

Cortical pedicle screw trajectory technique using 3D printed patient-specific-guide

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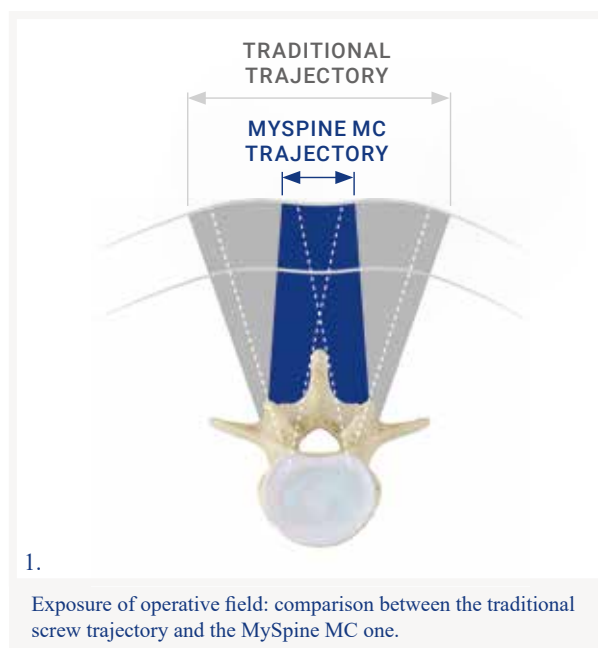
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ABSTRACT

Cortical bone trajectory (CBT) has recently attracted attention as an alternative to the traditional pedicle screw trajectory because of its strong fixation and minimal invasiveness. However, to achieve satisfactory results in terms of biomechanical and clinical outcomes, it is becoming clearer that long cortical pedicle screws directed toward a more anterior position of the vertebral body is more beneficial compared with the original CBT. In order to obtain a longer trajectory while optimizing contact of the screw with the cortical bone, high surgical skill and intraoperative radiation exposure are usually required. We report our experience using a 3D printed patient-specific guide, MySpine Midline Cortical, for longer cortical bone pedicle screws.

INTRODUCTION

In contrast to the traditional pedicle trajectory directed along the anatomical axis of the pedicle, cortical bone trajectory (CBT) starts at the pars interarticularis and follows a craniolaterally-directed path through the pedicle. While traditional pedicle screws achieve stability mainly in cancellous bone from the pedicle to the vertebral body, CBT screws are characterized by maximum contact area with the cortical bone. This technique has attracted attention as a new treatment strategy for spinal diseases in the elderly, and its use is expected to increase, since it even provides strong fixation for an osteoporotic vertebral body. CBT has also a great appeal as a minimally invasive technique. By inserting screws from the pars interarticularis, the method allows to minimize involvement of the craniolateral region, compared to the traditional method. Because of that it reduces damage to the paraspinal muscles, preserves the medial dorsal ramus of the lumbar nerve, and avoid iatrogenic injury to the adjacent facet joints. It is also reported that this technique contributes to reduced long-term impairment of the adjacent spinal segments, which is one of the major problems requiring additional surgical treatment and is inevitable in spinal fusion surgery (Figure 1).



The CBT technique has been increasingly accepted as a new alternative to the traditional method because of its strong fixation and minimal invasiveness. However, there are problems associated with this procedure, such as bone cyst formation around the intervertebral cage and delayed bone union. Disadvantages of CBT, such as short screws that are ineffective in distribution of loads on the vertebral body and divergent trajectory (short lever arm from the median axis) could lead to inferior axial rotational damping properties. Our basic and clinical studies of CBT revealed that the “long cortical bone screws” directed toward a more anterior position of the vertebral body contributed to an improved clinical outcomes, compared with the original CBT. Although the long cortical bone screw

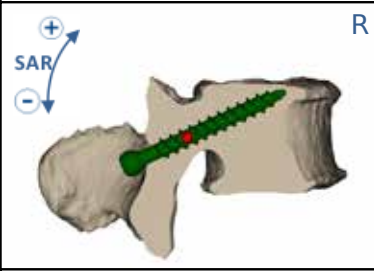


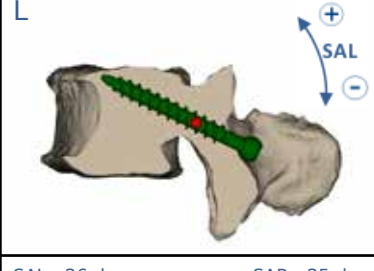
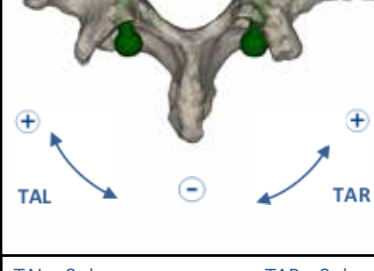

has superior fixation, the acceptable range of trajectory is limited, posing challenges in terms of surgical skills, as long as intraoperative fluoroscopy is needed to create pilot holes. This method is still not familiar to all spinal surgeons because of the learning curve and also demand of frequent x-ray checks creates concerns for radiation exposure. Based on this, a new surgical path is supported with the usage of patient matched jigs to deliver precise screw trajectory.






Pre-operative planning allows for fine tuned screws positioning thanks to the implant parameters selection. In particular, the

chance to choose screws with optimal length and diameter, provides an added advantage to optimize bone purchase and pull-out resistance while reducing the irradiation thanks to the navigated assisted guides.

PREOPERATIVE PLANNING

An online interactive 3-dimensional planning tool is used for reliable pedicle targeting and screw trajectory identification.

Level: L04					
SAGITTAL PLANE		TRANSVERSAL PLANE		CORONAL PLANE	
	R		L		R
	L		R		R
SAL: -26 deg	SAR: -25 deg	TAL: -8 deg	TAR: -8 deg	HDL: 17.4 mm VDL: -5.4 mm	HDR: 17.0 mm VDR: -5.3 mm

SCREW LENGTH (cross-section in the screw plane)		3D VIEW	SCREW DIAMETER (min cross-section of the pedicle)	
				
Length: 45 mm Cortical gap: 2 mm	Length: 45 mm Cortical gap: 3 mm		Diameter 6 mm	Diameter 6 mm

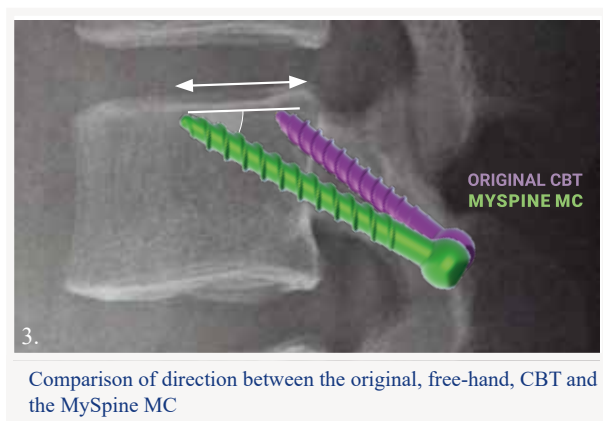
SAR/SAL: Sagittal plane angle right/left, angulation of the screw shaft in relation to pedicle center line, center of rotation is located at the minimal cross section of the pedicle (Red dot)
 TAR/TAL: Transversal plane angle right/left, angulation of the screw shaft in relation to the pedicle center line, center of rotation is located at the minimal cross section of the pedicle (Red dot)
 HDL/HDR: Horizontal distance left/right
 VDL/VDR: Vertical distance left/right

2.

Preoperative planning

The following three points are important in the cortical bone screw method for good surgical results and can be optimized thanks to the 3D pre-operative planning: 1) maximize contact with the cortical bone; 2) select long trajectory into the vertebral body; and 3) avoid interference with the adjacent superior facet joints. In this technique the entry points are sufficiently distant from the adjacent facet joints and the trajectory, following the region from the pars interarticularis to the inferior edge of the pedicle, is abundant in terms of cortical bone. Furthermore, the trajectory along the inferior border of the pedicle allows for the insertion of longer screws into the vertebral body.

For this reason, while the original CBT method granted a length of screws no longer than 25–30 mm, MySpine MC allows the use of longer screws, with a minimum length of 40 mm, directed toward half of the vertebral body endplate leading to improved clinical outcomes (Figure 3).



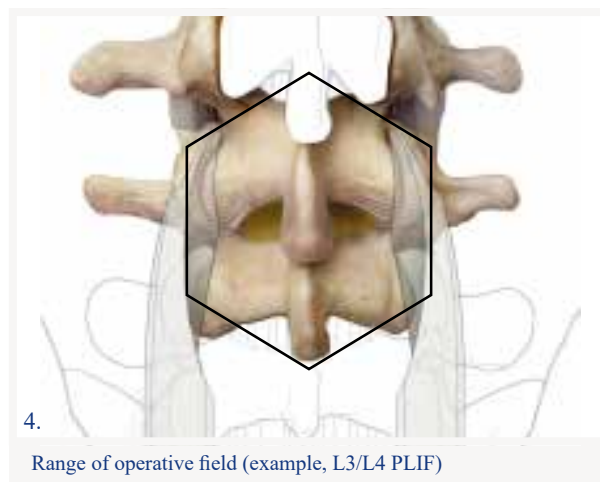
3.

Comparison of direction between the original, free-hand, CBT and the MySpine MC

SURGICAL PROCEDURE

The advantage of the MySpine MC technique is that spinal surgeons can perform all procedures including decompression, interbody manipulation, bone grafting, and screw insertion through a standard, limited midline incision being more advantageous than the percutaneous pedicle screw system (Figure 1).

A midline incision is made over the corresponding vertebrae (4 to 5 cm for single segment posterior lumbar interbody fusion), and the paraspinal muscles are dissected to expose the lateral edge of the pars interarticularis (Figure 4). Surgeons can use a spinous process splitting approach if needed.



4.

Range of operative field (example, L3/L4 PLIF)

The following two cautions should be heeded for exposure of the operative field.

1. Exposure of the most cranial facet adjacent to the fused segment is not necessary.
2. Meticulous bone surface exposure, especially at the caudal end of the lamina and preservation of any bony structure are needed in order to secure the contact surface with the MySpine MC guide for the best coupling.

Once the guide is stably placed on the vertebral arch, the surgeon may confirm the appropriateness of entry point and trajectory direction by using lateral fluoroscopy. Then, the surgeon drills pilot holes through the guide with the caution of (1) Pushing the guide firmly to the lamina to secure stable positioning. And (2) avoiding slipping of the drill tip in a cranial direction when making starting holes.

Special attention need to be paid that any vibration during drilling can loss proper fit of the guide and cause errors. Following screw path creation, surgeons then perform decompression and the interbody procedure before screw insertion as the medial position of the screw heads can hinder the process. After bone grafting and interbody cage insertion, the screw paths are tapped to the same size as planned screw in order to avoid an unintentional cortical fissures and microcracks which result in fixation failure. Placement of a K-wire in the prepared bone path is helpful to accurately guide the tapping and screwing process. Finally, after rod positioning, compression forces can be applied as well as cross-link connector to improve rotational fixation.

CLINICAL EXPERIENCE

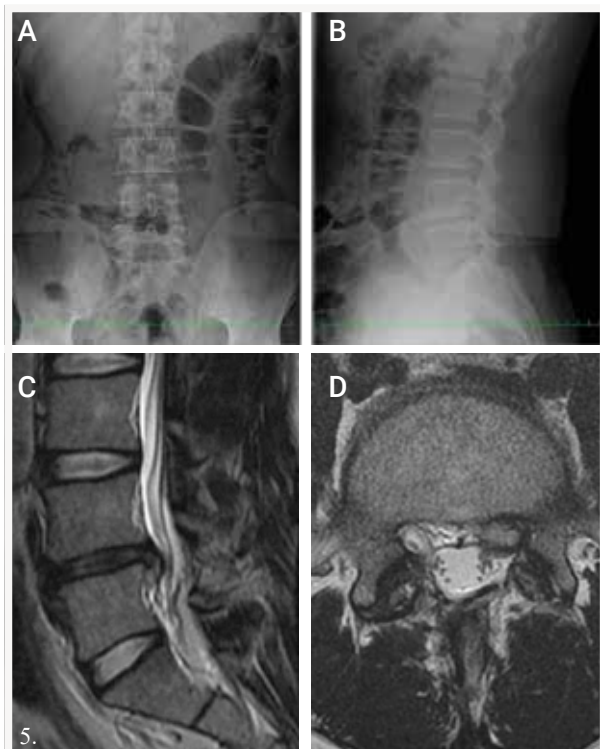
Between November 2016 and May 2018, 28 patients underwent CBT-posterior lumbar interbody fusion using the MySpine MC (average number fused: 1.5 segments). The diagnoses of underlying diseases were degenerative lumbar spondylolisthesis (n = 20), degenerative lumbar scoliosis (n = 4), and others (n = 4). A total of 126 cortical pedicle screws were inserted with the assistance of lateral fluoroscopy. The screw size for each patient had been predetermined thanks to the pre-operative planning, and the screws were positioned in all patients. The most used sizes are ø6x40mm and ø6x45mm that, together, represent more than 70% of the implanted pedicle screws. Postoperative computed tomography (CT) showed displacement of one screw (1/126 = 0.8%), but there was no other cortical perforation. Comparison of insertion angles between preoperative planning and postoperative evaluation using CT showed that the mean error in the axial plane was 1.06 degrees and the error in the sagittal plane was 1.39 degrees.

A representative case is presented

A 38-year-old man, self-defense officer

Main complaint: Left leg pain

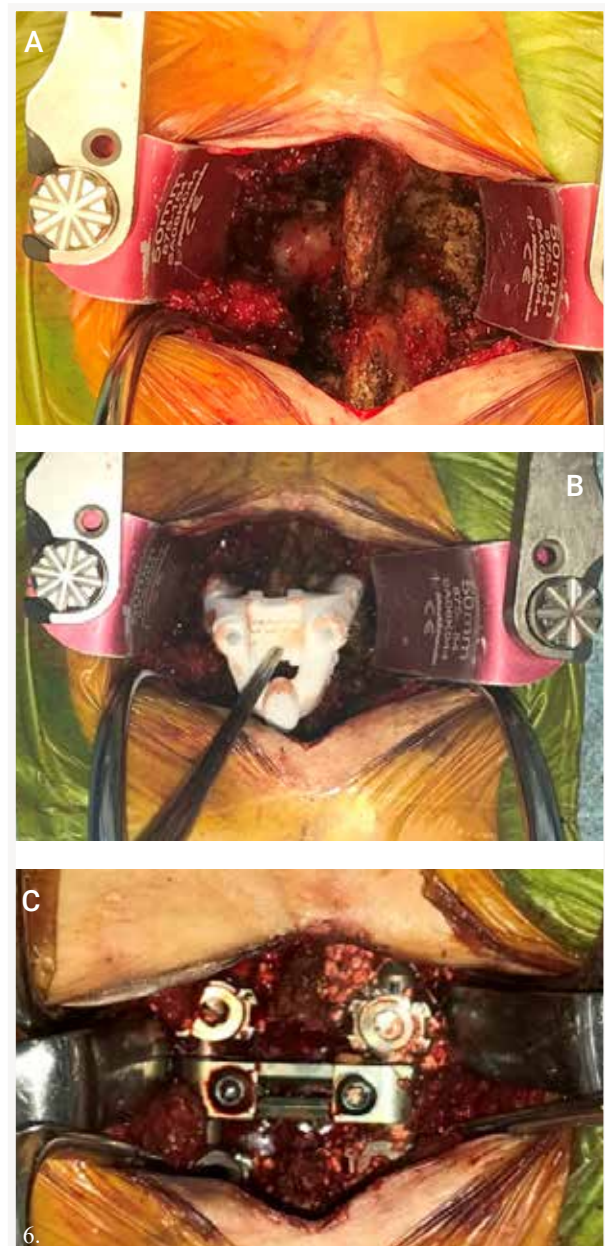
History of illness: The patient had previously undergone surgery twice for lumbar disc herniation at the level of L4/5. The patient was diagnosed with a recurrence of lumbar disc herniation at the level of L4/5 (Figure 5). Patient symptoms were resistant to conservative therapy, and lumbar fusion surgery was planned.



Preoperative imaging (a, b, plain X-ray; c, d, MRI)

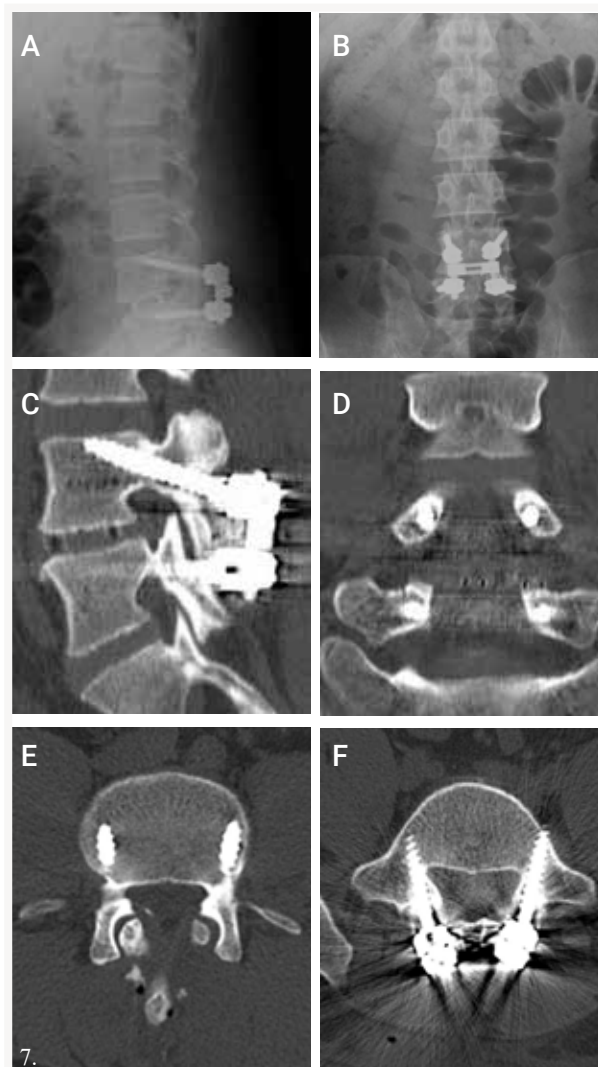
Clinical course: Preoperative planning of the trajectory reaching to the mid-point of the vertebral body was made (Figure 2).

Through a midline skin incision of 5 cm in length, soft tissue on the bone was removed (Figure 6a). The MySpine MC was placed on the vertebral arch, and good stability was confirmed (Figure 6b). Pilot holes were created under intraoperative fluoroscopy guidance. After decompression and interbody manipulation, screws were placed and fixed to the rods and the cross connector (Figure 6c).



Intraoperative images a) exposure of operative field; b) placement of the guide; c) after implant placement

Postoperative imaging showed appropriate placement of the screws (Figure 7).



Postoperative imaging (a, b, plain X-ray; c,d,e,f CT)

There was no implant failure in the observation period. Bone union was observed at six months after surgery (Figure 8).

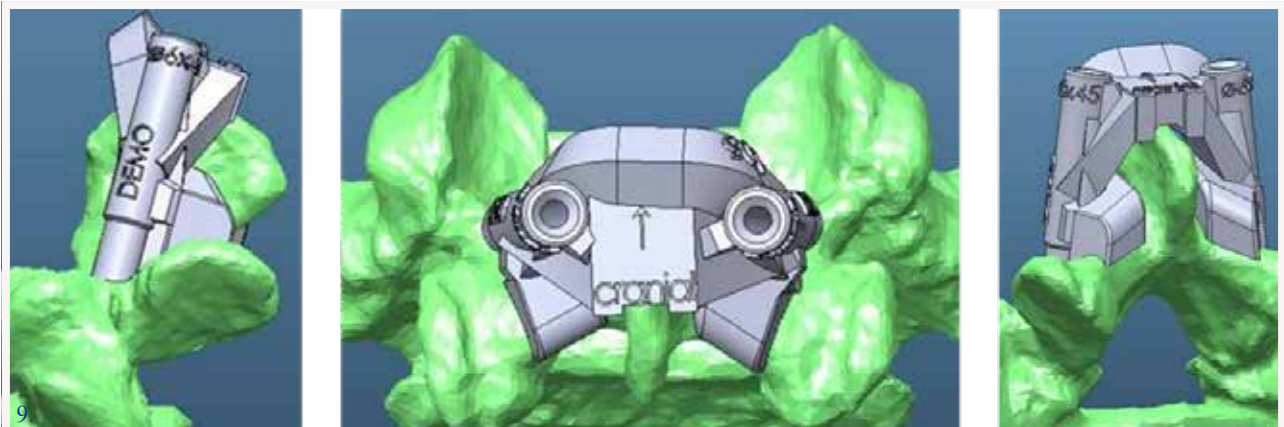


CT at 6 months after surgery

DISCUSSION

In the early phase of introduction of CBT, emphasis had been placed on fixation strength using maximum contact with cortical bone. Then the technique has increasingly attracted attention as a minimally invasive technique, due to its specific trajectory. In a broad sense, CBT is a craniolaterally-directed path through the pedicle, and the insertion trajectory differs between surgeons. However, caution is required because original CBT has disadvantages when looking at a vertebral body construct, although each screw provides strong fixation. The disadvantages include the following: 1) inferiority of fixation against rotational and lateral bending; and 2) inferiority of load distribution on the vertebral body due to short screws. To minimize these disadvantages as much as possible, the use of longer and larger screws “vehicled thru MySpine MC” has been proposed based on the findings from clinical and biomechanical studies. This method has a longer trajectory with optimized contact of the screw with the cortical bone, thereby limiting the acceptable range of trajectory. The “creation of longer cortical trajectory” poses challenges in surgical skills. In addition, once pilot holes are created, it is difficult to correct them. Therefore, intraoperative fluoroscopy and navigation systems are usually employed for creation of pilot holes with consequent high X-ray radiation dose.

It is of great significance that the minimally invasive MySpine MC guide system was useful for placing screws in the optimal position. The greatest advantage is that the guide provides both low profile and high accuracy (Figure 9), although these two factors are usually opposed. In general, guide systems become larger in order to improve accuracy when using other system rather than MySpine MC. The most salient characteristic of this new guide is the improved stability given by design. The caudal docking hook allows reduction of the contact area between the guide and bone surface, which contributes to its low profile.



Design of the MySpine MC guide

In addition, it is known that the caudal part of the lamina in contact with the guide is insulated from the influence of lumbar degenerative change. The guide yields high accuracy and reproducibility by minimizing the contact with degenerative parts such as osteophyte and articular hypertrophy.

Further studies on clinical outcomes are required. It is expected that the role of CBT as a treatment option in spinal fusion surgery will be much greater in future. This highly accurate and minimally invasive guide system embodied by MySpine MC is

expected to improve safety through reduction of the learning curve and intraoperative radiation exposure, as well as stress on the surgeon, and should contribute to improving long-term surgical outcomes.

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