Cortical bone trajectory for lumbosacral fixation: penetrating S-1 endplate screw technique

Technical note

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Object. A cortical bone trajectory (CBT) is a new pedicle screw trajectory that maximizes the thread contact with cortical bone surface, providing enhanced screw purchase. Despite the increased use of the CBT in the lumbar spine, little is known about the insertion technique for the sacral CBT. The aim of this study was to introduce a novel sacral pedicle screw trajectory. This trajectory engages with denser bone maximally by the screw penetrating the S-1 superior endplate through a more medial entry point than the traditional technique, and also has safety advantages, with the protrusion of the screw tip into the intervertebral disc space carrying no risk of neurovascular injury.

Methods. In this study, the CT scans of 50 adults were studied for morphometric measurement of the new trajectory. The entry point was supposed to be 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 direction was straight forward in the axial plane without convergence, angulated cranially in the sagittal plane penetrating the middle of the sacral endplate. The cephalad angle to the sacral endplate, length of trajectory, and safety of the trajectory were investigated. Next, the insertional torque of pedicle screws using this technique was measured intraoperatively in 19 patients and compared with the traditional technique.

Results. The mean cephalad angle in these 50 patients was 30.7° ± 5.1°, and the mean length of trajectory was 31.5 ± 3.5 mm. The CT analysis revealed that the penetrating S-1 endplate technique did not cause any neurovascular injury anteriorly in any case. The new technique demonstrated an average of 141% higher insertional torque than the traditional monocortical technique.

Conclusions. The penetrating S-1 endplate technique through the medial entry point is suitable for the connection of lumbar CBT, has revealed favorable stability for lumbosacral fixation, and has reduced the potential risk of neurovascular injuries.

KEY WORDS • cortical bone trajectory • sacral endplate • sacrum • lumbar bicortical sacral screw • lumbosacral fixation • insertional torque • technique

PEDICLE screws have become common and reliable instruments in treating a variety of spinal disorders. A cortical bone trajectory (CBT) is a novel lumbar pedicle screw trajectory that was advocated by Santoni et al. in 2009.24 The traditional technique of pedicle screw insertion uses a transpedicular path through the anatomical axis of the pedicle. In contrast, CBT follows a medially and caudocranially directed path through the pedicle and maximizes thread contact with the cortical bone surface, providing enhanced screw purchase. Biomechanical study of CBT revealed a 30% increase in uniaxial yield pullout load and equivalent characteristics of the screw-rod construct compared with the traditional trajectory.22,24 In addition, screw insertion through a medial starting point offers advantages in avoiding wide dissection of the superior facet joint and minimizing muscle dissection.14,24 Despite the increased use of CBT screws in the lumbar spine, little has been reported on the insertion technique for sacral CBT.

A variety of techniques for sacral pedicle screw fixation have been described, and an anteromedially inserted screw with or without anterior cortex purchase is the most popular technique. However, this entry point is located lateral to the adjacent facet joint and is too lateral a position for connecting with the lumbar CBT in the coronal plane, requiring complicated rod bending. For performing the CBT technique in the lumbosacral region, a sacral starting point is limited and must be positioned medially compared with that in the traditional technique.

Additionally, achieving satisfactory sacral fixation is troublesome because of the unique 3D anatomy of the sacrum, which mainly consists of cancellous bone.5,15,21 To obtain more rigid fixation, screws can be placed bicortically, with purchase into the anterior cortex or the sacral promontory (tricortically).11,25 but there is still the
the middle column. The penetrating S-1 endplate area of the S-1 vertebral body has a higher BMD than other layers of the S-1 body, and the lateral column sacral endplate has a higher bone mineral density (BMD) entry point than in the traditional trajectory. The superior etrating the S-1 superior endplate through a more medial entry point to maximize engagement with denser bone by the screws penetrating the S-1 superior endplate through a more medial entry point than in the traditional trajectory. The superior sacral endplate has a higher bone mineral density (BMD) than other layers of the S-1 body, and the lateral column area of the S-1 vertebral body has a higher BMD than the middle column. The penetrating S-1 endplate screw (PES) is directed straight forward at this anatomical region to obtain better bone quality contact and safety advantages with the protrusion of the screw tip into the intervertebral disc space. The aims of the present study were to conduct morphometric measurement of the PES trajectory using CT, and evaluate its stability by measuring the insertional torque of the PES intraoperatively.

**Methods**

**Penetrating S-1 Endplate Screw Technique**

The PES trajectory was defined as described below. 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 (Fig. 1). The trajectory was directed straight forward in the axial plane without convergence, angulated cranially in the sagittal plane penetrating the middle of the sacral endplate (Fig. 2).

**Morphometric Measurement of the PES Trajectory**

The CT scans of 50 healthy adults (47 men and 3 women, mean age 37.0 ± 14.0 years, range 20–88 years) who underwent examination for spinal problems were studied. Computed tomography scans were analyzed using 3D reconstruction software (AquariusNET, Terarecon). The cephalad angle and the length of the PES trajectory were examined (A and B, respectively, Fig. 3 left). The angle formed between the trajectory and the line of the sacral endplate in the sagittal plane was defined as the cephalad angle. The length of the PES trajectory was determined as the distance from the posterior cortical insertion point to the anterior cortical penetration point of the sacral endplate along the trajectory. In addition, the anatomical constraints of the PES technique were explored. The maximum anteroposterior length for sacral endplate penetration (C, Fig. 3 right) was determined by measurement of the distance from the anterior surface of the sacrum to the posterior line of the sacral body in the sacral endplate axial section. The anteroposterior diameter of the sacral body (D, Fig. 3 right) was also measured and C/D × 100 (%) was defined as the area of safety from the posterior aspects for sacral endplate penetration.

**Measurement of Insertional Torque During Pedicle Screw Insertion Using the PES Technique**

A total of 38 sacral pedicle screws (33 screws using the PES technique and 5 screws using the traditional technique) were placed in 19 patients with degenerative disorders (8 men and 11 women, mean 57.5 ± 16.9 years, range 24–76 years) who underwent lumbosacral CBT fixations. In 5 of the 19 patients, hybrid surgical technical procedures were performed, which formed the hybrid group. In this group, each sacral body was subjected to the PES technique on one side and the traditional pedicle screw technique on the contralateral side, and a side-by-side comparison was performed (Fig. 4). The operative indication of the hybrid group was lumbar foraminal stenosis. These patients required extensive facetectomy to decompress the exiting nerve root, and thus the ideal entry point of lumbar CBT was no longer available in many cases. Therefore, we selected the traditional insertion technique in place of the CBT/PES technique for 1 side.

The entry point and the direction of the PES were the same as previously described. For the traditional technique, the entry point was the inferolateral 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, but not beyond the anterior sacral cortex. For each technique, anteroposterior and lateral fluoroscopy was used to verify the correct screw trajectory. Using a 3-mm, high-speed, round-bur drill, the entry point was made and the pilot hole was made using a 3.5-mm probe. The length of the bone path was measured with a depth gauge to select an appropriate screw length. After 1-mm undersize tapping, 6.5-mm-diameter multiaxial SOLERA Spinal System screws (Medtronic) were used for both techniques. The screws were designed with cortical thread at the base and cancellous thread at the screw tip. A screwdriver connected with a torque meter (HTG2–5N, Imada) was used to insert the screws and measure the torque generated during screw insertion. The real-time torque was recorded every 0.05 seconds. All screws showed a steady increase in torque toward the end of the insertion, and the maximum insertional torque was measured in the last phase (Fig. 5). Each screw was placed at a depth that did not involve connection of the entry point cortex with the screw head, because the insertional torque increased rapidly when the screw head made contact with the near cortex during the last phase. In addition, BMD of the femoral neck was assessed by...
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dual-energy x-ray absorptiometry scans and correlated with the maximum insertional torque. Statistical analysis was performed using the Pearson correlation coefficient to analyze BMD data and torque, and significance was defined as $p < 0.05$.

Results

Morphometric Measurement of the PES Trajectory

The mean cephalad angle to the sacral endplate line was $30.7^\circ \pm 5.1^\circ$, and the mean length of trajectory was $31.5 \pm 3.5$ mm. The maximum anteroposterior length for
sacral endplate penetration and the anteroposterior diameter of the sacral body were 27.1 ± 3.4 mm and 34.8 ± 2.8 mm, respectively. The area of safety from the posterior aspect for sacral endplate penetration was 77.8% ± 8.0% and was greater than 50% in all cases.

Measurement of Insertional Torque During Pedicle Screw Insertion Using the PES Technique

Postoperative CT scans showed that all pedicle screws had been implanted in the correct position. In all patients, the mean BMD was 0.75 ± 0.16 g/cm² and the mean maximum insertional torque using the PES technique was 2.96 ± 1.33 Nm. In the hybrid group (mean BMD 0.71 ± 0.15 g/cm²), in which each sacrum was subjected to both PES and traditional techniques, the mean maximum insertional torque was 2.32 ± 0.75 Nm in the PES group and 0.95 ± 0.09 Nm in the traditional screw group (Table 1). The PES technique demonstrated a 141% higher average insertional torque than the latter technique, which was statistically significant (p < 0.01). Positive linear correlations between maximum insertional torque and BMD were found in both techniques (PES: r = 0.74, p < 0.01; traditional: r = 0.89, p < 0.05; Fig. 6).

Discussion

Transpedicular screw insertion in the lumbar spine has been relatively successful, but sacral screw fixation remains challenging for clinical problems such as pseudarthrosis, loss of lumbar lordosis, and screw loosening or breakage. The failure of sacral screw fixation may be a result of excessive stress on the lumbosacral region, inadequate sacral bone purchase, inappropriate direction or depth of the screw insertion, and the peculiar features of the sacrum. The sacrum does not contain a true pedicle of cortical bone ring, but rather a confluence of cancellous bone from the first sacral segment vertebral body out to the sacral ala. In addition, there are many limitations to be overcome for inserting screws into the sacral body, including the smaller anteroposterior diameter, the increase in the ratio of cancellous to cortical bone, the thinner anterior cortex, and the proximity to major neurovascular structures anteriorly. From the anatomical point of view, Zheng et al. showed that BMD of the S-1 body was 31.9% higher than that of the sacral ala. They also revealed that BMD of the superior sacral endplate was higher than that of any other transverse layer, and columns near the lateral part of the S-1 body had the highest BMD. In addition, findings have shown that the anterolateral part of the upper S-1 body was the densest area of the sacral trabecular intersection. Peretz et al. referred to sacral osteoporotic changes, stating that the sacral ala appears to atrophy first, resulting in a concentrated dense area centrally at the sacral body, and the densest area of trabecular bone was consistently observed closer to the proximal endplate at the sagittal section. The PES trajectory is targeted to these anatomically favorable regions of the lateral part of the sacral endplate, obtaining dense bone contact.

In the current study, we measured the torque during screw insertion as an objective value concerning pedicle screw stability. The insertional torque of the screw, generated primarily by the shearing force and friction in the bone-screw interface, is defined as an angular moment of the force required to advance the screw into the bone.
The insertional torque of PES was 141% higher than that of a monocortical traditional screw. Many studies have demonstrated the relationship between initial screw stability and insertional torque; Therefore, it has been proven that the PES possesses sufficiently high stability. Our results showed a high correlation between BMD and insertional torque, which was also found in several other reports. Bone mineral density may be a useful pre-operative predictor of sacral screw fixation strength when these techniques are used. In our clinical experience, all 33 screws inserted using the PES technique showed no loosening or breakage, with very satisfactory results.

Furthermore, the PES technique offers 3 major advantages in addition to its high screw stability. First, the arrangement of the screw heads matches the lumbar CBT screws. Considering the connection with the upper CBT screws, the entry points for sacral screws are limited for achieving solid fixation. In cases of poorly trabeculated osteoporotic bone or multilevel spinal fusion to the sacrum, supplemental distal fixations such as a sacral alar screw, an S-2 pedicle screw, and an S-2 iliac screw have often been used. These screws are also suited to the PES because their entry points are in line with CBT and PES anchors. A combination with an iliac screw is also available with a cross-linking connector. Second, the penetration of the sacral endplate while probing or tapping, and the protrusion of the screw tip into the intervertebral disc space, do not carry any risk of vascular injury. Moreover, the screw tips are located at the lateral part of the endplate, which does not interfere with intervertebral cage insertion in almost all cases. Finally, screw insertion through the medial starting point with a straight forward position enables less muscle dissection compared with that in the traditional technique, which requires medially oriented screw placement through a more lateral entry point.

On the other hand, the PES technique has two unique properties. One is its screw length, which is shorter than medially angled traditional S-1 pedicle screws. Findings show that increased length of screw purchase significantly increases bone screw fixation strength in vertebral bone. In contrast to these data, the PES technique, which has a shorter length of the bone path, demonstrated 141% higher insertional torque than the traditional technique. With regard to the value of insertional torque, no in vivo study has been reported on the sacral pedicle screw. In 2 in vitro studies referring to bicortical fixation to the anterior cortex, insertional torque was 1.98 ± 0.76 Nm (17 cadavers, mean age 41 years old) as reported by Luk et al. and 1.93 ± 0.67 Nm (11 cadavers, mean age 31 years old) as reported by Zhu et al. The mean insertional torque of 2.96 ± 1.33 Nm in the current study using the PES technique was higher than any other results. As also noted by Luk et al., we believed that the endplate would offer the best screw fixation, which was confirmed by the higher insertional torque despite its screw length. The other unique property of the PES technique is the lack of a triangulation effect because screws are inserted in parallel without convergence. Because the entry point of the PES trajectory is medial, the risk of spinal canal penetration by a screw increases with increasing angle of convergence. However, the increased bone purchase of the individual screws using the PES method provides favorable screw stability and appears to exert a major stabilizing effect on the screw-rod construct. Moreover, for osteoporotic patients, we have used larger-diameter screws for PES and have provided supplemental sacroiliac fixations as required.

When performing the PES procedure, proper attention to its direction parallel to the vertebral sagittal midline is indispensable. Potential complications are injury to the neural elements, usually caused by medially misdirected screws, and vascular injuries by laterally misdirected screws. Especially in the latter case, unintended screw misplacement may occur due to muscle mass and insufficient muscle retraction during screw placement, which results in failure to obtain better bone contact and causes implant failure. Ota et al. investigated the location of the bilateral common iliac vein using CT and showed that it was approximately 6 mm distance from the anterior sacral cortex to the common iliac vein. The most important point when performing the PES procedure is to avoid damaging these structures. In the present study, the area of safety from the posterior aspect for sacral endplate penetration was 77.8% on average (range 56.3%–94.9%). We therefore aimed the screws at the middle of the sacral endplate for safe screw placement and experienced no neurovascular injuries. The mean length of the trajectory.

### TABLE 1: Patient demographics and torque data of the hybrid group

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>PLIF Procedure</th>
<th>BMD (g/cm²)</th>
<th>PES Insertional Torque (Nm)</th>
<th>Traditional Insertional Torque (Nm)</th>
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<tr>
<td>1</td>
<td>75, M</td>
<td>L4–S1</td>
<td>0.63</td>
<td>2.05</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>61, F</td>
<td>L5–S1</td>
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<td>3.55</td>
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<td></td>
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<tr>
<td>3</td>
<td>70, F</td>
<td>L4–S1</td>
<td>0.62</td>
<td>1.88</td>
<td>0.97</td>
<td></td>
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<tr>
<td>4</td>
<td>73, M</td>
<td>L5–S1</td>
<td>0.89</td>
<td>2.49</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>5</td>
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<td>L4–S1</td>
<td>0.56</td>
<td>1.64</td>
<td>0.83</td>
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<tr>
<td>average</td>
<td>69.2</td>
<td>0.71</td>
<td>2.32</td>
<td>0.95</td>
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</tbody>
</table>

* PLIF = posterior lumbar interbody fusion.

Fig. 6. Correlations between maximum insertional torque and BMD. The correlations between the insertional torque and BMD revealed the superiority of the PES technique.
was 31.5 ± 3.5 mm. We often chose screws of 35–40 mm in length, which was longer than the measured depth to the sacral endplate, to ensure proper penetration of the endplate and to leave the screw head from the dorsal cortex of the sacrum to capture the rod without complicated rod bends. Excessively anteriorly directed screws or inappropriately long screws are dangerous and could damage the anterior major vessels.

There are some limitations in this study that should be noted. One limitation is that almost 90% of the CT scans reviewed were of men and the mean patient age was 37 years, because most patients were military personnel. Further investigation is needed to evaluate if any of the morphometric findings vary with sex or age. Another limitation is the small number of cases for direct-paired comparisons between two insertional techniques. Because the number of patients with lumbar foraminal stenosis, which was the operative indication of the hybrid group, was few in our case series, we performed 5 cases of comparison within opposite pedicles of the same sacrum. Thirty-three screws using the PES techniques provided sufficiently higher insertional torque as compared with the traditional technique reported by others, but additional research with a large number of patients and long-term results is necessary to verify the usefulness of PES.

Conclusions

The favorable stability and advantages of PES are reported in this study. Especially in poorly trabeculated osteoporotic bone, the PES technique, with the screw penetrating the sacral endplate, may be a prominent procedure in maximizing the thread contact with the dense bone purchase and achieving a solid lumbosacral fusion.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Matsukawa, Asazuma. Acquisition of data: Matsukawa, Imabayashi. Analysis and interpretation of data: Matsukawa, Yato, Kato. Drafting the article: Matsukawa. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Matsukawa. Statistical analysis: Matsukawa. Administrative/technical/material support: Matsukawa, Yato, Imabayashi. Study supervision: Yato, Nemoto.

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