CLINICAL ARTICLE

Isthmus-guided Cortical Bone Trajectory Reduces Postoperative Increases in Serum Creatinine Phosphokinase Concentrations

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Objective: This study aimed to determine whether an isthmus-guided cortical bone trajectory (CBT) technique provides better clinical outcomes than the original cortical bone trajectory CBT technique for screw fixation.

Methods: A consecutive series of 21 patients with lumbar spondylolisthesis who had undergone CBT screw fixation using the original technique from June 2012 to February 2013 and 33 who had undergone the isthmus-guided technique from March 2013 to August 2014 was retrospectively reviewed. The number of screws inserted, interbody fusion and screw misplacements, amount of blood loss, and creatinine phosphokinase (CPK) ratios (postoperative day 1 CPK/preoperative CPK) were reviewed to evaluate clinical outcomes and compared between the original and isthmus-guided CBT techniques.

Results: Postoperative serum CPK concentrations were significantly lower with the isthmus-guided than the original CBT technique ($P < 0.05$). There were no significant differences in age, blood loss, or number of screws, vertebral interbody fusions and patients with history of previous decompression surgery at the same level. There was a trend to higher incidence of screw misplacement with the original than the isthmus-guided CBT technique; this difference was not significant ($P = 0.53$). There were no major intraoperative complications. In all the CBT procedures performed in our institution, almost half (47%) the screw misplacements have occurred at the level of L₅, and most on the right side.

Conclusions: Right-handed operators should take care inserting screws on the right side. From the viewpoint of screw misplacement, isthmus-guided CBT provides superior or equivalent safety to the original CBT technique.

Key words: Cortical bone trajectory; Lumbar degenerative spondylolisthesis; Pedicle screw

Introduction

A pedicle screw (PS) fixation system has been widely used for spinal reconstruction. In 2009, Santoni *et al.* studied insertional techniques and advocated a new fixation technique called the cortical bone trajectory (CBT)¹. In the conventional PS technique, screws are inserted through the anatomical axis of the pedicle into the vertebral body, whereas in the CBT technique, the trajectory follows a caudocephalad path sagittally and a medial-to-lateral path to maximally purchase the

cortical bone from the pedicle to the vertebral body. Fixation with the bone cortex is achieved at four sites: the dorsal, posteromedial, and anterolateral sides of the pedicle and the marginal region of the vertebral body (Fig. 1).

The CBT technique enables implant fixation regardless of the bone mineral density of the trabeculae, whereas with the conventional method elderly patients and others with osteoporosis may have problems with PS fixation caused by resorption of cancellous bone trabeculae, leading to development of

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Fig. 1 Diagrammatic representation of trajectories of screws in screw fixation. The left arrow indicates a screw inserted using the conventional PS technique and the right arrow a screw inserted using the CBT technique. The CBT technique offers better purchase on cortical bone than the conventional technique.

such complications as loosening and displacement of screws. Because osteoporosis has a far greater effect on cancellous than on cortical bone²⁻⁶, the CBT technique is considered to provide better biomechanical stability in patients with osteoporosis. Several cadaveric biomechanical studies have shown that CBT provides significantly denser bone for screw purchase than the traditional PS trajectory^{1,7} and shown a 30% increase in uniaxial yield pullout load relative to the traditional PS fixation¹. Additionally, in a human cadaveric study, the insertional torque of pedicle screws was highly correlated with the pullout strength⁸, the insertional torque of the CBT technique reportedly being about 1.7 times greater than with the traditional PS technique⁹. Furthermore, a recent study has shown that cortical trajectory screws may also be used as a rescue option in the setting of a failed or compromised PS construct in the lumbar spine without need for augmentation or additional levels of fixation and fusion. Salvaging loose or compromised pedicle screws may be necessary for a number of reasons, including errors in screw placement, hardware failure and pseudarthrosis. Knowing that there is a viable rescue option may make surgeons more comfortable to attempt spinal fixation in the appropriate circumstances¹⁰.

The traditional PS method uses a screw designed for insertion into cancellous bone, whereas the cortical trajectory screw, which maximizes thread contact with the higher density cortical bone, is used in CBT¹. In general, cortical screws used in orthopedic surgery have a dense thread with a smaller bite, whereas screws used for cancellous bone have a larger bite and a larger pitch. Recently, Ueno *et al.* investigated whether the increased strength of CBT derives from the specific trajectory or the characteristics of the screw thread in contact with the

cortical bone by studying the relationship between screw entry trajectory and screw shape in animal experiments. These authors found that although both the screw thread characteristics and entry trajectory contribute to the increased pull out strength achieved with the CBT technique, the specific trajectory, which enables contact with cortical bone, is the more influential factor¹¹. It has been shown that fixation strength comparable to that of the conventional PS method is achieved even when using shorter and/or thinner screws than those used in the conventional PS method^{9,12,13}. Although the CBT technique has clear advantages, there are still a few problems in clinical application. For example, in the original CBT technique, the insertion points are in the vicinity of the ends of the inferior articular processes. This joint has been destroyed in many patients requiring intervertebral fusion surgery, which can make it difficult to use it as a landmark for screw insertion^{14,15}. With severe lateral slippage and so on, the screw insertion site can become dislocated sideways, possibly damaging the inside of the spinal canal and the nerve root. Also, although CBT screws have a more medial point of insertion than traditional pedicle screws, which minimizes soft-tissue dissection and intraoperative retraction, the minimal tissue exposure of the CBT technique requires better comprehension of the anatomy and more accurate surgical skills.

In general, the trajectory can be freely selected as long as it remains inside the pedicle; thus, there are numerous starting points for CBT screws². We have been able to increase the safety of the original CBT method by using the isthmus of lamina as a screw location landmark for inserting the screws, while keeping clear of the intervertebral foramen using lateral fluoroscopy. The isthmus of the lamina is less affected by joint degeneration or lateral slippage of the vertebra than the original of the end of the inferior articular process. We here propose our isthmus-guided cortical bone trajectory (isthmus-guided CBT) technique for lumbar screw insertion. In the present study, a small series of consecutive patients who had undergone the original or isthmus-guided CBT procedures was explored and their outcomes compared.

Materials and Methods

Patient Characteristics

This retrospective study comprised a consecutive series of patients who had undergone posterolateral fusion for management of lumbar degenerative spondylolisthesis with spinal canal stenosis. The indications for CBT screw fixation at the authors' hospital include neurogenic claudication, radiculopathy and/or intractable low back pain. Pedicle screw fixation was performed on 21 patients (9 men and 12 women) using the original CBT technique from June 2012 to February 2013 and on 33 patients (15 men and 18 women) using the isthmus-guided CBT technique from March 2013 to August 2014 (Table 1). The patients' presentations included neurogenic claudication, radiculopathy and/or intractable low back pain. All but one patient undergoing the original CBT technique and all but two patients undergoing the isthmus-guided CBT

TABLE 1 Patient characteristics

CBT	Period	Number	Age (years)	Male : female	Screws
Original CBT	June 2012 to February 2013	21	65.1	9:12	162
Isthmus-guided CBT	March 2013 to August 2014	33	64.4	15:18	204

technique underwent posterior interbody fusion with CBT screw fixation from the side with greater leg pain.

Surgical Technique

The original CBT method has some drawbacks. In the original CBT method, insertion points are positioned in the vicinity of the end of the inferior articular process. This joint has been destroyed in many patients requiring intervertebral fusion surgery, sometimes making it difficult to use it as a landmark for the screw insertion point. Moreover, in patients with severe lateral slippage, the screw insertion site can become dislocated sideways, resulting in damage inside the spinal canal and/or of the nerve root.

To overcome some drawbacks of the original CBT method, we developed screw insertion points with the lateral margin of the isthmus and the superior margin of the intervertebral foramen as imaged by lateral fluoroscopy as landmarks (isthmus-guided CBT technique, Fig. 2). In this method of screw insertion, because the lateral margin of the isthmus, which is unlikely to be affected by degeneration, is exposed, nerve root damage and screw deviations into the spinal canal are theoretically avoided, even in patients with severe intervertebral joint degeneration. Screws are inserted at a point 3 mm medial to the lateral margin of the isthmus, staying away from the intervertebral foramen as guided by lateral fluoroscopy. The CBT screws used are 4.5–5.5 mm in diameter and 25–35 mm in length (Zodiac; Alphatec Pacific, Tokyo, Japan).

Preoperative planning was performed using a three-dimensional CT workstation. The entry point and trajectory were simulated and the appropriate screw length, medial-

lateral angle of the screws and distance between the bilateral screw insertion points estimated (Fig. 3). Even when the articular process on one side had been destroyed, this preoperative simulation of the width of the screw insertion points helped operators identify the correct screw insertion point by measuring the distance from the entry point on the healthy side.

Clinical Assessment

Postoperative CT scan images were examined if the CBT screws were located within the confines of the pedicles. The number of screws inserted, interbody fusion and screw misplacements, amount of blood loss and ratio of creatinine phosphokinase (CPK) concentrations (postoperative day 1 CPK/preoperative CPK) were reviewed to evaluate clinical outcomes and to compare the original and isthmus-guided CBT techniques.

Statistical Analysis

Continuous variables are presented as means and categorical variables as frequencies and percentages. The independent Student's *t*-test was used to compare continuous variables and Fisher's exact test to compare categorical variables between the original and the isthmus-guided CBT techniques. All *P* values are two-sided, and *P* values < 0.05 were considered to indicate significance.

Results

During the study period, 21 consecutive patients were treated with the original and 33 with the isthmus-guided

Fig. 2 Diagrammatic representation of screw insertion point in isthmus-guided CBT. (A) A screw is inserted in the vicinity of the inferior articular process from the dorsal side at a point 3 mm medial to the lateral margin of the isthmus. (B) Lateral view showing how the superior margin of the intervertebral foramen serves as a landmark.

Fig. 3 Preoperative planning using a 3D-CT workstation. (A, B) The screw lengths, medial-lateral angles of the screw and distance between the bilateral screw insertion points are estimated. (C) Intraoperative view of measurement of the distance between the bilateral screw insertion points. This helps in identifying the appropriate screw insertion point, even when the articular process has been destroyed.

CBT technique. With the original CBT technique, 162 screws were used and with the isthmus-guided 204. Relevant patient characteristics are presented in Table 1. The mean patient ages at the time of surgery by the original and isthmus-guided CBT techniques were 65.1 ± 12.4 years (range, 29–81 years) and 64.4 ± 12.8 years (range, 32–80 years), respectively. Table 2 shows

the comparisons of clinical outcomes between original CBT and isthmus-guided CBT. The CPK ratio (postoperative day 1 CPK/preoperative CPK) was significantly less with the isthmus-guided than the original CBT technique (3.8 vs. 6.1; $P < 0.05$). There were no significant differences in age, number of screws, number of vertebral interbody fusions, blood loss,

TABLE 2 Comparisons of patients' characteristics and outcomes according to CBT technique

Variable	Original CBT	Isthmus-guided CBT	P value
Number of screws per patient	7.7	6.2	0.06*
Number of interbody fusions per patient	1.8	1.6	0.52*
Blood loss (mL)	690.0	592.6	0.64*
CPK ratio (preoperative/ postoperative)	6.1	3.8	0.04*
Screw misplacements, patients (%)	5 (23.8)	7 (21.2)	0.54†
Number of screw misplacements (%)	7 (4.3)	8 (3.9)	0.53†
Previous decompression, patients (%)	7 (33.3)	11 (33.3)	0.37†

*, Student's t-test, †, Fisher's exact test.

TABLE 3 Analysis of the cases with screw misplacements

CBT	Case	Age (years)	Sex	Misplacement (screws)	Location		Previous surgery
					Left	Right	
Original CBT	1	71	F	1		L ₄	–
	2	71	M	1		L ₅	–
	3	76	F	1		L ₅	–
	4	68	F	2		T ₁₂ , L ₂	–
	5	75	F	2		L ₂ , L ₄	+
Isthmus-guided CBT	1	68	F	1		L ₅	–
	2	62	M	1		L ₃	–
	3	65	F	1		L ₃	–
	4	67	F	1		L ₅	–
	5	65	F	1	L ₅		–
	6*	64	M	1	L ₅		+
	7	75	F	2	L ₅	L ₂	+

*, this patient underwent reoperation because of postoperative radiculopathy; F, female; M, male.

and number of patients with a history of previous decompression surgery at the same level.

Each patient was examined for screw misplacements caused by inappropriate insertion into the pedicle. The number of such deviations was 7/162 screws (4.3%) in five of the 21 patients operated on using the original CBT technique and 7/204 screws (3.9%) in seven of the 33 patients operated on using the isthmus-guided CBT technique. There was a trend toward fewer screw misplacements with the isthmus-guided than the original CBT technique; however, this difference was not significant ($P = 0.53$). No screws caused dura mater laceration, bone fractures or surgical site infections. The cases of screw misplacement are summarized in Table 3. Among the 12 patients with screw misplacement, one patient who had undergone the isthmus-guided CBT procedure presented with radicular pain in the territory of the left L₅ spinal nerve root and underwent re-placement of one involved screw. Through-

out our series, almost half (47%) of the screw misplacements occurred at the level of L₅ (Table 3, Fig. 4). Most screw misplacements occurred on the right side (Table 3, Fig. 5).

Discussion

The most serious complication to be avoided during screw insertion is screw penetration into the spinal canal. In the original CBT method, insertion points are positioned in the vicinity of the end of the inferior articular process. Because this joint has been destroyed in many patients who meet indications for intervertebral fusion surgery, it is sometimes difficult to use as a landmark for the screw starting point¹⁴. In the isthmus-guided CBT procedure, the screw insertion point is determined by exposing the lateral margin of the isthmus, which is affected neither by joint degeneration nor lateral slippage of the vertebra. Although significant differences in outcomes were not found in this small study, as far as

Fig. 4 Left panel: Pie chart showing vertebral levels of screw misplacements. Almost half occur at the level of L₅ in patients in whom a lateral recess of the spinal canal has developed. Left panel: CT image showing misplaced screw at the L₅ level.

Fig. 5 Pie chart showing that most screw misplacements occurred on the right side. Diagrammatic representation of reason for predominance of right-sided screw displacement when the operator is right-handed.

screw misplacement is concerned isthmus-guided CBT provided superior or equivalent safety to the original CBT technique.

Throughout all of the CBT procedures performed in our institution, almost half of the screw misplacements occurred at L₅ in patients in whom a lateral recess of the spinal canal had developed (Fig. 4). Thus, the medial-lateral angle trajectory of the CBT screw should be increased according to the extent of development of the lateral recess to avoid screw penetration into the spinal canal. In addition, 80% of screw misplacements occurred on the right side. This is partly attributable to the operative locations of the C arm fluoroscopy unit and the operator, as well as the operator's dominant hand. When the C arm fluoroscopy unit is located cranial to the patient, the direction of left CBT screw insertion is toward the operator, whereas the direction of the right one is away from the operator (Fig. 5). Because the right CBT screw has to be inserted against the axis of the operator, it is more difficult to maintain an adequate medial-lateral insertion angle of the right CBT screw than with the left one.

Basically, with the CBT technique the screw insertion point is positioned more medially than with the conventional PS method, there is less soft tissue dissection and traction, and the skin incision is shorter. Moreover, the isthmus-guided CBT technique is associated with smaller increases in postoperative CPK concentrations than the original CBT technique. Serum concentration of CPK increases following muscle injury

caused by cardiac disease, trauma or surgery^{16–18}. Serum concentrations of CPK are often used to evaluate muscle injury in the early postoperative stage. In the isthmus-guided CBT technique, the range of dissection is limited to the lateral margin of the lamina, neither the facet joint nor the transverse process requiring exposure. The reduced anatomic exposure with the isthmus-guided CBT method results in a smaller increase in postoperative CPK concentrations.

In recent years, the use of vertebral fusion surgery using screws in the field of spine surgery has steadily increased. In addition to lumbar vertebrae, the CBT technique has also been used for lower thoracic and sacral vertebrae¹⁹. We believe that our proposed isthmus-guided CBT method is safer, less invasive, and simple enough to become a widely used technique for CBT fixation.

Conclusions

From the perspective of screw misplacement, isthmus-guided CBT provides superior or equivalent safety to the original CBT method. Using the isthmus as a landmark for the screw starting point reduces postoperative increases in CPK concentrations. Right-handed operators should take care when inserting screws on the right side: particularly in cases where a lateral recess of the spinal canal has developed, an insufficient medial-lateral angle trajectory may result in screws penetrating the spinal canal and causing nerve root injury.

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