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Pars/Pedicle Fracture And Screw Loosening Associated With Cortical Bone Trajectory: A Case Series And Proposed Mechanism Through A Cadaveric Study

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ABSTRACT

Background Context: Cortical bone trajectory (CBT) technique for pedicle screw placement in the lumbar spine has become more popular since its introduction in 2009. The distinct advantages of utilizing CBT technique involve increased screw purchase within cortical bone and reduced surgical dissection. However, contrary to several favorable biomechanical results, there were anecdotal reports of clinical complications associated with CBT.

Purpose: First, to report on two unique pars/pedicle fracture cases involving the use of CBT technique; secondly, to perform a cadaveric pilot study to determine the possible mechanism for this fracture pattern.

Study Design/Setting: Case report and cadaveric study.

Methods: After presenting two clinical case, 19 fresh frozen lumbar vertebrae were obtained from eight cadavers. Pedicle screws were instrumented on each level using CBT under video recording. After the instrumentation, X-Ray images were obtained and anatomical dissections were performed.

Results: To be able to reach necessary angle for medial to lateral CBC trajectory, 13 out of 19 (68%) spinous process had to be removed. There were total of 7 complications. One pars/pedicle fracture out of 37 trajectories (2.7%) and six out of 37 trajectory deviations (16.2%), which resulted in gross loosening were observed.

Conclusions: The head of the pedicle screw impinging on the base of spinous process and lamina was observed in our cadaveric model. This mechanism could potentially explain both screw loosening and fractures associated with CBT technique.

Keywords: *Pedicle screw instrumentation, cortical bone trajectory, complication, pedicle fracture, pars fracture, screw loosening*

Introduction

Cortical bone trajectory (CBT) technique for pedicle screw placement in the lumbar spine has become popular since its introduction in 2009 by Santoni.[1] The distinct advantages of utilizing CBT technique involve increased screw purchase within cortical bone and reduced surgical dissection.[2-4] These factors makes CBT technique an attractive alternative to standard pedicle screw fixation. This technique is particularly attractive in patient with metabolic bone disease. Several biomechanical studies[1, 5-10] were able to demonstrate comparable pullout and cyclic fatigue strength between CBT and traditional pedicle screw technique. In contrary to these favorable biomechanical results, Glennie et al.[11] reported screw loosening in 5 of 8 patients. This finding is consistent with our initial series involving 2 out of 22 patients who developed pars/pedicle fractures and 2 additional patients who developed early screw loosening.

The objective of our study was two fold: First, to report on two unique pars/pedicle fracture cases involving the use of CBT technique; secondly, to perform a cadaveric pilot study to determine the possible mechanism for this fracture pattern.

Case 1

A 77 year old female with aBMI of 27, presented to clinic with symptoms of neurogenic claudication and back pain. The patient's Oswestry Disability Index (ODI) and Visual Analogue Score (VAS) were 24 and 6, respectively. Neurological examination was unremarkable for any significant sensory or motor deficits. This patient had failed to respond to conservative therapy which included medication, physical therapy and steroid injections. Imaging studies showed central canal stenosis involving L3-L4 and L4-L5 along with grade 1 spondylolisthesis at both levels.

Surgery: Decompression was performed at both L3-4 and L4-5 levels. Pedicle screws (5.0 x30 mm) using the CBT technique (Medtronic, Minneapolis, MN) were placed on the left side first without complication. However, when placing screws using CBT technique on the right, a fracture through the pars of L3 was encountered (Figure 1). Given the significant pars fracture that had occurred intra-operatively, use of CBT technique was aborted and traditional pedicle screw placement was employed on the on right side at L3, L4 and L5 (Figure 2). Post operatively the patient's pain improved with ODI and VAS scores of 6 and 0, respectively. The patient's most recent follow up was 15 months after her initial surgery.

Case 2

A fifty-six year old male with a BMI of 27.8 and history of hypertension and 42 year-pack smoking history presented to the clinic with severe progressive low back and right leg pain. The patient's ODI and VAS scores were 36 and 10, respectively. Additionally, he complained of associated numbness, weakness, and paresthesias within the right L5/S1 nerve distribution. The patient failed conservative treatment including medication, therapy and epidural steroid injection.

Surgery: The patient underwent decompression at L5-S1 and posterior instrumentation at L4 and L5 using CBT technique (6.5 x 30 mm screws, Medtronic, Minneapolis, MN). Sacral alar screws (7.5 x 30 mm) were placed at S1. Bone graft was placed posterior laterally from L4 to S1. Post-operatively the patient reported initial modest improvements; however, after 4 weeks he began to have increasing low back pain. A CT scan of the lumbar spine revealed a right pars/pedicle fracture on the right at L5, as well as loosening of both sacral alar and right L5 pedicle screws (Figure 3). The patient subsequently required 2 additional revision surgeries. The first revision surgery included anterior instrumentation and fusion from L3 to S1 which subsequently resulted in pseudarthrosis and broken hardware 9 months after first revision surgery (Figure 4). The second revision surgery involved posterior L3 to S1 fusion with L3 to ilium instrumentation (Figure 5). Two screws were placed at each L3 pedicle using both CBT technique and standard pedicle screw trajectories. Rods were connected from pedicle screws to cortical screws using a rod-to-rod connector to increase the stability of the construct.

Cadaveric Study

Given these two similar clinical complications, we decided to perform a cadaveric study to determine the possible mechanism of these fractures.

Material & Method:

19 fresh frozen lumbar vertebrae were obtained from eight cadavers. To quantify bone mineral density (BMD), each vertebral level was scanned with dual energy X-ray absorptiometry (DEXA). All screws were inserted using cortical bone trajectory technique as described by Matsukawa et al.[12] The starting point for

CBT technique was at the level of the caudal aspect of the transverse process; approximately 2 mm medial to the lateral margin of pars inter-articularis. A surgical burr with diameter of 1.7 mm (Midas Rex Legend, Medtronic, Minneapolis, MN) was used to create a staring point then directed to approximately 25° cephalad and 8° lateral. Tap of 4.5 mm was used to tap line to line. 4.5x25 mm poly-axial pedicle screw (Nuvasive, San Diego, CA) was inserted. The insertion continued until either tulip head contacted the pars/lamina or a fracture occurred. A total of 37 pedicle screws were placed under video recording. X-ray of AP/Lateral/Axial views of each vertebra were obtained after instrumentation. Anatomical dissections were performed at the end of the experiment to directly visualize each vertebra to confirm screw placement and identify potential fractures.

Results:

BMD of the donors, instrumentation levels, and complications were summarized in the Table 1. To be able to reach necessary angle for medial to lateral trajectory, 13 out of 19 (68%) spinous process had to be removed (Figure 6). There were total of 7 complications. One pars/pedicle fracture (2.7%) and six trajectory deviations (16.2%) resulted in gross loosening observed in 7 out of 37 screws (18.9%).

The fracture observed during the cadaveric experiment was identical to the fractures previously described in the aforementioned clinical cases. The fracture started at the screw insertion point on the lateral border of the pars, extended in a semi-sagittal oblique plane through the medial aspect of the superior facet, continued through the pedicle, then exited out the lateral aspect of the pedicle (Figure 7).

Through video analysis, it was clear that both screw loosening and development of fracture were created by the same mechanism. There was no observable abnormality during the initial drill and tap process. However, during final screw placement, the head of the screw impinged medially against the base of spinous process and lamina thus causing a subtle but sudden lateral deviation to the initial tapped trajectory (Video 1). This deviation caused either the loss of purchase or in the extreme case, the fracture of the pars/pedicle. To determine the actual deviation from the tapped trajectory, we measured the trajectory angle before and after screw head impingement on the posterior element (Figure 8).

Discussion

To our knowledge, there has only been one study in the literature mentioning complications of CBT technique. Glennie et al.[11] retrospectively reviewed records for a 2-year period at their institution and found a total of 8 patients who had undergone pedicle screw placement with CBT technique. Their mean follow-up time was 16.4 months. They placed CBT pedicle screws using O-Arm and trajectories were confirmed with post-op CT scan. Of the 8 patients who had underwent instrumentation of the lumbar spine using CBT technique, 5 had screw loosening, and 2 of them required revision surgery after a period of one year. They suggested that a possible mechanism of this early failure involved the trapezoidal shape of final construct; stiff, oblique rod-screw construct; and short screw size. This high rate of early instrument loosening of 62% with CBT technique is rather alarming.

It is important to point out that during the cadaveric experiments, the deviation from the tapped trajectory is very small, usually less than 15 degree. The surgeon during the experiments can usually feel a sudden but subtle decrease in insertional torque during the final screw insertion when head of the screw impinge against the posterior elements. This slight change in trajectory and insertional torque may not be noticed by the operating surgeons who are not specifically looking for this complication. The axial radiograph of the instrumented vertebrae may still show that the CBT screws are inside of the pedicles, (Figure 9). However, through video imaging we are able to capture the sudden change in trajectory. This could potentially explain why in the study by Glennie et al , the screw placement was acceptable as confirmed by both intra-operative navigation and post-operative CT scan.

In a biomechanical study by Paik et al.,[13] the effect of the pedicle screw head hubbing against the lamina with traditional trajectory was examined. Hubbing was defined as an additional aperture purchase of the dorsal lamina to the ventral aspect of the screw head. In their study, hubbing pedicle screw resulted in significantly lower pullout strength compared to the non-hubbing pedicle screws. These differences persisted irrespective of bone mineral density. They also encountered fractures in 11 out of 22 screws that were hubbed. The fracture pattern was visualized through lamina, superior articular facet, and the lateral pedicle wall. Their observations demonstrated that deeper screw insertion essentially resulted in catastrophic failure with fracture propagation through the dorsal lamina, pedicle and, the superior articular facet. The hubbing mechanism with head of screw impinging against posterior bony elements inducing a fracture could certainly be similar to the mechanism of pars/pedicle fracture caused by cortical bone trajectory.

There were multiple limitations to our study. Firstly this was intended as a pilot study only. We did not have enough sample size to reach statistical power to analyze and compare BMD values, vertebral levels ,and trajectory angle deviation values. Secondly, this was a cadaveric study. Each vertebra was completely exposed so the surgeon has visualization of anatomy from all angles. This did not replicate in-vivo conditions of operating on live patients, which may not show the same mechanism. In addition, there were more upper lumbar vertebrae than lower lumbar vertebrae tested, which might have falsely increased our complication rate. We observed in our experiment that, the risk of screw head impinging against the posterior elements and causing trajectory deviation was higher in the upper lumbar levels because the distance from medial wall of pedicle to the base of spinous process was shorter than that of the lower lumbar vertebrae. A significant limitation to this type of descriptive study is lacking a control or a comparative group. In the future, it may be reasonable to conduct a controlled cadaveric study to compare modular and non-modular headed screws to determine the effect of impingement of the tulip head against the posterior bony elements. Risk factors based on patient-specific anatomy and pre-op radiographs can be studied in order to avoid potential complication.

The strength of this paper is that it is the first study to describe the pars/pedicle fracture in CBT technique and and it proposes a mechanism for the fracture and cortical screw loosening. Based on the mechanism described, complications can potentially be avoided by the following guidelines:

1. Performing a decompressive laminectomy prior to final screw insertion to avoid head of screw impinging against the posterior elements,
2. Leaving the screw proud to avoid hubbing
3. Using screws with modular head assembly, so the head of the screw can be assembled after the shank of the screw bypass the posterior elements.

Conclusions

This study was able to demonstrate specific pars/pedicle fracture pattern during pedicle screw insertion using cortical bone trajectory technique. The impingement of the head of the pedicle screw on the base of spinous process and lamina was observed in a cadaveric model. This mechanism could potentially explain both screw loosening and fracture formation associated with CBT technique. Possible surgical techniques were proposed based on the cadaveric study to avoid potential complication.

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Figure Legend

Figure 1: CT scan of the L3 shows the fracture started at the pars, continued through the facet joint and extends to the lateral aspect of pedicle.

Figure 2: AP and lateral imaging after the surgery of Case 1. Traditional pedicle screw trajectory construct on the right side, cortical bone trajectory on the left side.

Figure 3: CT scan shows right pars/pedicle fracture on the right at L5 (circle), as well as loosening of both sacral alar (arrow) and right L5 pedicle screws.

Figure 4: CT scan shows broken hardware 9 months after first revision surgery of Case 2.

Figure 5: AP, lateral X-Ray, and CT images after the second revision surgery of Case 2. Arrow a shows rod connecting cortical screws, arrow b shows rod connecting pedicle screws. Arrow c showing screw using traditional trajectory and arrow d showing screw using cortical bone trajectory. Both screw are going thru the same pedicle. Black arrow shows broken S1 ALIF screw.

Figure 6: As shown with dashed line, the cortical bone trajectory is not possible due to the spinous process preventing the drill to aim lateral enough to reach the pedicle. Straight line is the correct trajectory, this can be achieved only after spinous process removal.

Figure 7: Images shows pars/pedicle fracture of the cadaveric vertebra while placing the pedicle screw using cortical bone trajectory. The fracture started at the screw insertion point on the lateral border of the pars (a), extended in a semi-sagittal oblique plane through the medial aspect of the superior facet (b), continued through the pedicle, then exited out the lateral aspect of the pedicle(c).

Figure 8: Picture A prior, picture B after the change of trajectory. Dashed arrow is the initial trajectory prior to impingement. Solid arrow is the final trajectory after the impingement. White arrow is point of impingement that causes trajectory change. Solid line drawn to approximate the posterior wall of vertebral body. Angle a, 75 degree, is between the solid line to screw trajectory prior to impingement Angle b, 90 degree, is between the solid line to screw trajectory after impingement.

Figure 9: Screw a is cortical bone trajectory without deviation. Screw b is deviated cortical bone trajectory after impingement. However, it is still inside of the pedicle.

Table 1: Cadaveric study. BMD, instrumentation, and complication level of donors. (Numbers are showing instrumented pedicles on each level)

Donor	BMD (g/cm^2)	L1	L2	L3	L4	L5	Total
1	0.875	2**	-	-	-	-	2
2	0.961	-	1^f	-	-	-	1
3	1.037	-	2	-	2*	-	4
4	0.875	-	-	-	2	2	4
5	0.864	2	-	-	-	-	2
6	1.075	2*	2**	-	-	-	4
7	0.941	2	2	2	2	2	10
8	0.726	2	2	2	2	2	10
	Total	10	9	4	8	6	*37*

**: 1 side loosening; **: 2 sides loosening; f: fractured.*