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New classification of S1 pedicle morphometry impacting pedicle screw insertion technique

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ABSTRACT

Background: The conventional entry point for the S1 pedicle screw insertion has been described as 'at the base of and lateral to the superior S1 superior facet'. However, many orthopaedic surgeons complain that this technique is extremely demanding and is faced with many challenges in execution. Therefore, alternative entry points and modifications of existing techniques are explored for a greater convenience.
Methods: We conducted a survey amongst 136 spine surgeons on the technical difficulties faced during insertion of the S1 pedicle screw. We also classified the S1 pedicles based by measuring their geometric parameters on 100 random computed tomography (CT) images.
Results: The S1 pedicle entry technique was considered to be the most difficult and challenging by the orthopaedic surgeons in our survey due to an inadequate medial angulation due to paraspinal muscle mass tension and an overhanging iliac crest. This could be explained by the hourglass shaped pedicle (type 3) with a desired medial angle more 50 degrees (type III) observed as the most common S1 pedicle in the study population. To overcome this limitation, most of them preferred a tri-corticate approach.
Conclusions: A more lateral entry point and a longer screw might be considered as solutions for a better and safer S1 pedicle entry. Also, the use of pre-operative CT can be considered to visualize the type of S1 pedicle and hence, decide on the most appropriate technique of screw insertion.

Keywords: S1, Pedicle shape, Hourglass, Chord length, Entry point, Iliac overhang

INTRODUCTION

Pedicle screw fixation of the S1 vertebra has been employed as a technique for stabilization of the lumbo-sacral spine as a management of degenerative disc diseases such as spondylolistheses, spinal deformities, traumatic or pathologic fractures, infections and malignancies (primaries as well as osteolytic metastases).[1-6] The conventional entry point for inserting the screw into the S1 pedicle has been reported to be 'below and lateral to the superior S1 facet'.[7] This technique was originally described by Carlson et al and Smith et al as a modification of Roy-Camill's technique which involved introducing converging screws medially.[8-10] By performing pull-out tests on cadaveric pelvises, Lee et al has demonstrated that the fixation of S1 pedicle screws by entering through the superior articular process provides multiple biomechanical advantages over other conventional methods of screw insertion.[11]

However, this technique of S1 pedicle screw insertion is met with many challenges by the orthopaedic surgeons during insertion of the screw. The entry point for the S1 screw is not clearly defined, compounded by the fact that the pedicle extends laterally into the sacral ala by Kubaszewski et al. It is also difficult to achieve a desired medial angulation due to inadequate retraction of the paraspinal muscles as a result of the overhanging iliac crests. Moreover, the sacrum is predominantly composed of cancellous bone, which inherently increases the risk of

loosening of the screw.[12] Mobbs et al in their review have enlisted the small size of the S1 pedicle, the proximity of the screw head to L5 vertebra, sclerotic pedicles, and changing direction with the percutaneous screw insertion as some of the technical challenges encountered during this procedure.[13] In order to overcome these associated challenges, various orthopaedic surgeons tend to use modifications of the S1 pedicle screw insertion technique.

There is also a risk of severe complications associated with an inaccurate performance of this procedure. A review of 279 patients who underwent lumbosacral fusion for degenerative spinal disease with stenosis revealed a significantly greater violation of the superior-level facet with percutaneous pedicle screw fixations as against open surgeries.[14] Moreover, inaccuracies in the screw placement can cause vascular and neurologic injuries and complications.[15,16]

More recently, the geometric parameters of the vertebrae have also been identified as important contributors to the technical challenges faced by surgeons during the S1 pedicle screw insertion. Differences in the depth and width of the vertebral endplates, posterior vertebral height, pedicle width, and height, average circumference and average surface area of the discs from L3 to S1 levels has been reported in an analysis of CT images from 126 patients.[17,18] Nevertheless, the existing literature does not identify the various shapes of the S1 pedicles, nor does it assess the impact of these shape variations on the ease and results of the screw insertion.

Aim and objective

We conducted this study to classify the S1 pedicles based on their geometric parameters, to assess whether this has any impact on the S1 pedicle screw insertion technique and to standardize the technique for screw insertion so as to eliminate the effect of these shape variations and to improve the overall performance of the technique.

METHODS

Study design

The study was of observational study.

Patient sample

One hundred patients were included in the study.

We have done S1 vertebra CT scans for random 100 patients who were getting CT scan for other abdominal emergencies.

Study place

The study carried out at Seth G. S. medical college and KEM hospital, Mumbai.

Study period

The study carried out from June 2020 to October 2020.

We first conducted a survey among more than 130 spine surgeons using a pre-designed, validated questionnaire so as to identify the technical difficulties faced by them during S1 pedicle screw insertion. We then measured the dimensions of the S1 pedicles along both the axial (Figure 1) and sagittal (Figure 2) planes in 100 computed tomography (CT) scans obtained from 100 random patients and determined the S1 pedicle height, width, transverse angle and the chord length at Seth G. S. medical college and KEM hospital, Mumbai. The pedicle height and width were measured at three specific points on either side: at the junction of the vertebral body and pedicle, at the middle of the pedicle along the pedicle axis, and at the end of the pedicle. All the above measurements were performed using the post DICOM software.

No ethics approval was taken as sample of the study were patients who were getting CT scan for other abdominal emergencies.

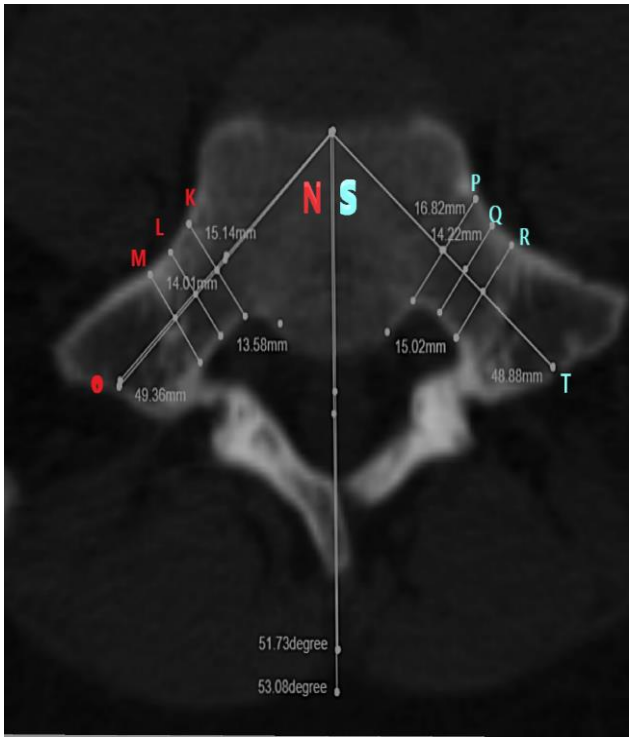

Figure 1: Measurement of S1 pedicle dimensions in the axial plane on CT scan.

K: width of the pedicle at the junction of "beginning of vertebral body and end of pedicle". L: width of the pedicle in middle along the pedicle axis. M: width of the pedicle at the posterior end of pedicle. N: transverse pedicle angle formed between pedicle axis and the midline connecting sacral body anteriorly and spinous process posteriorly. O: chord length (mm) measured as the distance between the posterior cortical entry point of the pedicle and the anterior vertebra body cortex in line with the pedicle axis. (It represents the maximum length that a screw can be inserted into a pedicle).

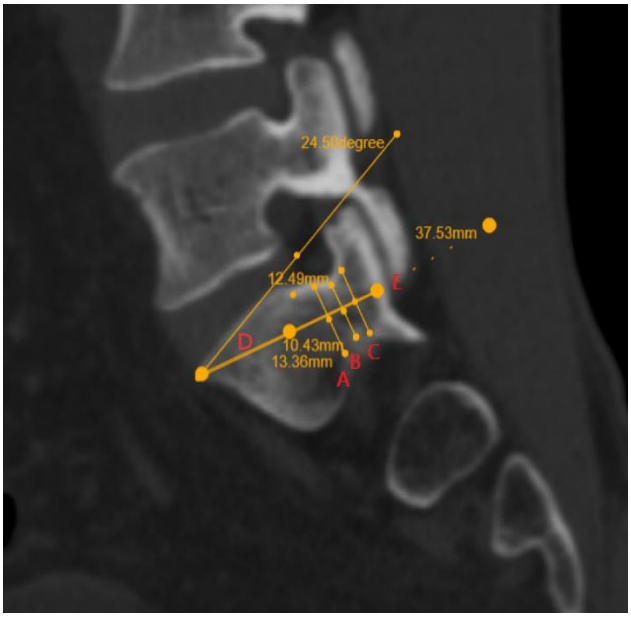

Figure 2: Measurement of S1 pedicle dimensions in the sagittal plane on CT scan.

A, B, C: heights of the pedicle at the anterior margin, middle, and posterior margins of S1 pedicle. D: angle formed between line parallel to superior end plate of vertebra and along the pedicle axis. E: chord length (mm) measured as in the axial plane.

Inclusion criteria

Patients who were getting CT scan for other abdominal emergencies.

Exclusion criteria

Patients with sacral ala, sacrum fracture, lumbar fracture, patients with degenerative spine changes, patients with spondylolisthesis changes, patients with dysplastic spine, patients previously operated for spinal surgeries including decompression and instrumentation and patients with congenital spinal abnormalities were excluded from the study.

Data was entered into Microsoft excel (Windows 7; version 2007) and analyses were done using the statistical package for social sciences (SPSS) for Windows software (version 22.0; SPSS Inc, Chicago)

Outcome measures

Modified technique and better hold of S1 pedicle screw based on pre op CT scan variables like pedicle shape determined by height, width, chord length and medial angulation of pedicle.

RESULTS

In the survey conducted on orthopaedic surgeons, we obtained the following responses:

Most difficult pedicle entry between L1 and S1 vertebrae

Seventy-eight percent of the surgeons (n=103) opined that between L1 to S1, entry into the S1 pedicle is the most difficult, followed by 16.7% (n=22) for the L5 pedicle (Figure 3).

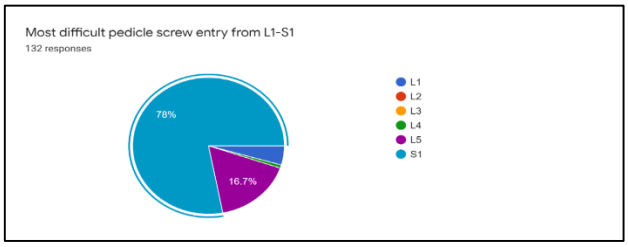

Figure 3: Surgeons' response to the most difficult pedicle entry between L1 and S1 vertebrae.

Preferred methods for pedicle fixation with screws

Almost 60% of the surgeons (n = 82) preferred a tricortical fixation (screw aimed at anterosuperior corner of S1 end plate) over bicortical (32.4%, n=44) and unicortical (7.4%, n=10) fixation methods, due to various reasons related to the geometrical variations in the pedicle shape (Figure 4).

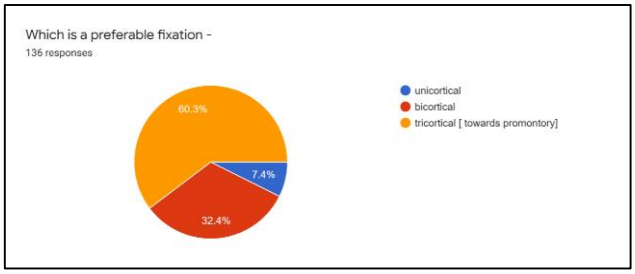

Figure 4: Surgeons' response to the preferred methods for pedicle fixation with screws.

Obstacles for the ideal trajectory to the S1 pedicle screws

Around 74% of the surgeons (n=101) replied that an inadequate medial angulation due to paraspinal muscle mass tension and an overhanging iliac crest were the major obstacles for correct entry and positioning of the S1 pedicle screws (Figure 5).

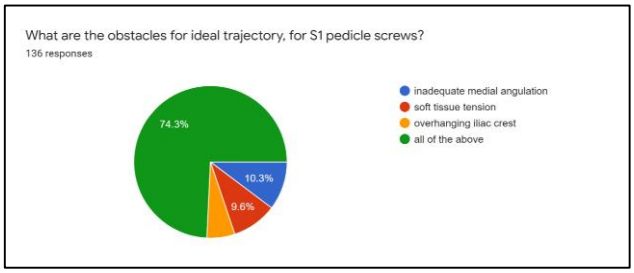

Figure 5: Surgeons' response to obstacles for the ideal trajectory to the S1 pedicle screws.

Possibility of modification in the entry point of pedicle screw

Around half of the surgeons (51.9%, n=69) opined that the entry point of the pedicle screw can be modified depending upon the variations in the shape of S1 pedicle, while 36.1% (n=48) were unsure about the same and 12% (n=16) replied in the negative (Figure 6).

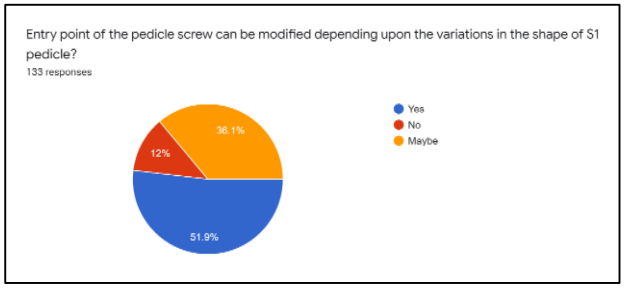

Figure 6: Surgeons' response to the possibility of modification in the entry point of pedicle screw.

Possibility of variation in the final purchase of the pedicle screw

Almost half of the surgeons (51.5%, n=70) were of the opinion that the final purchase of the S1 pedicle screw can be modified depending upon the variations in the shape of S1 pedicle, while the remaining 48.5% (n=66) replied in the negative (Figure 7).

In the second part of our study, we made an attempt to classify the S1 pedicles based on the shape and the medial angulation of long axis of the pedicle in the axial plane into 4 types. As no such classification has been previously proposed in the literature, we relied upon the findings obtained from the 100 CT scans we evaluated in our study and the measurements of the S1 pedicle dimensions obtained from them.

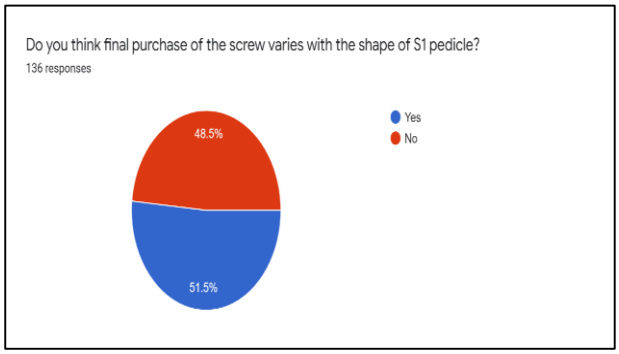

Figure 7: Surgeons' response to the possibility of variation in the final purchase of the pedicle screw.

Classification of S1 pedicles based on shape

We classified the S1 pedicles into four shapes as observed in our study: reverse cone, cylinder / oval, hourglass, and cone (Table 1, Figure 8). We observed that the hourglass pedicle was the most common shape (incidence of 75%), followed by cone (13.5%), reverse cone (10%) and cylinder (1.5%) (Table 1). Interestingly, we also observed that the shape of the pedicle in same individual also varied in many cases between left and right sides (Table 1).

Table 1: Classification of S1 pedicles based on shape.

Type	Characteristics	Incidence
Type 1: Reverse cone	K>L>M The posterior third of the pedicle is the narrowest and the anterior third is the broadest.	Right: 13/100 Left: 7/100 Mean: 10/100 Incidence: 10%
Type 2: Cylinder/ oval	K=L=M The anterior third, middle third and the posterior third of the pedicle are of the same width.	Right: 2/100 Left: 1/100 Mean: 1.5/100 Incidence: 1.5%
Type 3: Hourglass	K>L<M The middle third of the pedicle is narrowest as compared with anterior and posterior thirds.	Right: 76/100 Left: 74/100 Mean: 75/100 Incidence: 75%
Type 4: Cone	K<L<M The anterior third of the pedicle is the narrowest and the posterior third broadest.	Right: 10/100 Left: 17/100 Mean: 13.5/100 Incidence: 13.5%

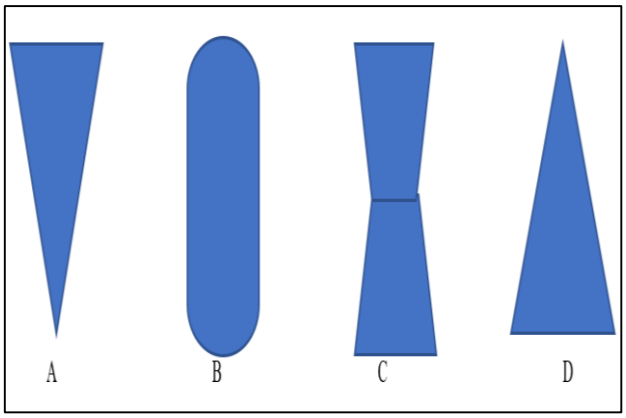

Figure 8: Shapes of S1 pedicle.
A: Reverse cone. B: Cylinder. C: Hourglass. D: Cone.

Classification of S1 pedicles based on medial angulation

We also classified pedicles into three types based on their medial angulation as 30-40^{O}, 40-50^{O} and greater than 50^{O} (Table 2). Most of the pedicles (around 70%) had their medial angles greater than 50^{O} (Type III) (Table 2).

Table 2: Classification of S1 pedicles based on medial angulation.

Type	Incidence (%)
Type I: 30-40^{O}	4.5
Type II: 40-50^{O}	29.5
Type III: >50^{O}	69.5

We then combined the classification of pedicles according to their shape and angulation and observed the type 3 shape (hourglass) with the type III angle (> 50^{O}) to be the most common (Table 3), as these were the most common types of pedicles in their respective groups.

Table 3: Combination of the classification of pedicles based on their shape and medial angulation.

Type	Incidence (%)
Type 1 pedicle with type II angle	2
Type 1 pedicle with type III angle	5.5
Type 3 pedicle with type II angle	26.5
Type 3 pedicle with type III angle	54.5

Pedicle height

The height of the S1 pedicle was measured at three different points (anterior, middle and posterior margins) in the sagittal plane (Table 4).

Table 4: Pedicle height measured at 3 different points (anterior, middle and posterior margins) in sagittal plane.

Side	Mean ± SD (mm)	Range (mm)
Sagittal right		
Anterior margin	12.62±2.87	7.6-19.7
Middle margin	10.46±2.68	8.07-18.28
Posterior margin	12.31±2.23	6.94-17.65
Sagittal left		
Anterior margin	12.47±2.96	5.67-19.65
Middle margin	10.24±2.95	3.54-17.38
Posterior margin	12.34±2.83	6.1-20.31

Pedicle width

The pedicle width was measured at three different points (at the junction of vertebral body and pedicle, in the middle along the pedicle axis, and at the posterior end of the pedicle) in the axial plane (Table 5).

Angle between superior end plate of S1 vertebra and pedicle axis

The angle between the superior end plate of S1 vertebra and pedicle axis was measured on both sagittal and axial planes on both the sides (Table 6).

Table 5: Pedicle width measured at three different points in the axial plane.

Side	Mean ± SD (mm)	Range (mm)
Axial right		
Junction of vertebral body and pedicle	16.91±3.76	8.38-24.95
In the middle along the pedicle axis	15.01±4.07	6.23-26.27
Posterior end of pedicle	16.50±4.03	7.36-27.40
Axial left		
Junction of vertebral body and pedicle	17.88±4.01	9.61-26.79
In the middle along the pedicle axis	15.61±3.93	7.75-23.64
Posterior end of pedicle	16.81±4.15	8.3-26.27

Table 6: Angle between superior end plate of S1 vertebra and pedicle axis.

Side	Mean ± SD	Range
Sagittal right	23.33±3.94	14.92-36.89
Sagittal left	22.67±4.05	11-33.99
Axial right	50.59±7.77	16.59-64.88
Axial left	52.14±6.50	34.18-65.91

Chord length

The chord length was also measured on both sagittal and axial planes on both the sides (Table 7).

Table 7: Chord length.

Side	Mean ± SD (mm)	Range (mm)
Sagittal right	33.61±4.77	20.03-45.94
Sagittal left	33.16±5.37	3.25-48.17
Axial right	48.87±7.21	18.56-63.89
Axial left	50.81±5.44	37.65-62.90

DISCUSSION

Based on the responses we obtained in our survey, we concluded that the S1 pedicle entry is considered to be the most difficult by orthopaedic surgeons due to various reasons such as inadequate medial angulation due to paraspinal muscle mass tension and an overhanging iliac crest. To overcome this limitation, most of them prefer a tri-corticate approach. Tricorticate fixation of a short lumbosacral segment was found to be associated with an enhanced stability at the lumbosacral junction with a reduced incidence of pseudo-arthroses and vascular injury in a retrospective analysis.[19] Also, most of them were open to modifications in the entry point of the pedicle screw and its final purchase if such an exercise made the task easier. This assured us that defining the screw entry technique for various shapes of the S1 pedicle and standardizing it would be gratefully accepted by the orthopaedic community.

We observed that an hourglass S1 pedicle with a medial angle greater than 50^{O} was the most common anatomic variant in our study population, accounting for almost half of the cases (Table 3). This might partially explain the technical difficulties experienced in the S1 pedicle screw insertion procedure, as the margin of error in such cases is very low. The risk of breaching the walls of the pedicle is greater in these cases due to a mismatch in the mediolateral width of the pedicle, which might lead to neurological and vascular injuries. As the middle part of the pedicle in this type of pedicles is the narrowest, the screw may have to be inserted with a greater medial angulation and therefore, a separate entry point would have to be considered in these cases. A review of two articles by Kubaszewski et al has also advocated a more medial placement of the screw in osteoporosis to improve the stability of the fixation and reproducibility of the procedure, confirming that there is no increase in the risk of spinal canal perforation.[7]

A longer screw might also be better to achieve the desired medial angulation. An *ex vivo* study on 80 porcine vertebrae identified better anchorage with long screws traversing the vertebrae and inducing bi-cortical anchorage.[20] Chua et al has recommended the optimal length if pedicle screws up to 85% of the vertebral body for the L1 vertebra, 80% for L2 to L4, and 75% for L5 for optimal purchase and fixation stability without the risk of breaching the anterior cortex.[21]

We also advocate the use of CT scan images to assess the anatomy of the S1 pedicle prior to deciding on the entry point for the pedicle screw. Similar conclusions have also been offered in the published literature. Carlson et al has evaluated thirty CT scan images and concluded that the safest entry point for the S1 iliosacral screws would be 'at the posterior sacral body sagittal and at the inferior S1 foramen coronally'.[22]

Other modifications in the pedicle insertion technique such as the assistance of fluoroscopic view of the pedicle axis have been attempted and reported to improve the accuracy of the screw placement and reduce the risk of complications.[23-26] With the advent of technology, computer simulation software have been developed, which can also be used for training and practice.[27]

Limitations

The sample size of the patients was relatively smaller to the general population.

CONCLUSION

The combination of hourglass shaped pedicle (type 3) with a desired medial angle more 50 degrees (type III) is the most frequent type of S1 pedicle observed in our study population. It poses the greatest challenge for lumbosacral fixation and hence, necessitates a separate entry point more laterally in order to get the desired medial angulation. Also, a longer length of the S1 pedicle screw is recommended for a better purchase.

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Ethical approval: The study was approved by the institutional ethics committee

REFERENCES

1. Kornblatt MD, Casey MP, Jacobs RR. Internal fixation in lumbosacral spine fusion. A biomechanical and clinical study. Clin Orthop Relat Res. 1986;(203):141-50.
2. Resnick DK, Choudhri TF, Dailey AT, Groff MW, Khoo L, Matz PG et al. Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 7: intractable low-back pain without stenosis or spondylolisthesis. J Neurosurg Spine. 2005;2(6):670-2.
3. Sevrain A, Aubin CE, Gharbi H, Wang X, Labelle H. Biomechanical evaluation of predictive parameters of progression in adolescent isthmic spondylolisthesis: a computer modelling and simulation study. Scoliosis. 2012;7(1):2.
4. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg. 2015;1(1):2-18.
5. Reid PC, Morr S, Kaiser MG. State of the union: a review of lumbar fusion indications and techniques for degenerative spine disease. J Neurosurg Spine SPI. 2019;31(1):1-14.
6. Sorour I, Elbary MA, Rabie A, Elhabashy AM. An early experience of lumbopelvic fixation techniques at Alexandria University. Egypt J Neurosurg. 2021;36:11.
7. Kubaszewski L, Nowakowski A, Kaczmarczyk J. Evidence-based support for S1 transpedicular screw entry point modification. J Orthop Surg Res. 2014;9:22.
8. Carlson GD, Abitbol JJ, Anderson DR, Krag MH, Kostuik JP, Woo SL et al. Screw fixation in the human sacrum. An in vitro study of the biomechanics of fixation. Spine (Phila Pa 1976). 1992;17(6):S196-203.
9. Smith SA, Abitbol JJ, Carlson GD, Anderson DR, Taggart KW, Garfin SR. The effects of depth of penetration, screw orientation, and bone density on sacral screw fixation. Spine (Phila Pa 1976). 1993;18(8):1006-10.
10. Roy-Camille R, Saillant G, Mazel C. Internal fixation of the lumbar spine with pedicle screw plating. Clin Orthop Relat Res. 1986;(203):7-17.
11. Lee YP, Ihn HE, McGarry MH, Farhan SD, Bhatia N, Lee TQ. Biomechanical Analysis of an S1 Pedicle Screw Salvage Technique via a Superior Articulating Process Entry Point. Spine (Phila Pa 1976). 2016;41(13): E778-84.

12. Hoel RJ, Ledonio CG, Takahashi T, Polly DW Jr. Sacral bone mineral density (BMD) assessment using opportunistic CT scans. J Orthop Res. 2017;35(1):160-66.
13. Mobbs RJ, Sivabalan P, Li J. Technique, challenges and indications for percutaneous pedicle screw fixation. J Clin Neurosci. 2011;18(6):741-9.
14. Babu R, Park JG, Mehta AI, Shan T, Grossi PM, Brown CR et al. Comparison of superior-level facet joint violations during open and percutaneous pedicle screw placement. Neurosurgery. 2012;71(5):962-70.
15. Weinstein JN, Rydevik BL, Rauschning W. Anatomic and technical considerations of pedicle screw fixation. Clin Orthop Relat Res. 1992;34-46.
16. Merloz P, Troccaz J, Vouaillat H, Vasile C, Tonetti J, Eid A et al. Fluoroscopy-based navigation system in spine surgery. Proc Inst Mech Eng H. 2007;221(7):813-20.
17. Zhou SH, McCarthy ID, McGregor AH, Coombs RR, Hughes SP. Geometrical dimensions of the lower lumbar vertebrae--analysis of data from digitised CT images. Eur Spine J. 2000;9(3):242-8.
18. Katsuura Y, Chang E, Sabri SA, Gardner WE, Doty JF. Anatomic Parameters for Instrumentation of the Sacrum and Pelvis: A Systematic Review of the Literature. J Am Acad Orthop Surg Glob Res Rev. 2018;2(8):e034.
19. Kato M, Taneichi H, Suda K. Advantage of pedicle screw placement into the sacral promontory (tricortical purchase) on lumbosacral fixation. J Spinal Disord Tech. 2015;28(6):E336-42.
20. Le Cann S, Cachon T, Viguier E, Miladi L, Odent T, Rossi JM et al. Pedicle Screw Fixation Study in Immature Porcine Spines to Improve Pullout Resistance during Animal Testing. PLoS One. 2015;10(10):e0127463.
21. Chua MJ, Siddiqui S, Yu CS, Nolan CP, Oh JY. The Optimal Screw Length of Lumbar Pedicle Screws during Minimally Invasive Surgery Fixation: A Computed Tomography-Guided Evaluation of 771 Screws. Asian Spine J. 2019;13(6):936-41.
22. Carlson DA, Scheid DK, Maar DC, Baele JR, Kaehr DM. Safe placement of S1 and S2 iliosacral screws: the quot; vestibule" concept. J Orthop Trauma. 2000;14(4):264-9.
23. Amato V, Giannachi L, Irace C, Corona C. Accuracy of pedicle screw placement in the lumbosacral spine using conventional technique: computed tomography postoperative assessment in 102 consecutive patients. J Neurosurg Spine. 2010;12(3):306-13.
24. Gelalis ID, Paschos NK, Pakos EE, Politis AN, Arnaoutoglou CM, Karageorgos AC et al. Accuracy of pedicle screw placement: a systematic review of prospective in vivo studies comparing free hand, fluoroscopy guidance and navigation techniques. Eur Spine J. 2012;21(2):247-55.
25. Soriano-Sánchez JA, Ortega-Porcayo LA, Gutiérrez-Partida CF, Ramírez-Barrios LR, Ortíz-Leyva RU, Rodríguez-García M et al. Fluoroscopy-guided pedicle screw accuracy with a mini-open approach: a tomographic evaluation of 470 screws in 125 patients. Int J Spine Surg. 2015;9:54.
26. Yoshii T, Hirai T, Yamada T, Sumiya S, Mastumoto R, Kato T, et. al. Lumbosacral pedicle screw placement using a fluoroscopic pedicle axis view and a cannulated tapping device. J Orthop Surg Res. 2015;10:79.
27. Klein S, Whyne CM, Rush R, Ginsberg HJ. CT-based patient-specific simulation software for pedicle screw insertion. J Spinal Disord Tech. 2009;22(7):502-6.

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