The Cortical Bone Trajectory: An Alternative to Traditional Pedicle Screw Fixation - A Review

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Abstract

The cortical based trajectory for pedicle screw fixation of the lumbar spine is not a novel as it once was. This is a review of the background, indications, advantages, disadvantages of cortical based trajectory pedicle screw fixation with an emphasis on biomechanical evidence and recent clinical studies which only now are just coming to light.

ABBREVIATIONS

CBT: Cortical Based Trajectory; PSF: Pedicle Screw Fixation

INTRODUCTION

Posterior spine fusion with screw fixation is a common and reliable method of instrumentation of the spine for a variety of spine pathologies when the ultimate aim of surgery is the fixation of the spine to allow bony fusion. The mainstay of this kind of surgery has been the use of pedicle screw fixation. The trajectory of pedicle screws aims to transverse the pedicle down its anatomical axis, with a screw specifically designed for fixation in cancellous bone. More recently, Santoni et al., in 2009 proposed using an alternative trajectory, a cortical bone based fixation technique, which utilises a different path down the pedicle with the aim of maximising thread contact with denser cortical bone [1]. This review's purpose is to briefly summarize various aspects of the cortical screw technique including its technical aspects, its potential applications, advantages and disadvantages. Particular focus will be pertaining to recent publications of biomechanical studies of the stability of the cortical screw technique.

Technical considerations

The mainstay of spinal fusion has for some time now been the use of pedicle screw fixation (PSF). The traditional PSF technique the screw is essentially introduced down the anatomical axis of the pedicle in the axial plane parallel to the superior end plate in the sagittal plane. Its initial stability arises from the interface between the screw thread and the cancellous bone of the pedicle and vertebral body in which it is inserted.

Whilst the cortical bone trajectory (CBT) has been described previously [1], the first formal biochemical study and technical description of the approach was published by Santoni and Hynes in 2009 [2]. The trajectory differs from the more traditional approach as the screw is introduced through the pedicle in a mediolateral and caudocranial path with the aim of maximising thread contact with denser cortical bone (Figure 1). Image guidance in the form of intraoperative fluoroscopy or navigation (Figure 2) can be utilized as in a standard PSF.

The starting point of a CBT screw is approximated at the intersection of the inferior border of the transverse process and the lateral superior articular facet. The trajectory is angulated cranially in the sagittal plane toward the anterior superior endplate without convergence in the transverse plane. Taking this path the screw passes through the inferior medial aspect of the pedicle terminating in the superior endplate [3]. The intention being to take advantage of these anatomically denser regions of the vertebrae and hence contribute to higher screw stability.

Matsukawa et al., approximated the CBT in the lumbar spine as lateral trajectories were 10° medial to lateral in the axial plane...
and followed 25° caudal to cranial path to the vertebral horizontal plane, through the midpoint of the pedicle [4].

**Morphometric studies in relation to CBT technique**

Osteoporosis is an increasing problem in the context of spine surgery given the aging population in western countries. In the Australian context 4.74 million Australians over 50 years of age (66% of people over 50) have osteoporosis or osteopenia and by 2022, it is estimated there will be 6.2 million Australians over the age of 50 with osteoporosis or osteopenia. That is a 31% increase from 2012 [5].

It has long been recognised that poor bone quality in conditions such as osteoporosis, can cause difficulties with initial stability of pedicle screw fixation (PSF) and ultimately lead to posterior fusion construct failure.

Studies have showed that cancellous screws have significantly lower pullout strength (POS) in vertebral bodies with lower density bone than when they are inserted into vertebra with higher density bone [6].

Achieving solid implant fixation in osteoporotic bone is an ongoing challenge in spine surgery. Techniques available include the anatomical trajectory, straight forward trajectory and extrapedicular methods.

The CBT screw insertion is proposed as an alternative to more traditional PSF techniques in such cases so to take advantage of cortical rather than cancellous bone of the vertebral fixation. This is relevant in patients with osteoporosis as cortical bone density is less affected by the condition making it an ideal target for screw fixation [7]. Santoni et al., reported that the CBT screw has a 30% higher POS than the traditional pedicle screw using osteoporotic cadaveric spine [1].

Imaging studies have demonstrated that the CBT goes through areas of denser bone in the osteoporotic vertebra. Regions of lower-density bone are found in the central portions of the vertebral body, and higher-density bone is found in the peripheral portions [8]. These of course correlate with the cortical bone areas of the vertebra.

Matsukawa et al., showed that CT based morphological studies of cadaveric vertebrae that the cortical bone is particularly concentrated between the pars interarticularis region and the lower part of the pedicle [9]. Steffee et al., described this area as the concept of the “force nucleus” at which the transverse process, lamina, inferior facet, superior facet, and pedicle all converge[10].

Additionally, Wray et al., determined the bone quality using CT based morphological analysis of cadaveric lumbar vertebrae [11]. They showed that a statistically significant increase in bone quality was observed for the cortical trajectories compared with traditional trajectories regardless which type of screws would be used whether cortical screws (42%; p < 0.001) or traditional pedicle screws (48%; p < 0.001). Emphasizing that the cortical trajectory itself seems to be the main factor for the favorable biomechanical results rather than properties of cortical screws. Importantly, this relationship also exists in the low bone density group adding weight to the potential utility of the CBT in patients with poor bone quality.

**CBT morphometric measurements**

Matsukawa et al., investigated the morphometric properties of the CBT in a total of 470 lumbar vertebrae using CT analysis [9]. In this trajectory, the starting point was supposed to be the junction of the center of the superior articular process and 1 mm inferior to the inferior border of the transverse process. Various measurements were made across the lumbar vertebrae and compared. The most relevant CT based measurements for surgical application of the CBT are briefly summarized here.

Measurement definitions:

- The pedicle width and height were measured in the smallest coronal section of the lumbar pedicle.
- Another measurement was made for the distance from the starting point to the lateral margin of the pars interarticularis at the same level.
- This trajectory was defined as the direction from the starting point to the mediolateral midpoint of the pedicle in the reconstructed axial CT plane and to the cephalo-caudal midpoint of the pedicle in the sagittal plane.
- The maximum diameter was defined as the width of the outer margin of the cortex.
- The maximum length was determined as the distance from the posterior aspect of the laminar cortex to the anterior aspect of the cortex of the vertebral body along the trajectory.
- The angle formed between the trajectory and a line of the vertebral midline in the horizontal plane was defined as the lateral angle.
- The angle formed between the trajectory and a line of the superior margin of the vertebral body in the sagittal plane was defined as the cephalad angle (measured after lateral angle established).
Summary of morphometric measurements

The following again is a brief summary of the results published by Matsukawa et al. with aim of orientating the reader to the technical and anatomical challenges of the CBT technique.

- The pedicle height tended to decrease slightly from L1 to L5 (from 16.5±1.3mm at L1 to 13.9±1.5mm at L5) and the pedicle width gradually increased from L1 to L5 (from 7.9±1.5mm at L1 to 15.3±2.0mm at L5).
- According to the pedicle height and width, the pedicle shapes were more elliptical in the upper levels and inclined in the vertical plane in the lower levels.
- The starting point was traced using the face of a clock for orientation and projected to the 5 o’clock orientation in the left pedicle and the 7 o’clock orientation in the right pedicle.
- The distances from the starting point to the lateral margin of the pars interarticularis tended to increase caudally from L1 to L5. From L1 to L5 were 0.8±1.1, 1.5±1.2, 2.0±1.1, 3.3±1.1, and 4.7±1.0 mm.
- The diameter of the trajectory was the smallest at the L1-L2 level (6.2±1.1mm) and gradually increased to L5 (8.4±1.4mm).
- There were no significant differences between each level of the lateral (approximately 9 degrees) and cephalad angles (approximately 25 degrees).

Benefits of the CBT technique

CBT has a clear benefit as an alternative method for posterior spine fixation to traditional pedicle screws particularly in the osteoporotic population. Other purported benefits of the cortical screw technique include reduced risk of neurovascular injury, increased mechanical stability with relation to interface surface area and reduced soft tissue dissection.

Reduced risk of injury

Potential risks of pedicle screw fixation is damage to associated structures including spinal cord/cauda equine, nerve roots and vascular structures depending on what part of the spinal column in question. The CBT could potentially put these structures at less risk: traditional trajectories going lateral to medial put the spinal cord/cauda equine at greater risk and the spinal nerves in the vertebral foramina may be injured with its more caudal trajectory in the sagittal plane. The CBT is directed away from the intervertebral foramen inferiourly and the spinal canal medially, reducing the risk of neurovascular injury to the structures within. Also screw is directed superiorly towards the superior endplate avoiding damage to anterior major vessels [7].

Wray et al., showed that the incidence of cortical wall breach with the cortical or traditional pedicle screw trajectories was not significantly different suggesting that at the very least that the CBT trajectory in not more dangerous to surrounding structures [11].

Salvage procedures

As the CBT screw follows a different path to the anatomical pedicle axis of the more traditional techniques, it is useful for salvage procedures where conventional pedicle screw fixation has failed [7]. The advantage of having the option of using a new trajectory rather than increasing pedicle screw size or using adjuncts such as cement with canalised screws using the existing screw path.

Increased stability

The ideally placed CBT screw makes contact with cortical bone at four points: lateral part of the lamina, lower part of the laminar, lower part of the pedicle, posterior lateral part of the vertebral body and the sub endplate cortical bone- all of which have high bone mineral density (BMD).

Higher density trabecular bone is found adjacent to end plates [8] and in the caudal aspects of the pedicle [13], the CBT takes advantage of this. Additionally, it has been proposed that in the osteoporotic patient cortical bone is relatively unaffected thus increasing the utility of CBT screws in these patients [7].

CBT in the thoracic spine allows for preservation of the dorsal cortex as opposed to the straight forward method which requires that it and the subchondral bone be drilled away. Karataglis et al., showed that preservation of this dorsal cortex can increase by 26% peak pullout strength [14].

Minimally invasive surgical aspects

Insertion point and trajectory of the CBT screw (medial to lateral) allows for less muscle dissection compared as the lateral aspect of the pars does not need to be exposed due to the more medial starting point. It has been demonstrated that in the context of traditional pedicle screw fixation, a minimally invasive percutaneous approach could reduce surgical trauma, blood loss and infection rates in comparison to open pedicle screw fixation [15]. Similar advantages would likely translate for the CBT approach too, which could have theoretical benefits with regard to post-operative pain and reduced recovery time post surgery.

Facet joint preservation

Studies have reported that violations of superior facet joint with traditional pedicle screw placement range from 4% to 24% in open posterior lumbar interbody fusion surgery using the pedicle screw technique [16]. Use of the CBT in posterior lumbar spine surgery has less risk of this as entry point is the pars articularis, this is reflected in the study by the recent study by Lee et al., (2015) which showed 0% rate of superior facet joint violation in a CBT group vs. 18% in the traditional pedicle screw group [17].

CBT techniques and sacral posterior fixation

Extending fixation to the sacral spine has long been troublesome mainly due the sacrum being mainly cancellous bone [18]. This has lead to attempts to increase fixation strength by attaining bi cortical fixation by attempts to direct screws to the sacral promontory cortical bone which has been implicated in increased risk of vascular injury [19].

Matsukawa et al., also applied a variation on the lumbar CBT to posterior fusion involving the sacrum with the aim of increasing stability and allowing better alignment of screw.
heards with lumbar CBT screws [20]. The aim of this study was to introduce a novel sacral pedicle screw trajectory that engages with denser bone by penetrating the S-1 superior endplate. The entry point was located at the junction of the center of the superior articular process of S-1 and approximately 3 mm inferior to the most inferior border of the inferior articular process of L-5. The trajectory was directed straight forward in the axial plane without convergence, angled cranially in the sagittal plane penetrating the middle of the sacral endplate.

The insitional torques of 38 pedicle screws inserted in 19 patients were measured. Additionally in 5 of the patients hybrid constructs were used: one side using the novel trajectory and the other using the traditional trajectory (the entry point was the infer lateral corner of the S-1 superior articular process and the trajectory aimed anteromedially, parallel to the S-1 endplate and into the anterior sacral cortex).

The new technique demonstrated an average of 141% higher insitional torque than the traditional monocolical technique. Matsukawa et al. suggest that in addition to increased stability of this technique includes aligned arrangement of the screw heads which match the lumbar CBT screws. The trajectory and more medial starting point also theoretical reduce risk of vascular injury with screw placement and reduce the need for as extensive soft tissue dissection.

**DRAWBACKS WITH THE CBT TECHNIQUE**

**Lack of convergence of CBT screws**

The starting point is located approximating at the intersection of the inferior border of the transverse process and the lateral superior articular facet. The trajectory is angled cranially in the sagittal plane toward the anterior superior endplate without convergence in the axial plane.

Standard screw insertion involves a trajectory that converges the pedicle screw medially by about 30°. A parallel trajectory of screws without convergence removes the addition of triangulation effect to construct stability [7]. Baber et al., showed that a convergence angle of pedicle screws could increase pull out strength by 28.6% [18].

**Pedicle screw diameter vs. cortical screw diameter**

With respect to thoracic pedicle diameter, Dhawan et al., showed through a CT based study that the anatomical trajectory of the pedicle is consistently the largest diameter compared with other trajectories [19].

**Cortical screw placement requires differing technique and prosthesis**

Because the CBT allows the screw to engage the denser regions, there is a potential risk of entrance point and pedicle fractures during screw insertion.

Traditional trajectory screws are inserted into the cancellous bone of the pedicle adding in the cancellous bone of the vertebral body. The screws therefore have deeper cutting thread with wider spaces between them. Also because cancellous bone is less dense these screws can be inserted using under tapping techniques, compressing the bone and potentially leading to increased POS.

The context of the increasing prevalence of osteoporosis with the aging population emphasises the importance of having an additional technique that takes advantage of the mechanical properties of cortical bone when cancellous bone is not abundant. Increased BMD has a direct effect on screw fixation strength [20].

Thus, factors related to screw mechanical properties are shaft and thread design, outer and core diameters, length, and pitches. Zindrick et al., showed that increases in the outer diameter and length of screw enhance the fixation stability [21].

**Biomechanical testing of CBT screws**

Matsukawa et al., investigated how the pullout strength of pedicle screws was affected by factors such as insitional trajectory and vertebral bone quality [4]. It was a biomechanical study examining the relationship between pedicle screw trajectory and fixation strength- the goal being to determine the optimal pedicle screw trajectory for various types of bone, especially for osteoporotic bone. CT based 3-dimensional models were made of 20 L4 vertebra and five different transpedicular trajectories were compared. This included the CBT and the traditional pedicle screw trajectories, using same dimensions of screw. Pullout strength was measured and this was correlated with bone BMD.

The CBT demonstrated 34.7% higher pullout strength than the traditional trajectory and the highest value among all trajectories (p < 0.001). Additionally, the correlation coefficient of traditional screws (r = 0.63, P < 0.01) was higher than that of the CBT screws (r = 0.59, P < 0.01). This highlights how traditional trans pedicle trajectory screws are more reliant on BMD for their initial fixation strength than CBT screws. Again highlighting how the CBT may be of use in the osteoporotic population.

Masaki U et al., [22] later addressed the question of whether the initial favourable biomechanical properties of the CBT may be due to the use of cortical screws (i.e. closer threaded screws) rather than inherent properties of the trajectory itself. This study investigates traditional trajectory and CBT using both cortical and cancellous screws in cadaveric pig vertebra. They showed that CBT cortical screws had 29.5% higher maximal pullout strength than cancellous screws inserted with the traditional trajectory. In other words, initial stability was significantly higher for the CBT using cortical screws than any other combination of trajectory and type of screws. The implication being that it is likely that the increased stability of screws in the CBT studies by Santori et al., and others was due to the novel trajectory as opposed to screw type used.

Importantly, irrespective of the type of screw used (being either cortical or cancellous screws) the pullout strength was higher with the CBT indicating that the methods underpinnings of maximising cortical bone contact to increase initial fixation stability is sound.

Taking this further, Matsukawa et al. also performed an in vivo study investigating the effectiveness of the CBT technique by measuring the insitional torque of screw insertion as a predictor of screw stability [3]. Of particular note this study included “the H group”- eight patients which had side-by-side comparison of two different insitional techniques for each
In these patients a traditional transpedicular screw was inserted on one side of the patient's vertebra and the novel CBT screw was inserted on the other and the insertional torque was measured. In addition, the insertional torque was correlated with bone mineral density.

The CBT screws showed 2.01 times higher torque and the difference was significant between the 2 techniques \( (P < 0.01) \) overall. In the “H group” the CBT screws demonstrated 1.71 times higher torque when compared to traditional pedicle screws inserted into the opposite side of the same vertebra. Statistical significance was achieved \( (P < 0.01) \).

Matsukawa et al., later showed that these principles also hold true in the thoracic spine [7]. In this morphometric study and biomechanical study they showed that insertional torque was increased 53.8% with the CBT than traditional technique \( (P=0.0003) \).

Recently, Wray et al., (2015) showed that not only that the bone quality of the CBT was higher than the traditional trajectory but it also had superior initial stability of the screw-bone interface. They did this using standard screw pullout and screw toggle testing techniques while taking into account dimensions of the pedicle vs cortical screws [11]. Across all mechanical testing end points comparing CBT with cortical screws compared with traditional trajectory with pedicle screws was not significantly different with screw profile or trajectory as applied to both osteoporotic and non-osteoporotic bone. In short, when taking the surface area of the bone/screw interface of the smaller cortical screws, the initial stability of cortical screws using the CBT is superior. Their conclusion being that CBT using cortical screws is a valid option in posterior fusion surgery.

With regard to construct stability of CBT techniques Perez-Orribo et al., demonstrated that when pedicle screw constructs are compared with cortical screw constructs where the interbody discs are left intact there is significant decrease in stiffness in the construct with axial loading- which can be rectified with the addition of an interbody device [23]. This raises concern regarding increased micro motion at the screw bone interface with the CBT using cortical screws potentially leading to increase risk of screw loosening.

This raises the question of how reliable is laboratory biomechanical testing with regard to construct stability- using techniques such as toggle testing and measuring outcomes such as pullout strength. As previously discussed, laboratory studies have shown that CBT has greater maximal POS than traditional pedicle screws however this must be interpreted with the understanding that under more physiological conditions where flexion/extension, axial loading and lateral forces exist.

In an attempt to bridge this gap Baluch et al., conducted a human cadaveric biomechanical study comparing the fixation of cortical with traditional pedicle screws under cyclic physiological loads (cyclic craniocaudal toggling) in vitro [24]. They point out that although uniaxial pullout is a common method of evaluating pedicle screw fixation, this may be an oversimplification of the more complex forces at play in construct failure in vivo. Forces exerted perpendicular to the long axis of the screws caused by movements in flexion/extension, rotation, and lateral bending resulting in loosening and/or screw pullout. Laterally directed cortical pedicle screws have superior resistance to craniocaudal toggling compared with traditional pedicle screws- requiring more cycles of craniocaudal toggling at increasing loads to cause pullout.

Recent clinical evidence relating to CBT screws

Glennie et al., investigated clinical outcomes of posterior fusion for degenerative spinal pathologies comparing a CBT with cortical screw approach and traditional pedicle based techniques [25]. It was a retrospective study of following up eight patients who underwent posterior fusion using the CBT technique. It was an early clinical study and should be interpreted with caution however two of eight patients were revised at an average of 12 months. Of the eight patients reviewed, two were revised, four demonstrated loss of reduction during the course of their clinical follow-up and five demonstrated evidence of frank screw loosening. Again this is an early study but it does highlight the need for further clinical data regarding the stability of posterior fusion constructs using the relatively new CBT technique.

Ninomiya et al., demonstrated that at least in the short term CBT in pedicle screw fixation had low levels of radiographic evidence of screw loosening [26]. They measured the rate of post operative radiolucent zones around 109 CBT screws from 19 patients who underwent pedicle screw fixation. Six screws had evidence of loosening as determined by observed clear zone formation (5.5%) and although this did not correlate with lower insertional torque statistically, it does indicate again that CBT in pedicle screw fixation may well be a robust option for pedicle screw fixation. The follow up time was 6 months, and while this is early compared with similar studies for traditionally placed pedicle screws, it does shows lower rates of clear zone positivity compared to similar studies for traditional pedicle fixation techniques. In one comparable study looking at rates of radiographic evidence of loosening of traditional pedicle screws, clear zone positivity in more than 1 screw in a particular construct was 41.1% at 6 months [27] compared to 26.3% in the Ninomiya series.

The CBT technique requires less muscle dissection than traditional techniques due to its more medial starting point and medial to lateral trajectory. With this seemingly reduced invasiveness of the CBT technique in mind, Kasukawa et al., showed that when CBT is used in combination with the transforaminal interbody lumbar fusion technique it had advantages such as less blood loss intraoperative and shorter procedural time [28]. Rates of non-union, degree of loss of lumbar lordosis and accuracy of the screws themselves were similar compared to minimally invasive and percutaneous techniques using the traditional pedicle screw trajectory. Highlighting how CBT has advantages over techniques which try to attempt to minimise muscle dissections and postoperative pain.

Further clinical studies are now coming to light. Of particular note Patel et al., focused on the rates of early complications (at 3 months) using the CBT technique. Specifically they looked at the rates of radiographic loosening or fractures, intraoperative durotomy, infections and neurological injury [29]. Of the 22 patients retrospectively included, 5 patients had some kind of JSM Neurosurg Spine 4(1): 1061 (2016)
complication including pedicle/pars fracture or screw loosening. None sustained neurological injury. Of the three patients that had screw loosening one underwent further surgery while the other two were expected to require it in the future.

**DISCUSSION AND CONCLUSION**

Posterior lumbar spine fusion using the cortical based trajectory has advantages over traditional pedicle screw techniques including reduced dissection and tissue trauma, increased biomechanical stability in both high and low quality bone and is thereby a valid alternative to traditional techniques. Recent clinical studies have highlighted potential concerns regarding early complications. Further clinical studies with regard to long term outcomes such as construct failure and screw loosening is still required however to determine if this technique should be reserved for complicated of osteoporotic patients or whether it should have more widespread applications.

**REFERENCES**


