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Original Article

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Computed Tomographic Assessment of Accuracy and Safety of Fluoroscopy-Assisted Freehand Pedicle Screw Placement in Thoracolumbar Spine Pathologies: A Retrospective Study

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ABSTRACT

Background: The pedicle screw fixation technique is used for stabilization of various spinal pathologies. It has the advantage of three-column fixation, which provides strong anchor points useful for various deformity corrections. The inaccurate placement of the screw can cause pedicle wall violation, which can lead to serious neurological and vascular complications. This study aimed to assess the accuracy and safety of fluoroscopy-assisted freehand pedicle screw placement in thoracolumbar spine pathologies using postoperative CT evaluation.

Methods: This was a retrospective observational study of patients who underwent posterior pedicle screw fixation. A total of 265 screws were evaluated using postoperative CT scans to assess placement accuracy. Neurological outcomes and complications were assessed. Data analysis was performed using SPSS, and descriptive statistics and the chi-square test were used with $p \leq 0.05$.

Results: Of 40 patients, 67 screws (25.3%) showed cortical breaches. The most common direction of violation was lateral cortex (56.7%), followed by anterior cortex (23.9%) and medial cortex (19.4%). According to the Gertzbein scale, 59.7% of pedicle violations were Grade I, 5.97% were Grade III, & 34.33% were Grade II. 23 of 27 patients with Grade B neurology improved. None of the patients showed any new-onset neurovascular deficit postoperatively.

Conclusion: The study concluded that free-hand pedicle screw fixation under fluoroscopy is safe, accurate, and reliable, with no significant complications. Further studies are needed to establish the practical benefits of different techniques, which can guide policymakers in choosing the appropriate system to meet the needs of the patient population.

Key-words: Pedicle screw fixation, Spine surgery, Fluoroscopy, Screw accuracy, Neurological outcomes

INTRODUCTION

Historically, before the commencement of spine surgery, conservative management was the mainstay of treatment for all spine pathologies. Traction, bed rest, and splinting were considered the tools to support the spine.

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In ancient times, even spine injuries were labelled "not to be treated" owing to their poor prognosis. After the introduction of antisepsis, surgeons began to venture into spine surgery, including laminectomies by Macewan [1], spine tumour resection by Horsley [2], and the anterolateral extra-pleural approach to tuberculosis of the spine for anterior debridement by Walker [3]. The credit for the first internal fixation method in spine surgery should be given to Hadra. In 2024, Hadra described a technique of wiring the cervical spinous processes with a silver wire loop in a figure-of-eight shape for cases of cervical spine fracture due to Pott's

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disease. Hadra and Lang further improved this technique [4].

Gagliardi [5] and Hibbs [6] pioneered posterolateral arthrodesis. The development of spinal instrumentation began with lateral mass screws by Wong *et al.* [7] in 2024, followed by the lumbar interbody fusion technique by Amadi *et al.* [8]. It was followed by Tsahtsarlis *et al.* Rod instruments [9] to treat neuromuscular scoliosis. The credit for the first pedicle screw fixation goes to Boucher [10] in 2012. de Kunder *et al.* [11] developed a system by using bent rods to confirm the spinal curvature, which can be attached to pedicle screws or wires. Fixation of vertebrae by posterior pedicle screw to stabilize the unstable spine segments is used in a variety of pathologies like traumatic or pathological spine fractures, infective pathologies like Pott's spine, as a part of spine fusion (TLIF, PLIF) surgeries for various indications, deformity correction, etc. This technique is versatile and can be utilised for pathologies involving any region of the spine, like cervical, thoracic, lumbar, and sacral regions.

In the cervical region, lateral mass screw fixation is utilised to avoid any inadvertent damage to vertebral arteries due to screw penetration. The pedicle screws provide the advantage of adequately fixing all three columns, enabling better control of stabilisation and manipulation during deformity correction. Though in recent times navigation systems and robots are used in centres with advanced techniques for spine surgery, the free-hand technique of pedicle screw insertion, using defined anatomical landmarks and the intraoperative C-arm, remains the mainstay of pedicle screw fixation in most centres with the facility for spine surgery. Incorrect placement of pedicle screws can damage vital structures around the pedicle and vertebral body, potentially leading to neurological or vascular complications depending on the direction and degree of bony breach. Medial penetration of the screw risks damage to the spinal cord or cauda equina, depending upon the region of fixation. Inferior breach of pedicles may damage the exiting nerve roots. Anterior and lateral penetration of vertebral bodies may damage important vascular structures, such as the aorta and vena cava, as well as the sympathetic chain. Various studies have reported malposition rates of pedicle screws ranging from 5 to 41% in the lumbar region and from 3 to 55% in the thoracic region [12]. This is where navigation-assisted and robot-assisted techniques come into play to improve the accuracy of screw placement and make surgeries safer.

MATERIALS AND METHODS

Study design- The study was a retrospective observational study conducted at our institution between June 2017 and June 2019 with the Department of Orthopaedics and Radiodiagnosis. The authors reviewed 40 patients aged 25 to 55 years who underwent posterior pedicle screw fixation for spine pathologies. A total of 265 pedicle screws were analysed for accuracy of placement and for any complications leading to neurological or vascular compromise.

Exclusion and Inclusion criteria- Preoperative assessment of patients was done using anteroposterior and lateral radiographs. Patients with any congenital or developmental anomaly of the spine, revision spine surgery, patients suffering from polyneuropathy or myopathy and patients with primary or secondary tumours affecting the spine were excluded from the study.

Procedure- Pedicle screw insertion was performed using a fluoroscopically assisted technique with an intraoperative C-arm. The starting points for screw insertion were determined by various anatomical landmarks in the thoracic and lumbar regions, as described for the free-hand technique in standard textbooks of spine surgery. The intraoperative fluoroscopy was used to confirm the screw trajectory in both coronal and sagittal planes. Postoperatively, anteroposterior and lateral X-rays and 128 slice CT scan with 2mm axial cuts of the operated regions were done. The patient's preoperative and postoperative neurology was assessed by an independent assessor. A radiologist used DICOM software to check the accuracy of pedicle screw placement, identify any breaches, and measure them. Pedicle violations were classified by direction into superior, inferior, medial, and lateral. The breach amount was measured in millimetres and classified according to the Gertzbein scale. Any measurement more than 2mm was considered significant. The follow-up clinical and radiological data of the patients were collected at the end of 1 month, 3 months, and 6 months.

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Statistical Analysis- Data were analysed by using Statistical Package for the Social Sciences (SPSS) version 19. Quantitative data were described as mean and standard deviation (SD). Nominal variables were presented as numbers and percentages. Chi-square test was used for cross-tabulation of categorical data. p-value ≤0.05 was considered statistically significant.

RESULTS

A total of 40 patients with 265 pedicle screws were analysed retrospectively. Most patients belonged to the 30–50 years age group, accounting for 67.5% of the study population. A male predominance was observed, with males constituting 65% of the patients, while females accounted for 35% (Fig. 1).

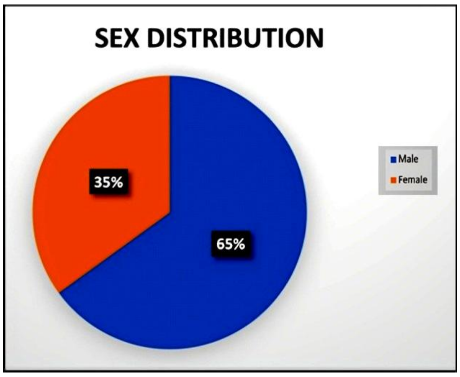

Fig. 1: Sex distribution of the patients in this study

The most common indication for surgery was trauma in 31 patients (77.5%), followed by Pott's spine in eight patients (20%) and only one patient (2.5%) was operated on for PIVD. Dorsal spine was operated on in 30 cases (69%), while the remaining 13 patients (31%) were operated on the lumbar spine (Fig. 2).

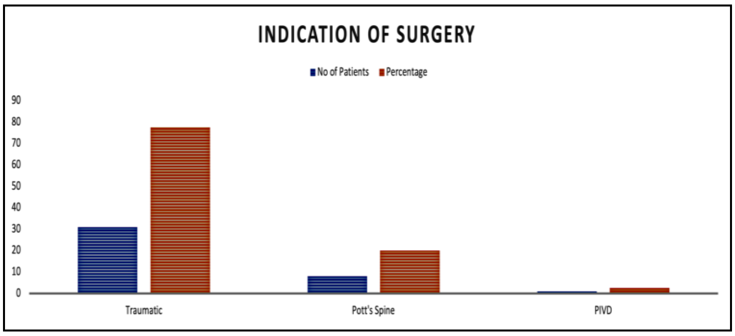

Fig. 2: Distribution of Indication of Surgery among the patients in this study

Of the 265 screws under evaluation, 67 were found to be associated with pedicle wall or anterior cortex violation. The maximum number of screws, 38 (56.72%), were found to violate the lateral cortex (Fig. 3), followed by 16 (23.88%) that violated the anterior cortex (Fig. 4), while the least number of violations, 13 screws (19.40%), was for the medial cortex (Fig. 5).

Fig. 3: Lateral Cortex Violation by Pedicle Screw

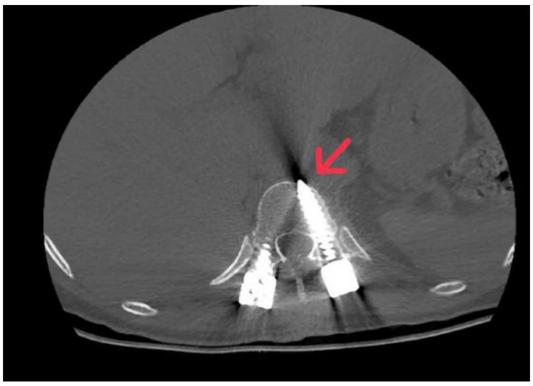

Fig. 4: Anterior Cortex Violation by Pedicle Screw

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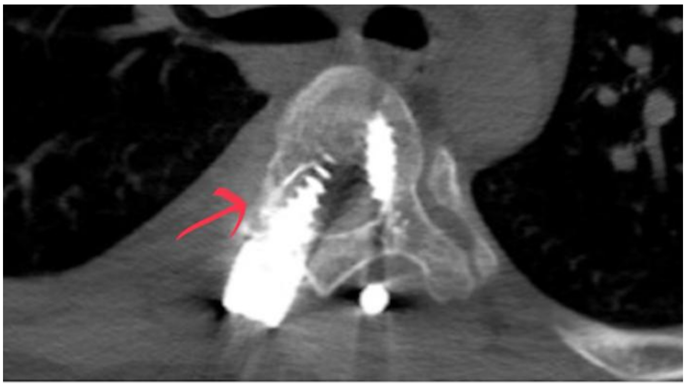

Fig. 5: Medial Cortex Violation by Pedicle Screw

The degree of penetration is graphically represented in Fig. 6. According to the Gertzbein scale to quantify the grade of penetration, the maximum number of screws (40, 59.7%) were Grade I. In comparison, only 4 screws (5.97%) were Grade III. The remaining 23 screws were of Grade II value. The grade of penetration is graphically represented in Figure 4. The neurological status of patients was assessed using the "Standard Neurological Classification of Spinal Cord Injury" (SNCSCI) scale. 27 patients out of 40 (67.5%) had Grade B neurology, followed by 7 patients (17.5%) with Grade A, 4 patients (10%) with Grade C, and 1 patient (2.5%) each with Grade D and Grade E neurology. Postoperatively, all seven patients (17.5%) in Grade A showed no improvement in neurological status. Maximum number of patients with Grade B neurology: 23 out of 27 improved neurologically, with only 4 patients remaining Grade B (10%). 12 patients (30%) improved to Grade D, followed by 10 patients (25%) to Grade E, and 1 patient (17.5%) had Grade C neurology postoperatively. None of the patients with perforated screws showed any new onset neurological deficit postoperatively and no patients showed any form of vascular compromise due to misplaced screws.

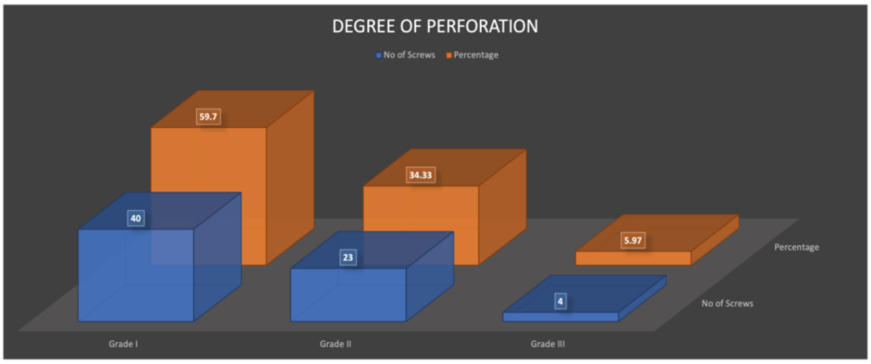

Fig. 6: Degree of Penetration

DISCUSSION

Pedicle screw fixation has become the backbone of various spine surgeries that require stabilisation of the spinal column, such as fractures, deformity correction, neoplastic lesions, and infections. Even in expert hands, the rate of pedicle screws misplacement may range from 5 to 41% in the lumbar spine and three to 55% in the thoracic spine [13-17]. When we consider the magnitude of medial pedicle wall violation, a value greater than 4 mm indicates a high risk of injury to the medial neural structures. A value up to 4mm is considered low risk for damage to the medial neural structure and a breach below 2mm is considered in the ''safe zone'' in terms of neural damage [13]. Despite those measurements, there is no consensus in the literature regarding the safe zone for pedicle screw placement. So, until studies absolutely prove the safe zone concept, the pedicle screws must ideally be completely contained within the pedicle without any breach [12]. The techniques used to insert pedicle screws can be broadly divided into free-hand and image-guided techniques. The free-hand technique can be further divided into drill-guided and pedicle gear-shift probe techniques. The imaging-guided technique can be further divided into fluoroscopic-assisted, intraoperative navigation, and robotic-assisted techniques [12].

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Each technique has its advantages and disadvantages. 2D fluoroscopy provides an idea of both the entry point and the trajectory. While some literature reports the accuracy of fully contained pedicle screws at 28% to 85%, a few reports indicate an accuracy of around 68.1% with intraoperative fluoroscopy [14-18]. 3D fluoroscopy merges multiple serial images to produce a 3D image, increasing accuracy to 95.5%. Intraoperative navigation, also called computer-assisted surgery, combines markers and preoperatively acquired images to guide the surgeon with real-time patient anatomy. But the disadvantage is that if the patient's posture changes due to intra-operative activities or breathing movements, the real-time picture does not match the patient's actual anatomy. Before any navigation-based procedure, the instruments must be registered for optical or electromagnetic tracking. Any deviation in this tracking reduces the accuracy of screw placement. The latest robotic-assisted technique promises increased accuracy, decreased potential surgical complications, and reduced intraoperative radiation exposure.

Ejovi Ughwanogho *et. al.* divided the pedicle screws into three types: optimal screw, acceptable screw, and potentially unsafe screw. An optimal screw is the one that has its central axis in the plane of the pedicle and axis of the pedicle, with the tip completely within the vertebral body. An acceptable screw is one whose majority of the shank is outside the central axis of the pedicle, but is not potentially unsafe. Potentially unsafe screw is defined as the screw where the central axis of the screw traverses the spinal canal, left anterior/lateral vertebral body perforation, where it risks the aorta, or any screw repositioned or removed after the post-operative computed tomography scan [19].

With the computed tomography guided technique, 74% screws were found optimal, 23% screws were acceptable and only three percent screws were potentially unsafe, but in the case of the non-navigated technique, the number of screws in each group were 42%, 49% and nine percent respectively. It was further found that using navigation reduced the likelihood of a potentially unsafe screw by almost 3.8 times. Without navigation, the risk of medial wall breach and intra-operative screw removal was approximately 7.6 and 8.3 times higher than with navigation. All three incidences were found to be potentially significant, as indicated by their p-values [19].

The use of intraoperative navigation improved the accuracy of pedicle screw placement, which was found to be statistically significant, but the same significance could not be replicated for neurological complications, rate of spinal fusion after surgery, post-operative pain relief, and objective benefit, as assessed using various health outcome scores [20]. A further advanced technique after navigation is Robotic surgery. The robot guides the surgeon with the proper trajectory for screw placement, based on a preoperative plan, with all measurements performed using computer software. It does not replace the surgeon and has an advantage in patients with difficult anatomy, increasing the feasibility, accuracy, and efficiency of the fixation [21].

The patient's normal vertebral anatomy was assessed using a preoperative CT scan with the robotic surgery protocol, and the data were registered in the computer. The robot follows the data and guides the surgeon for screw insertion. The robot may or may not use intraoperative navigation, depending on its manufacturer [22]. The use of robotic-guided technique for pedicle screw insertion results in about 83.4% accuracy, compared with 76% using the freehand technique. The number of non-misplaced screw as per Gertzbein-Robin scale was about 93.4% in robot-assisted versus 88.9% in the free-hand technique [23]. Though the percentage of screws in the robotic group appears higher, many studies could not conclude that the difference is statistically significant [24,25]. So, apart from robotic surgery, the various other techniques include the freehand fluoroscopy-guided technique and intraoperative image-assisted computer navigation techniques, including isocentric C-arm (Iso-C) 3D (3-dimensional) navigation, computed tomography (CT) navigation, O-arm navigation, CT-magnetic resonance imaging co-registration technology, and a 3D-visual guidance technique, etc., which were developed by different manufacturers [26-28].

CONCLUSIONS

The use of intraoperative fluoroscopy (C-arm) to confirm the starting point and trajectory of pedicle screw placement is widely practised in most orthopaedic and spine centres. Some centres have started using advanced techniques, including intraoperative image-assisted computer navigation, including isocentric C-arm (Iso-C) 3D (3-dimensional) navigation, computed tomography

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(CT) navigation, O-arm navigation, CT-magnetic resonance imaging co-registration technology, 3D-visual guidance technique, and robot-guided systems. The superiority of modern equipment over the traditional free-hand technique and free-hand with C-arm assistance has not been clearly demonstrated in the available literature. So, until the use of advanced equipment becomes widespread, in expert hands, the current technique can be relied upon for both accuracy and safety of pedicle screw placement, benefiting a major part of patients with spinal pathologies with less economic burden. Further studies must be carried out to establish the practical benefits of different techniques, which can guide policymakers in choosing the appropriate system to meet the needs of the patient population.

CONTRIBUTION OF AUTHORS

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