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ORIGINAL ARTICLE

Pedicle Screw Placement in the Thoracic and Lumbar Spine by the C-arm Guided Navigation and the Free Hand Method: A Technical and Outcome Analysis

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ABSTRACT

Introduction: The use of pedicle screws in stabilizing all three columns of the spine is a well-known but technically demanding procedure. Various assisted techniques like intraoperative fluoroscopy and stereotaxy-guided techniques have marginally increased placement accuracy along with increased radiation exposure to the surgeon and the patient, with an increased operative time.

Over the last two decades, a detailed understanding of the anatomy of the thoracolumbar pedicles has led to the emergence of the "free-hand" technique.

Objectives: To analyze the pedicle screw placement in thoracic, lumbar, and sacral spine over a 3-year period in terms of the intraoperative and immediate postoperative procedural results using navigation-guided and free hand techniques.

Materials and methods: A retrospective study was done over a period of 3 years from November 2012 to December 2015 in a tertiary care center by a single surgeon, involving 118 cases that were done using the C-arm navigation and the free hand technique.

Results: The study involved a total of 118 patients and 546 screws over a period of 3 years. The indications consisted of degenerative diseases (72%), infection (12.7%), trauma (12.7%), and malignancy (2.54%). The initial 77 cases were done by image guidance under C arm navigation and the later 41 cases with free hand techniques. Among these, there were eight breaches noted (6.72%), five (6.49%) in the image-guided technique *vs* three (7.3%) in the freehand technique. The direction of breach was lateral in one case (12.5%) and medial in seven cases (87.5%). Three patients (37.5%) with suboptimal screw placement underwent revision surgery. Four patients (3.36%) in the present study had postoperative neurological deficit in the form of foot drop and preoperative durotomies noted in nine patients (7.62%). Postoperative surgical site infections were noted in four cases (3.38%).

Conclusion: Free hand pedicle screw placement based on external anatomy alone can be performed with acceptable safety and accuracy in experienced hands and allows avoidance of radiation exposure encountered in fluoroscopic techniques.

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INTRODUCTION

Pedicle screws have been used in posterior spinal fixation since first reported by Boucher[1] in 1959 and subsequently popularized by Roy-Camille et al[2] in the 1960s. Today, pedicle screws are routinely used throughout the vertebral column because of their proven effectiveness in stabilizing all three columns of the spine. However, pedicle screw placement remains technically demanding to place, particularly in the thoracic region because of the smaller size and more complex morphology of thoracic pedicles. Because of this, multiple methods have been developed to facilitate accurate screw placement, including intraoperative fluoroscopy and stereotaxy-guided techniques.[3-7] Although these techniques slightly increase placement accuracy, they are also associated with increased radiation exposure to the patient and surgeon as well as increased operative time. The last two decades have seen the advent of a freehand technique purely based on anatomical landmarks, avoiding the drawbacks of navigation techniques.

The purpose of this study is to describe and evaluate the 3-year experience of a single surgeon with regard to the placement of thoracolumbar pedicle screws using the C-arm navigation guidance during the initial period and later the free hand technique, with evolving surgical acumen.

OBJECTIVES

To analyze the cases operated by a single surgeon for pedicle screw placement in the thoracolumbar spine in terms of intraoperative and immediate postoperative procedural results while comparing the two methods used during the period of study, the C arm navigation and the freehand techniques.

MATERIALS AND METHODS

A retrospective study was done from November 2012 to December 2015 over a period of 3 years in a tertiary care center by a single surgeon. The study involved 118 cases that were done with C arm navigation and free hand technique.

Surgical Technique

Pedicle screw placement with C arm navigation has been an established procedure. And many centers still rely on C arm navigation as the more recent techniques of navigation are yet not easily accessible. Anatomical landmarks are important for freehand pedicle screw placement. The pedicle screw placement relies on the visual and palpable cues during the procedure.

After adequate exposure of the posterior bony elements (including the lateral borders of pars interarticularis, transverse process, and superior and inferior facet joints), an intraoperative lateral radiograph is taken for localization and to establish the alignment of the spine.

In thoracic spine, entry point is at the midpoint of the junction of the transverse process and pars interarticularis at T1–T3 and at T12. It goes gradually medial and cephalad as we approach T7 from both T4 and T12. At T7, it lies at the midpoint of the base of superior articular process. For better exposure of the base of the superior articular process, removal of overhanging approximately 5 mm of inferior articular process is done (Fig. 1). In lumbar spine, the entry point is taken at the junction of the proximal edge of the transverse process with the lamina and the superior articular facet.

At sacral (S1) level, the entry point is selected at the inferolateral aspect of the base of the superior articular process of sacrum, just above the S1 dorsal foramen (Fig. 2).

Once the entry point is selected, a pilot hole is created using an awl. This is followed by gear shift probing. Here the gear shift probe is introduced with the tip pointing laterally initially (approximately 20 mm) to avoid medial cortical breach. Then the tip is turned medially and the gearshift probe is reinserted and continued further. The pedicle blush seen signifies the penetration into the cancellous bone (at the base of the pedicle)

In thoracic spine, the coronal and sagittal angles are 25–30° at T1 and T2 and 20–10° from T3 to T12, with a gradually reducing angulation in both the planes at each level, keeping the screw alignment parallel to the upper end plate (Fig. 1). In the lumbar spine, the sagittal (rostro caudal) angulation increases with a cranial inclination gradually from L1 (5°) to L3 (15°), and at L4 it is neutral (0°) and L5 onward it is caudally inclined (L5: 15° and S1: 20–25°). The coronal angulation increases gradually from L1 to S1 with a 5° increase at each level (L1: 5°, L2: 10°, L3: 15°, L4: 20°, L5 25°, and S1: 30°) (Fig. 2).

Then, by using pedicle probe (pedicle feeler), all bony borders are felt for their integrity. If any breach is detected at this point, the path trajectory is revised with the gearshift probe and reconfirmed with pedicle probe. Then, the pedicle tract is tapped with an undersized tap of approximately 0.5 mm less diameter than the intended screw, followed by confirming with the pedicle probe. Finally, the screw placement is done. The size of the screw is selected based on the preoperative and intraoperative imaging and the selected segment. Typically, for lumbar spine, 40 to 55 mm long screws are taken with 6 to 7.5 mm diameter. In thoracic spine the screws are usually 4 to 6 mm in diameter with screw length of 30 to 45 mm.

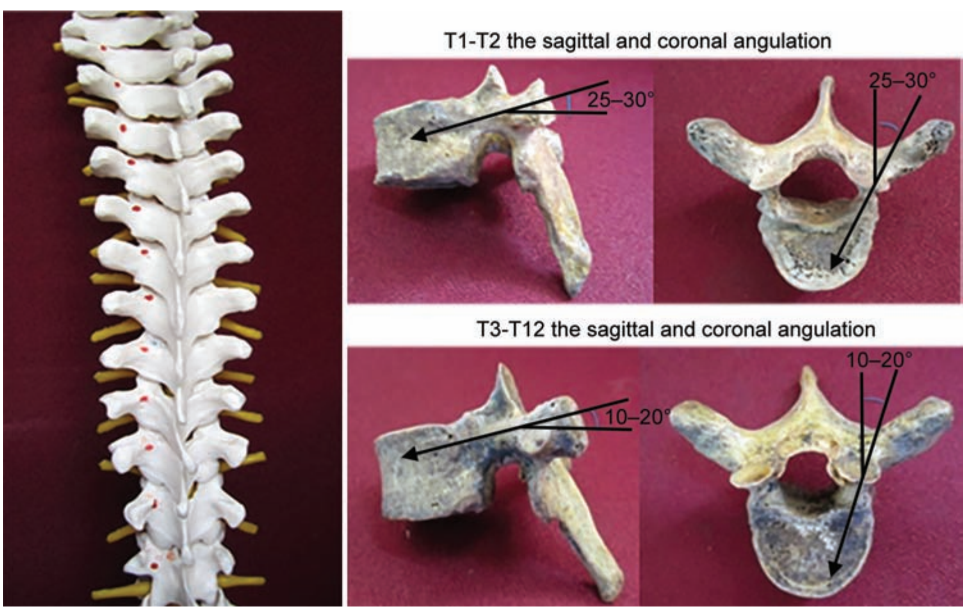


Fig. 1: Pedicle entry point and screw trajectory for thoracic spine (the images are not representative of actual vertebrae. They are just to demonstrate the angle)

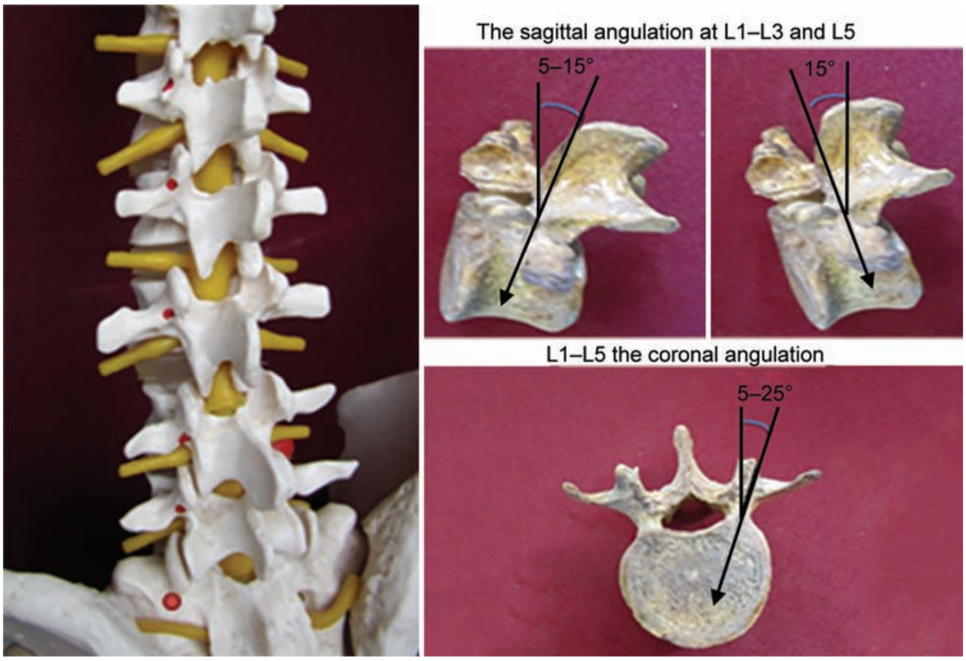


Fig. 2: Pedicle entry point and screw trajectory for lumbar and sacral spine (the images are not representative of actual vertebrae. They are just to demonstrate the angle)

After placing all the screws, anteroposterior (AP) and lateral radiographs were taken preoperatively to confirm the proper screw placement.

Postoperatively, both AP and lateral X-ray images were performed in all patients within 48 hours after drain removal to reconfirm the accuracy of the inserted hardware. In cases where there was doubtful screw placement, a computed tomography (CT) scan was done to confirm the same.

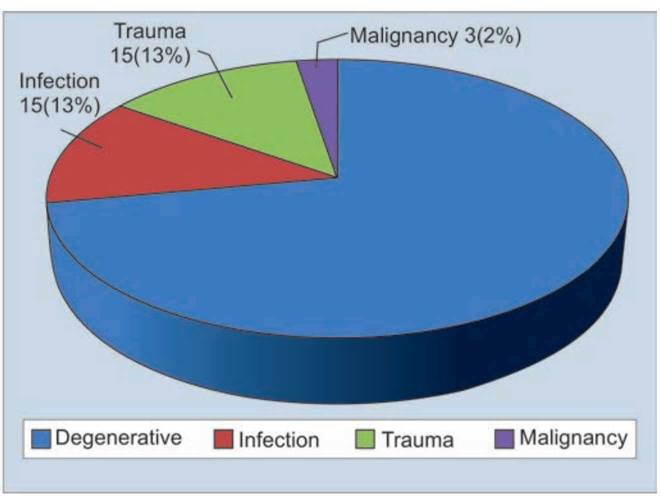
RESULTS

A total of 118 patients were involved in the study, done in our institute over a period of 3 years that required screw placements in thoracic, thoracolumbar lumbar, and lumbosacral regions. In this study, a single surgeon's experience is considered.

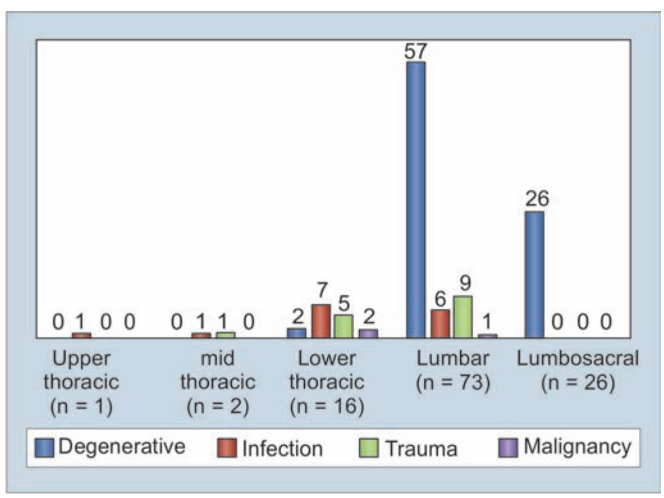
The indications for the spine stabilization with implants consisted of degenerative diseases (85 cases, 72%); infections, predominantly Pott's spine (15 cases, 12.7%); trauma (15 cases, 12.7%); and malignancy (3 cases, 2.54%) (Graph 1).

A total of 546 screws were considered in 118 patients, of whom the initial 77 cases were by C arm image guided navigation and the later 41 cases were done by a free hand technique.

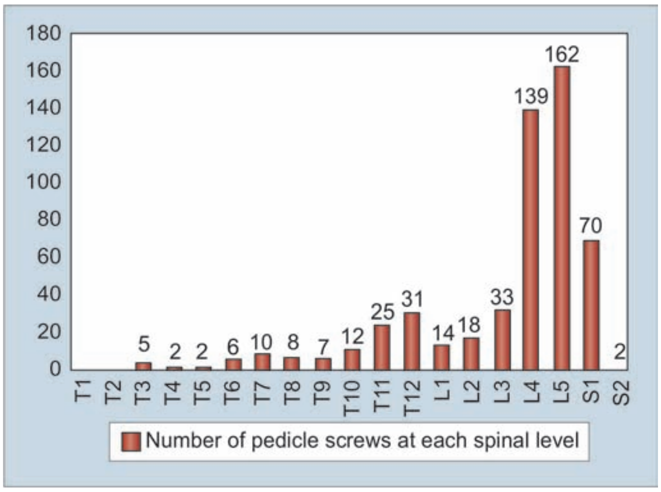
The study included 19 thoracic cases mounting to 16.1% of all cases. Among these, 1 case was in the upper dorsal (T1–T4), 2 cases in the midthoracic (T5–T8), and 16 cases in lower thoracic regions (T9–T12). There were 73 lumbar (61.86%) and 26 lumbosacral (22%) fusion cases (Graph 2).



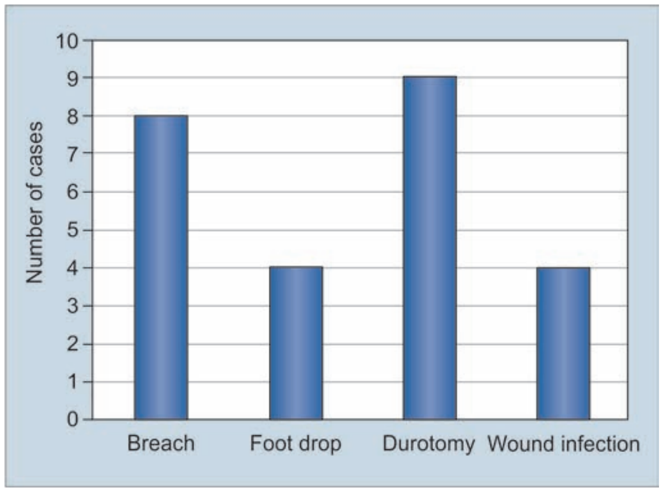
Graph 1: Incidence of pedicle screw placement by the indications



Graph 2: Etiological occurrence of cases at the spinal level



Graph 3: Number of pedicles screws at each spinal level with a total of 546 screws placed



Graph 4: Incidence of occurrence of complications

At the spinal level, the number of screws placed were as follows: 5 (0.91%) at T3, 2 (0.36%) at T4, 2 (0.36%) at T5, 6 (1.1%) at T6, 10 (1.83%) at T7, 8 (1.46%) at T8, 7 (1.28%) at T9, 12 (2.2%) at T10, 25 (4.58%) at T11, 31 (5.68%) at T12, 14 (2.56%) at L1, 18 (3.3%) at L2, 33 (6.04%) at L3, 139 (25.46%) at L4, 162 (29.67%) at L5, 70 (12.82%) at S1, and 2 (0.36%) at S2 (Graph 3).

Among these, pedicle breach was noted in eight cases (6.72%). Two of these cases (25%) were in the thoracic spine and six (75%) were in the lumbar spine. The direction of breach was lateral in one case (12.5%) and medial in seven cases (87.5%). In the lumbar spine, maximum number of breaches were noted at L5 level.

The breach occurred in five cases (6.49%) under navigation and three cases (7.3%) with the freehand technique (Table 1). The occurrence of breach was significantly more in the freehand group than in the navigation-guided group ($p < 0.05$) (Chi-square with Yates correction). Pedicle breaches that were noted preoperatively and rectified immediately on table were not considered.

Three patients (37.5%) among the eight cases with suboptimal screw placement underwent revision surgery to correct the malpositioned screw. All the three had a medial breach. Two among these had a foot drop, which persisted in the immediate postoperative period, and one had radicular pain, which improved postoperatively. Other five were not revised, as they were asymptomatic and without any deficits. Two other patients in this series who had preoperatively rectified breach also had a foot drop. So a total of four patients (3.38%) in the present series had postoperative neurological deficit in the form of a foot drop, with one patient having a bilateral foot drop.

Table 1: The breach occurrence with respect to the technique used

Breach occurrence		*Navigation guided*	*Free hand*
Thoracic spine	Medial	+ (T12)	+ (T9)
	Lateral	–	–
Lumbar spine	Medial	+ (L4) +++ (L5)	+ (L5)
	Lateral	–	+ (L4)

Peroperative durotomies were noted in nine patients (7.62%), which were sutured primarily or sealed with durafoam. No patient in the series had cerebrospinal fluid (CSF) leak from the wound or meningitis.

Postoperative surgical site infections were noted in four cases (3.38%), which needed debridement, thorough wash followed by secondary suturing (Graph 4).

DISCUSSION

Spine stabilization has seen a great change in technique and accuracy over the past few decades. The introduction of pedicle screws had revolutionized the field of spine stabilization few decades ago. Then came the introduction of navigation systems, which saw a huge transition from fluoroscopy initially to the recent trend of 3D CT guided navigation. The purpose behind the various navigation systems has been to reduce the morbidity associated with the procedure. The minimally invasive procedures have further revolutionized the dynamics of fusion with very minimal morbidity. But the indications for minimally invasive procedures are quite restricted and also the costs are high. Also there is no free availability of advanced navigation techniques at every institute considering the high cost involved.

We restricted ourselves to the open technique and tried to analyze the fluoroscopy-based technique and the freehand technique of pedicle screw insertion by a single surgeon.

Our analysis includes 118 cases studied with regard to spine stabilization with pedicle screw placement for different conditions. This was done by a single surgeon over a period of 3 years. Initially, the fusions were performed under the C arm guided navigation.

After the surgeon developed adequate experience with the instrumentation and a good acquaintance with the anatomy, the freehand technique was adopted. The initial 10 cases operated by the freehand technique were done by C arm assistance, and subsequently, a total freehand technique was adopted.

The maximum number of screws were inserted in the lumbar spine particularly at the L4 and L5 levels, demonstrating that degenerative spine disease constitutes the predominant indication with a predilection for lower lumbar spine.[8] The next common level was the lower dorsal spine, which was particularly affected by trauma. The thoracolumbar junction has been one of the most common sites affected by trauma.[9,10] Infection was seen predominantly to effect the dorsal spine, more so the lower dorsal spine. Infection constituted the third major indication for fusion almost on par with trauma.

One of the major complications of pedicle screw placement is cortical breach. This is more challenging in the thoracic spine, especially the midthoracic levels (T3–T9), where the pedicle size is small with varied and complex anatomy with diminished space between the spinal cord and the medial border of the pedicle.[11]

In this study, the major complication considered was pedicle breach. The breaches that were identified intraoperative and immediately repositioned were not considered for the study. Only those breaches that were identified during the immediate postoperative period were considered for the study purposes. These were considered for further evaluation through a CT scan and were planned for repositioning of the involved screw when required.

There were in total eight breaches noted among the 546 screws inserted (1.4% of total screws placed) in the study, including seven medial breaches and one lateral breach. The breaches were noted more in the lumbar spine (six cases) than in the thoracic spine (two cases), which could be attributed to a significantly greater number of lumbar screws placed in the study.

However, in the study by Parker et al,[8] it was noted that breaches were common in the thoracic than in the lumbar spine (2.5 and 0.9% respectively) and were more often lateral (61.3%) than medial (32.8%) or superior (2.5%). This was attributed to the lumbar spine having larger pedicles, which allow more degrees of freedom for accurate screw placement along with the pedicle's thick medial cortical wall and also the surgeon's desire to avoid potential injury to the spinal cord. Also, in the "in-out-in" technique, screws are intentionally placed more laterally to decrease the risk of medial breach and potentially increase bony rib purchase in the thoracic spine.[11]

In the study, breaches were noted in the five cases (6.4%) of the total 77 cases operated by the navigation guided technique and three cases (7.3%) of the total 41 cases by the freehand technique. There were seven medial breaches and one lateral breach. The one lateral breach that was observed was in a case operated by the freehand technique. However, as suggested by Gelalis et al[12] in their systemic review, greater tendency of medial cortical perforation was seen in the freehand technique and lateral perforation more often with CT navigation guidance. This was explained by the difference between the longitudinal midline axis of the pedicle (ideal screw trajectory) and the anatomically feasible axis on CT-based navigation leading to more often lateral cortical breach.

Among the seven cases with medial breach that were noted postoperatively, two patients had a foot drop for which screw repositioning was done. There were two more cases of foot drop, which were due to preoperative nerve root injury. There were no other cases of neurological injury noted in the study and hence no neurological injuries noted with thoracic spine cannulation in the present study. All the foot drops were noted in cases with C arm navigation guided screw placement in the initial part of the study probably due to the initial learning curve.

There were totally nine cases in whom durotomies were noted during surgery. Durotomies were noted more in the lumbar region than in the thoracic spine, again possibly attributable to the greater number of screws placed in the lumbar spine. Among these, five cases (6.4%) were noted under navigation guidance and four cases (9.7%) under the free-hand technique. Durotomies were repaired primarily by suturing the defect or by covering with durafoam when suturing was not possible. None of these cases in the study had a persistent CSF leak in the postoperative period to mandate re-exploration, nor did any patient have meningitis.

The existing literature shows a clear bias toward navigation guided techniques over the freehand technique for spinal fusion. Studies state that computer-assisted navigation has the benefit of increased visualization of a pedicle's trajectory with higher accuracy and increased safety in pedicle screw placement and also less neurovascular complications, thus being superior to the conventional techniques.[12-15] Also, according to a meta-analysis by Wei Tian et al,[13] among different latest navigation systems (such as preoperative CT, intraoperative CT, and ISO-C navigation), there appeared to be no difference in the accuracy of pedicle screw placement.

The pedicle screws can be consistently and safely inserted using a freehand technique based on the knowledge of spinal anatomy when performed in a consistent, step-wise manner for lumbar pedicle screw placement and even for the thoracic spine.[16,17] Also, the neurosurgery residents can, under appropriate supervision, safely place freehand pedicle screws with an acceptable breach rate.[18] Screw placement without intraoperative radiological guidance avoids the harmful effects of radiation exposure to both the patient and the surgeon significantly (10–12 times more radiation than other nonspinal musculoskeletal procedures that involve the use of a fluoroscope). It also shortens the duration of surgery, which has been correlated to a reduced incidence of surgical site infection in procedures involving spinal instrumentation.[11,18]

Limitations noted in the study were, first, the study was retrospective in nature. Second, the study is based only on C arm guided navigation in an era of advanced navigation systems due to the lack of availability during the period of the study. Third, long-term follow-up was not considered for further assessment of the results.

CONCLUSION

Appropriate techniques must be chosen at the surgeon's discretion. However, a surgeon's ultimate decision must be based on individual experience and comfort with a given technique and the specific pathology.[11] The free hand technique can be safely considered for the screw placement but has a steep learning curve.

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