBT)	Case series LE: 4 Not reported	Lumbar degenerative spondylolisthesis	Original CBT vs. IGCBT	Not reported	4 Screws (12.5%) misplacements with traditional CBT and 1 (4.2%) with IGCBT
Ohkawa et al., 2015 [30]	21 CBT vs. 33 IGCBT.	Retrospective case series LE: 4 12–24 mo	Lumbar degenerative spondylolisthesis	Original CBT vs. IGCBT	Lower serum CPK levels in IGCBT	No major intraoperative complications. A mean of 4% (15 screws) were misplaced, without differences between groups.
Mizuno et al., 2014 [31]	12	Case series LE: 4 6 mo	Lumbar spondylolisthesis	PLIF or TLIF and CBT (MIDLF)	Recovery 66.1%	One cortical bone fracture. 4 Screws (8.3%) perforated pedicle wall. At 20 months follow-up there were not screw loosening.
Okudaira et al., 2014 (data not published)	16 CBT vs. 19 TT+PLIF	Retrospective case-control study LE: 4 Not reported	Unspecified	PLIF vs. PLIF and CBT	Lower surgical time (148 min CBT vs. 184 min TT), lower blood loss (132 mg CBT vs. 182 mg TT) and similar clinical outcomes.	No in CBT group. One wound infection in PLIF that produced permanent neurological deficit.

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Table 3. Continued

Author	No. of patients	Type of study and follow-up	Pathology	Technique	Results	Complications
Rodriguez et al., 2014 [32]	5	Retrospective case series LE: 4 10–15 mo	Adjacent-segment lumbar disease	CBT plus previous TT fixation	Average surgical time 218 min, and 500 mL blood loss. Patients discharged at a mean of 2.8 days.	No complications. Improved symptoms in all patients with radiological fusion.
Takata et al., 2014 [33]	6	Case series LE: 4 3 mo	Degenerative spondylolisthesis	Hybrid CBT	Surgical time 175 min, 70–200 mL blood loss. Good morphometric results.	One mild infection. Mean percent slippage before surgery was 19.8%, and this was reduced to 3.9% at 3 mo after surgery.
Pacione et al., 2015 [34]	1	Case series LE: 4 4 mo	Osteoporotic fracture	CBT plus kyphoplasty	Improvement in ODI and SF-36	No complications
Glennie et al., 2015 [35]	8	Retrospective case series LE: 4 12–19 mo	Degenerative spondylolithesis	CBT	3 Patients dissatisfied with surgery	2 Revision surgeries, 5 screw loosening, and 4 failed to maintain reduction.
Ninomiya et al., 2015 [38]	19	Retrospective case series LE: 4 6 mo	Lumbar canal stenosis with or without spondylolisthesis	CBT with PLIF	Relation between clear zone and insertional torque p=0.06.	6 Screws (5.5%) in five patients (26.3%) presented clear zone sign.
Patel et al., 2016 [36]	22	Retrospective case series LE: 4 Not reported	Unspecified	CBT	Not reported	2 Screw loosening, 1 intraoperative fracture, 1 intraoperative dural tear and a pedicle fracture and screw loosening.
Cheng et al., 2016 [37]	22	Case series LE: 4 Not reported	Neurogenic claudication and back pain	CBT and cadaveric study.	Not reported	Two pars and pecidule fracture, 2 screw loosening
Ninomiya et al., 2016 [39]	11 CBT vs. 10 TT	Case-control study LE: 4 12 mo	Degenerative spondylolisthesis	PLIF plus CBT or TT	Slippage reduction improved significantly in both groups without differences. Lumbar lordosis did not change significantly in either of them.	Not reported
Snyder et al., 2016 [40]	79	Retrospective case series study LE: 4 3–41 mo	Degenerative lumbosacral disease	CBT with or without ALIF, LLIF, TLIF/PLIF, etc.	Compared to previous surgery there was difference with blood loss and hospital discharged.	2 Hardware failures, 2 pseudoarthrosis, 2 PE and 2 DVP, a wound infection and an epidural hematoma.

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Table 3. Continued

Author	No. of patients	Type of study and follow-up	Pathology	Technique	Results	Complications
Mori et al., 2016 [41]	32	Case series LE: 4 12–24 mo	Degenerative lumbar spondylolisthesis	PLIF plus CBT	Leg pain relief, JOA scores, slippage and lumbar lordosis significantly improved postoperatively.	Loss of correction was observed in 3 cases. 1 Case of surgical site infection. No pull-out of screws or pedicle fracture was found. No patient needed additional surgery.
Dabbous et al., 2016 [44]	25	Prospective case serie LE: 4 7–19 mo	Grade I spondylolisthesis or micro-instability	PLIF plus CBT (MIDLF)	Lower intraoperative blood loss (200–700 mL), operative time (190 min) and lower hospital stay (mean of 2 days). Improvement in postoperative ODI (59% vs. 34%). 84% of patients reduced pain-killers intake and 44% stopped using them. Median postoperative pain-free walking distance increased from 50 (0–3,520) to 1,000 (0–8,880) yards.	Three complications were reported without any significant morbidity: a durotomy, a pedicule fracture and a cage migration.
Hung et al., 2016 [45]	16 CBT vs. 16 TT	Case-control study LE: 4 18 mo	Degenerative lumbar spondylolisthesis (grade I or II) or spondylosis with stenosis	PLIF plus CBT or TT	Fat infiltration was greater in PLIF plus TT (2.52% vs. 9.34% in superior adjacent level $p<0.001$; and 7.67% vs. 16.71% at inferior adjacent level ($p=0.002$).	Not reported
Orita et al., 2016 [46]	20 pCBT vs. 20 pTT	Case-control study LE: 3 12 mo	Spondylolisthesis	TLIF plus pCBT or pTT	Shorther incision length, duration of fluoroscopy and better VAS improvement in CBT ($p<0.05$)	No complications
Sakaura et al., 2016 [48]	95 CBT vs. 82 TT	Case-control study LE: 4 24 mo	Degenerative spondylolisthesis	PLIF plus CBT of TT	Better postoperative JOA score, and less symptomatic adjacent-segment disease in CBT ($p<0.05$). No differences in fusion rate.	Not reported

CBT, cortical bone trajectory; LE, level of evidence; TT, traditional trajectory; MISS, minimally invasive spine surgeries; PLIF, posterior lumbar interbody fusion; TLIF, transforaminal lumbar interbody fusion; IGCBT, isthmus-guided cortical bone trajectory; CPK, creatine phosphokinase; MIDLF, midline lumbar fusion; ODI, Oswestry disability index; SF-36, 36-item short form health survey; ALIF, anterior lumbar interbody fusion; LLIF, lateral lumbar interbody fusion; PE, pulmonary embolism; DVT deep vein thrombosis; JOA, Japanese Orthopedic Association Score; pCBT, percutaneous cortical bone trajectory; pTT, percutaneous traditional trajectory; VAS, visual analogue scale.

outcomes and better results for blood loss, surgical time, time to hospital discharge, and morphometric corrections [28,29-34,40-43]. Clinical outcomes for CBT were similar to those for TT, with better perioperative parameters, which can lead to fewer complications [40]. CBT is also less invasive, as measured by serum or clinical parameters, such as incision length [30,46]. However, although these data show a theoretical benefit of CBT fixation, over the last few years, some authors have published clinical series reporting high complication rates. We differentiated complications related to screw loosening or misplacement from those related to clinical results. Results related to screw loosening are not clear in clinical series, because clear zone, as a sign of screw loosening, has been observed to disappear in two-thirds of the cases after a 3-year follow-up. In this context, the results of Ninomiya et al. [38], who did not observe significant screw loosening at 6 months' follow-up, contrasted with those from the series reported by Glennie et al. [35], with 62% screw loosening; however, this high level was not reflected in other studies, where the screw loosening rate was estimated at around 0%–16.2% [36,37,40,41]. Construct failure appears to be around 2.5% [40], and pedicle fracture, which is a frequent complication with CBT, has an incidence of around 4% (0%–8.3%) [30,36,37,41,44]. Screw misplacement is more frequent with CBT than with TT, as shown in systematic reviews of neuronavigation systems, in which TT showed misplacement at around 10% in the worst cases [49], whereas pedicle fracture could reach 6.6% with TT [50]. The incidence of misplacement with CBT has been reported to be around 4%–12.5% [8,30], which does not represent an important difference from TT. Clinical complications were not frequent compared to those with other techniques described (0%–8.1%) [27,28,33,36,40,41,44]. Note that, in most of the studies, the follow-up period was short (median, 12 months); this could result in the underestimation of posterior complications, especially those due to screw loosening and non-union, as well as postoperative pars and pedicle fractures. In contrast, clinical outcomes with CBT were at least as good as those with TT, and new studies have reported better results for CBT [29,44,46,48].

CBT has been shown to have applications for various pathologies, such as the double-fixation system [28], hybrid techniques for avoiding major exposure [33] or for congenital spinal deformation [47], treatment of adjacent segment disease [32], in combination with other techniques such as kyphoplasty [34], or the recently proposed percutaneous CBT [46]. However, these have been reported only as case studies and the indication has not been clearly elucidated. Sakaura et al. [48] reported a minor rate of adjacent segment disease in their series with CBT, but in the other cases, the main indications were to obtain greater rigidity of fixation using CBT in combination with TT [28,32], but also CBT can be used to avoid TT in case it was previously used for kyphoplasty or for removing pedicle screws previously placed in that position [32,34], or to achieve adequate vertebral fixation with minor exposure [33,46]. It should also be emphasized that the double-fixation system demonstrated better strength in flexion, extension, lateral bending, and axial rotation compared to CBT or TT alone [26].

However, most of the studies published to date have been retrospective case series or case-control studies. Prospective evidence on the CBT technique is scarce, making it difficult to reach a definitive conclusion about its superiority over TT.

In summary, it is our opinion that the majority of the literature confirms that CBT is a safe technique that can improve results in some situations compared to traditional techniques. The vast majority of authors found that, because CBT needs less lateral exposure as there is no need to reach the transverse process, it could improve perioperative parameters such as blood loss, surgical time, or hospital stay [29,31-33,40,44], and result in lower levels of CPK and postoperative fat infiltration [29,31,45]; it could therefore benefit patients where MIS techniques are more suitable, such as for an obese population [4]. However, these potential benefits should be attributed not only to the lesser exposure but also to an appropriate selection of patients [44]. We also think that CBT should be considered with caution as a new technique. Although Dabbous et al. [44] reported that results were favorable even during the learning curve, a period of previous training is required before this technique is offered to patients, particularly because the incidence of pars of pedicle fracture and misplacement is not negligible. CBT presents good biomechanical parameters compared to TT, opening the field to new applications for this technique; however, the technique was initially devised for osteoporotic patients, but fewer clinical studies have been conducted with this group of patients [21,34,36]. Furthermore, although in this article we have tried to summarize all the information about CBT published to date, we emphasize that the majority of the studies offer weak evidence because most involved small cohorts, case series, clinical cases, or comparisons with historical control groups. Thus, further investigation of CBT must involve randomized controlled trials or homogeneous systematic studies rather than low-evidence studies. Finally, most of the previous studies compared CBT with other techniques, and most of the cases that have compared it with TT also presented the PLIF technique. The study by Sakaura et al. [48] is one of the latest to show good results. However, to date, few studies have compared CBT with TT alone.

Conclusions

CBT is increasingly used, and is a new and interesting minimal invasive technique that is demonstrating good results with acceptable morbidity. Various new applications have been proposed. However, more clinical studies are required to clarify several aspects of this technique.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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