International Journal of Orthopaedics Sciences

E-ISSN: 2395-1958
P-ISSN: 2706-6630
IJOS 2024; 10(2): 241-245

https://www.orthopaper.com
Received: 02-03-2024
Accepted: 08-04-2024

Oussama Mohamed Arakeep
Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt

Tarek Ibrahim Abo El-Noor
Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt

Ahmed El-Sayed El-Tantawy
Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt

Sherif El-Sayed El-Daw
Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt

Corresponding Author:
Oussama Mohamed Arakeep
Department of Orthopedic Surgery, Faculty of Medicine, Tanta University, Tanta, Egypt

Thoracolumbar pedicle screw instrumentation: Different types & insertional techniques

Oussama Mohamed Arakeep, Tarek Ibrahim Abo El-Noor, Ahmed El-Sayed El-Tantawy and Sherif El-Sayed El-Daw

DOI: https://doi.org/10.22271/ortho.2024.v10.i2d.3557

Abstract
A common procedure performed worldwide to treat many spinal illnesses, such as trauma, deformity, degenerative disease, and malignancy, is spinal fixation. The management of numerous spinal disorders, including those caused by trauma, deformity, degenerative disease, and tumors, is accomplished globally through the use of spinal fixation operations. Reliable pedicle screws placement is crucial to achieve a safe and rigid fixation. One common technique for instrumenting and stabilizing the lumbar and thoracic spine is pedicle screw fixation. One of its advantages is that it can stabilize all three columns with a single technique. There are a number of assistive procedures that can be used to place the pedicle screws more precisely, but they come with a higher cost, longer surgery time, and more radiation exposure. All three of the spine's columns are crossed by the pedicle screw. Even in the event that three columns are disrupted, it serves as a sturdy bridge across them and offers strong fixation.

Keywords: Spinal fixation, pedicle screws, spine surgery

Introduction
Surgical spinal fixation procedures are utilized on a global scale to treat a variety of spinal disorders, including trauma, deformity, degenerative disease, and tumor. Ensuring a secure and inflexible fixation requires precise insertion of pedicle screws. Screws that are positioned incorrectly may damage important structures or result in fixation failure. It can also be life-threatening for the patients or cause a permanent neurological damage [1].
According to numerous studies, using a freehand method might result in high rates of screw misplacement-up to 30% in certain circumstances. Furthermore, the surgical teams who employ the freehand technique are exposed to a high level of radiation because it necessitates a large amount of fluoroscopy. Radiation dose has attracted a lot of attention after the reported high frequency of tumors among spinal surgeons [2]. 3D Virtual Surgical Planning (VSP) technology, also known as medical three-dimensional (3D) planning, has made substantial strides in recent years. Accurate preoperative planning of screw trajectory in spine surgery can be facilitated by VSP. VSP is translated to the operation room using patient-specific 3D printed drill guides. Because each guide is made to match a particular vertebra, they stay accurate even when there is movement of the vertebral levels during surgical manipulation [3].

Pedicle screw accuracy determination
To classify the precision of pedicle screws, the Gertzbein and Robbins system (GRS) is applied, which is based on CT. Grade 0 (per GRS): Secure the pedicle with a full fastener. Pedicle wall fracture of less than 2 mm is grade A. 2.4% to 4.0% infraction for grade B. level C: exceeding 4 millimeters of transgression [4].

Screw characteristics
A head, neck, and body make up the screw. Cylindrical or conical bodies are both possible. Both an inner and an exterior diameter can be seen on it. There is a thread depth variation between the two. The separation between two neighboring thread crests is known as the thread pitch [5].

Pedicle screw types include

Polyaxial pedicle screws: For work on degenerative spines, polyaxial screws are currently the most used kind of fixation. A variable-in-multidirectional direction angle between the tulip and screw shaft facilitates the coupling of the screw with a longitudinal rod [6].

Monoaxial / Uniaxial pedicle screws: A monoaxial screw employs a fixed angle between its tulip and screw shaft. This may potentially enhance the rotational control of the vertebra. In spite of the potential advantages of these screws, however, the trajectory in which they must be positioned in order to facilitate coupling with a rod may be technically challenging [6].

Fenestrated pedicle screws: Fenestrated screws are composed of a cannulated core equipped with an opening in the distal thread portion. Various screw types have varying diameters [7].

Cannulated pedicle screw: The two types of cannulated pedicle screws are Cement-Injectable Cannulated Pedicle Screws (CICPS) and incomplete cannulated pedicle screws [7].

Expansion/Expandable pedicle screws: Enhanced anchorage in trabecular bone is achievable without jeopardizing pedicle integrity due to the aforementioned screws' broad diameter [7].

The anchor pedicle screw type: A polyetheretherketone (PEEK) anchor is encircled by the application of an anchor pedicle screw [8].

Different Types and Techniques of Fixation

Systems of Wiring: Wire-rod procedures are still utilized in the thoracic spine, despite the widespread abandonment of sublaminar wiring techniques. The most often utilized method is the Luque approach. Extra anchors are the sublaminar wires that are affixed to every vertebra. At the nonrigid segmental spine, these wires are subsequently wound around rods [9].

Flexible Bands

Metal clamps and polyester belts have recently been created as alternatives to pedicle screw fixation and/or metal wiring (Minneapolis, Minnesota, United States of America; Zimmer Spine; Universal restraint) [10].

Hooks

There is an extensive selection of hooks available, Pedicle hooks, laminar hooks, and transverse process hooks are each endowed with unique characteristics. Strongest fixation is achieved with pedicle pins. T_1 through T_{10} are applicable. The pedicle hook is consistently positioned in a cephalad orientation between the lamina of the instrumented vertebra and the superior articular process of the inferior vertebra [11].

Pedicle Screws

Pedicle screws offer the most rigid structure presently feasible from a biomechanical standpoint, in addition to enabling posterior manipulation of the spine in all three planes. Its outer diameter is the most critical determinant in preventing withdrawal of a pedicle screw in normal bone; the stronger the construct, the more precisely the threads penetrate the inner cortex of the pedicle [12].

Placement of pedicle screws techniques

Free-hand technique

Numerous anatomical landmarks must be comprehended in their intricate interrelationships for free-hand pedicle screws to be positioned precisely at each level of the thoracolumbar spine. The lumbar and thoracic spines each utilize analogous entry sites that are governed by differential anatomy. The anatomical locations are designated in a manner that permits straight progression along the axis of the pedicle, thereby ensuring optimal stability of the screws. When determining an initial entry site, intraoperative localizing radiographs are often employed to assess spinal alignment [13].

The triangle formed by the lower border of the superior articular facet, the medial border of the transverse process, and the pars interarticularis in the thoracic spine should be the target of initial penetration (Figure 1) [14].

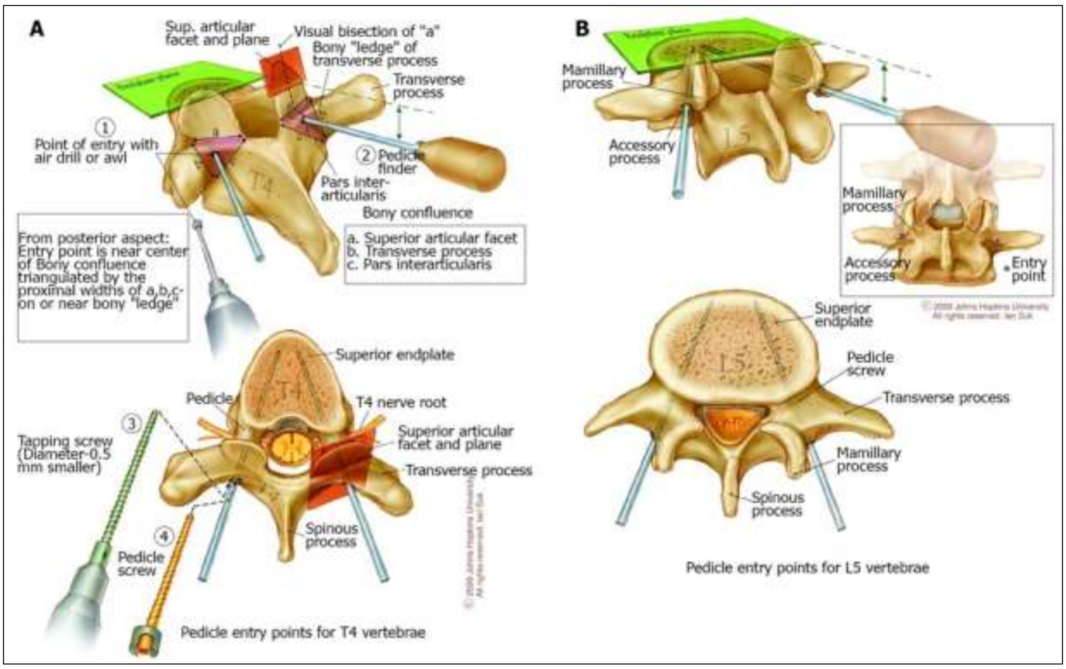

Fig 1: Artist depiction of the entry site used in the T_4 (A) and L5 (B) vertebrae [14]

The precise location of this area, which is where the lateral one-third and medial two-thirds of the superior articular process converge, has been described inconsistently This region, which is defined as the intersection of the medial two-thirds and lateral one-third of the superior articular process, has been inconsistently described in terms of its precise location. Entry sites become progressively more medial and cephalad as the thoracic spine advances from T_{12} to T_7. Adjacent and lateral entry sites are customarily located above T_7 [15]. Commonly utilized in the thoracic spine, the "in-out-in" technique entails purposefully situating screws laterally with the intention of diminishing the probability of medial fracture and potentially augmenting bony rib purchase. Patients with congenitally small thoracic pedicles may also benefit from the implementation of the "in-out-in" technique [15].

The point of entry for instrumentation is the lumbar spine, precisely where the bony confluences of the instrumented vertebrae's mammillary process, pars interarticularis, and transverse process converge. A medial entry site, specifically at the inferior border of the superior articular process, may be appropriate for patients afflicted with degenerative joint disease that impedes adequate stability for pedicle screws at this particular instance [14].

When a cavity is created at the thoracic pedicle entry site using a drill or awl, the biomechanical superiority of this trajectory over more anatomical trajectories generally provides justification for employing a trajectory parallel to the superior endplate. It is critical to initially direct a curved gear shaft pedicle probe laterally in order to avert a medial breach of approximately 15-20 mm. This measurement denotes the distance immediately beyond the spinal canal's broadest point. Following this, the probe or drill can be redirected towards the media to prevent lateral breach, given the significantly reduced probability of medial breach. After the integrity of the tract has been assessed using a feeler, it is optional to utilize an initial "tap" to determine whether the screw tract is precise and appropriately guided, before proceeding with the use of the final, more substantial screw [16].

More precisely, Parker *et al*., [14] discovered that breaches were most likely to occur in fasteners inserted into T4 and T6, while Modi *et al*., [17] found that screws inserted into the pedicles of T_5-T_8 had the highest incidence of breaches, particularly those that compromised beyond a 6-mm wide secure zone. Furthermore, it is unsurprising that free-hand techniques entail a significant period of adjustment after mastery.

Three-dimensional (3D) printed drill guide

One of the initial applications of 3D printing in spine surgery was to establish preoperative visualization and surgical planning aided by 3D models (Figure 2) [18].

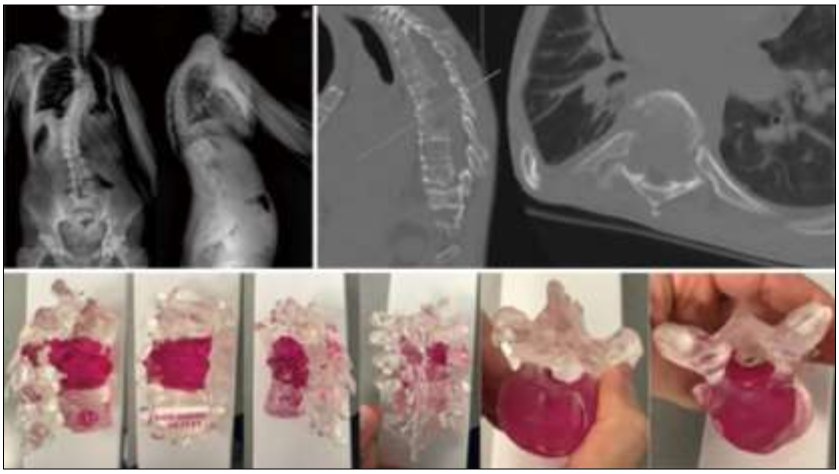

Fig 2: Imaging studies (top) of a 30-year-old male with an undifferentiated high-grade post-radiation sarcoma involving the thoracic spine [18]

Numerous scholarly investigations have observed that physical three-dimensional models, particularly with the ongoing advancements in 3D printing technology and model sophistication, offer a heightened perception of distinctive or intricate surgical pathology that might otherwise go unnoticed or be entirely overlooked when assessed exclusively through preoperative imaging [19]. Research has shown that the utilization of preoperative 3D modeling during spine surgery for complex deformities can enhance intraoperative speed and accuracy, while concurrently reducing blood loss [20]. Previous research has indicated that in situations involving congenital abnormalities such as myelomeningocele, where conventional imaging modalities are inadequate to evaluate global and intersegmental relationships due to distorted anatomy, the application of 3D models can assist with preoperative planning [21].

Pedicle screw guides

One initial application of 3D printing in the field of spine surgery was the creation of drill guides and templates that were customized for individual patients. These tools were intended to mitigate certain limitations observed in early image-guided navigation systems, such as the need for laborious stereotactic arrays, substantial initial investment in technology, the risk of surgeon interference, extended surgical duration, and more. In contrast to computer-navigated methods, proponents of 3D printed guides assert that they perform the same function without requiring expensive technology, which may be unfeasible or unattainable in developing countries [22]. With varying degrees of effectiveness, personalized 3D-printed drill guides in four distinct designs were utilized on cadaveric specimens during the first pedicle screw guide study, which was published in 2005 by Berry *et al.* Subsequent to its inception, 3D printed pedicle screw guides have significantly enhanced their accuracy and precision through design modifications and manufacturing process advancements, thereby broadening their utility in the field of spine surgery [23].

O-arm navigation

An example of the resultant progress in navigation technology is O-arm navigation, which is a computer-assisted system

specifically engineered to aid surgeons during the percutaneous insertion of pedicle screws in real-time. It is capable of delivering real-time three-plane virtual images that enable surgeons to manipulate instruments in the vicinity of bony structures. Despite assertions to the contrary, Toshiaki *et al*. found that O-arm navigation merely reduced the operational duration of pedicle screws rather than enhancing their precision. Further investigation is necessary in order to ascertain the efficacy of O-arm navigation system treatment, given the scarcity of clinical data on the subject. While there was initial assertion that the implementation of O-arm navigation enhanced the accuracy of pedicle screw placement, Toshiaki *et al*. found that it merely reduced the overall duration of the procedure. Further investigation is necessary in order to ascertain the efficacy of O-arm navigation system treatment, given the scarcity of clinical data on the subject [24].
O-arm navigation provides the surgeon with unambiguous intraoperative guidance and images of comparable quality to traditional C-arm scans. Historically, spinal navigation techniques required overlaying the positions of surgical instruments onto computed tomographic scans obtained prior to the procedure or fluoroscopic images acquired during the procedure in the operating room. Contemporary 3D O-arm instruments provide intraoperative navigation with three-dimensional image sets in addition to traditional two-dimensional fluoroscopic images (radiographs). Intraoperative O-arm systems are capable of rendering 3D anatomic structures visible via 3D real-time navigation. A substantial benefit in intricate spine surgery is the more intuitive three-position guidance [25].

Computed tomographic (CT) navigation
The implementation of CT-based navigation improves the accuracy of positioning pedicle screws. There is speculation that improving the accuracy of pedicle screw placement could potentially avert complications that may occur due to breach of the pedicle wall [26]. Commonly, imaging is performed subsequent to surgical procedures to verify instrument integrity and proper positioning, evaluate the progress of osseous union, detect disease progression or the emergence of new conditions, and identify potential complications such as hematoma or infection. Imaging purposes are predominantly carried out using conventional radiography. Nonetheless, CT is more beneficial when a definitive diagnosis cannot be established and there is uncertainty regarding the presence of fracture or misplacement [27].
Electrode placement complicates the spinal examination of patients undergoing orthopedic metallic hardware. In recent years, novel techniques have been developed for multichannel CT to assist in minimizing the impact of metal artifacts on the imaging process. By means of narrower sections, these processes facilitate quicker scanning durations, which subsequently diminish motion artifacts. By doing so, a scanned volume of isotropic voxels can be generated, ensuring that the image resolution is identical across all planes. Further, the imaging experience can be enhanced through the generation of a higher x-ray tube current [27].

Robotic surgery: A preoperative surgical strategy is more effectively executed when preoperative planning software and robotic guidance are utilized during the insertion of pedicle screws. This, in turn, improves the plan's feasibility and accuracy while mitigating the potential for catastrophic complications that may arise due to the intricate and variable nature of the pedicle and adjacent structures [28].

Indications
Patients with osteoporosis or severe spinal deformities require revision or repeat surgery. The importance of preconception planning and robotic guidance, which allow the surgeon to "visualize the invisible" of complex pedicle anatomy, has been demonstrated in a number of these instances [29, 30].
Patients undergoing minimally invasive procedures, individuals undergoing less strenuous open procedures that involve pedicle screw insertion, pedicle anatomy that is distorted or difficult to navigate, and for the purpose of cannula placement during vertebral cement augmentation. Previously executed spine surgeries; spinal tumors, neurofibromatosis, neuromuscular scoliosis, osteomyelitis, kyphosis, stenosis, spondylolysis, ankylosing spondylitis, fracture, Scheuermann kyphosis, neurofibromatosis, osteomyelitis, and stenosis. Vertebroplasty and kyphoplasty, as well as a spinal tumor biopsy, are performed. Disturbances, malignant growths, and injuries are pathologic entities. Molliqaj *et al*. [31] emphasized the challenge associated with pedicle screw implantation, especially in revision surgeries involving the modification of anatomical landmarks and spinal deformities induced by tumors, degeneration, or trauma. Their findings concerning the accuracy and safety of the robotic technique suggested that it provided a feasible resolution for the cases, as opposed to the conventional freehand fluoroscopic method. Furthermore, the robotic-guided technique finds application not only in biopsies but also in obstructed anatomic spaces to access arteriovenous fistulas and extraforaminal disc herniation, as well as in distorted anatomic spaces, where screws are not intended to be inserted [32]. Additionally, robotic technology has the capability to optimize the implementation of translaminar facet screws, in addition to facilitating the use of pedicle screws for spinal segment stabilization.

Contraindications
Being severely obese or afflicted with osteoporosis may render accurate registration impossible to achieve. Insufficient knowledge of conventional open methodologies for pedicle screw insertion [28].

Conflict of Interest: Not available.

Financial Support: Not available.

References
1. Pijpker PA, Kraeima J, Witjes MJ, Oterdoom DM, Vergeer RA, Coppes MH, *et al*. Accuracy of patient-specific 3D-printed drill guides for pedicle and lateral mass screw insertion: an analysis of 76 cervical and thoracic screw trajectories. Spine. 2021;46:160.
2. Cecchinato R, Berjano P, Zerbi A, Damilano M, Redaelli A, Lamartina C, *et al*. Pedicle screw insertion with patient-specific 3D-printed guides based on low-dose CT scan is more accurate than free-hand technique in spine deformity patients: A prospective, randomized clinical trial. European Spine Journal. 2019;28:1712-1723.
3. Tetsworth K, Block S, Glatt V. Putting 3D modelling and 3D printing into practice: virtual surgery and preoperative planning to reconstruct complex post-traumatic skeletal deformities and defects. Sicot-J; c2017. p. 3.
4. Vardiman A, Wallace D, Crawford N, Riggleman JR, Ahrendtsen L, Ledonio C, *et al*. Pedicle screw accuracy in clinical utilization of minimally invasive navigated robot-assisted spine surgery. J Robot Surg. 2020;14:1-5.
5. Cho W, Cho SK, Wu C. The biomechanics of pedicle

screw-based instrumentation. J Bone Joint Surg. Br. 2010;92:1061-1065.
6. Essig DA, Miller CP, Xiao M, Ivancic P, Jegede K, Badrinath R, *et al*. Biomechanical comparison of endplate forces generated by uniaxial screws and monoaxial pedicle screws. Orthopedics. 2012;35:e1528-e32.
7. Rahyussalim AJ, Kurniawati T, Besri NN, Hukmi K. Osteoporotic pedicle screw: Review of various types of pedicle screw and cement augmentation. AIP Conference Proceedings. 2019;2193:22-31.
8. Manon J, Hussain MM, Harris J, Moldavsky M, La Marca F, Bucklen BS, *et al*. Biomechanical Investigation of a Novel Revision Device in an Osteoporotic Model: Pullout Strength of Pedicle Screw Anchor Versus Larger Screw Diameter. Clin. Spine Surg. 2017;30:265-271.
9. Cavali PTM. Posterior Thoracolumbar Fixation: Overview of Implants and Surgical Techniques. Surgery of the Spine and Spinal Cord; c2016. p. 243-261.
10. Sale de Gauzy J, Jouve JL, Accadbled F, Blondel B, Bollini G. Use of the Universal Clamp in adolescent idiopathic scoliosis for deformity correction and as an adjunct to fusion: 2-year follow-up. J Child Orthop. 2011;5:273-282.
11. Kanno H, Onoda Y, Hashimoto K, Aizawa T, Ozawa H. Innovation of Surgical Techniques for Screw Fixation in Patients with Osteoporotic Spine. J Clin. Med. 2022;11:15-90.
12. Van de Kelft E, Costa F, Van der Planken D, Schils F. A prospective multicenter registry on the accuracy of pedicle screw placement in the thoracic, lumbar, and sacral levels with the use of the O-arm imaging system and Stealth Station Navigation. Spine (Phila Pa 1976). 2012;37:1580-1587.
13. Avila MJ, Baaj AA. Freehand Thoracic Pedicle Screw Placement: Review of Existing Strategies and a Step-by-Step Guide Using Uniform Landmarks for All Levels. Cureus. 2016;8:501-525.
14. Parker SL, McGirt MJ, Farber SH, Amin AG, Rick AM, Suk I, *et al*. Accuracy of free-hand pedicle screws in the thoracic and lumbar spine: Analysis of 6816 consecutive screws. Neurosurgery. 2011;68:170-178; Discussion 8.
15. Chung KJ, Suh SW, Desai S, Song HR. Ideal entry point for the thoracic pedicle screw during the free hand technique. Int. Orthop. 2008;32:657-662.
16. Lehman RA, Jr., Polly DW, Jr., Kuklo TR, Cunningham B, Kirk KL, Belmont PJ, Jr., *et al*. Straight-forward versus anatomic trajectory technique of thoracic pedicle screw fixation: A biomechanical analysis. Spine (Phila Pa 1976). 2003;28:2058-2065.
17. Modi H, Suh SW, Song HR, Yang JH. Accuracy of thoracic pedicle screw placement in scoliosis using the ideal pedicle entry point during the freehand technique. Int Orthop. 2009;33:469-475.
18. Sheha ED, Gandhi SD, Colman MW. 3D printing in spine surgery. Ann. Transl. Med. 2019;7:164-175.
19. Mobbs RJ, Parr WCH, Choy WJ, McEvoy A, Walsh WR, Phan K, *et al*. Anterior Lumbar Interbody Fusion Using a Personalized Approach: Is Custom the Future of Implants for Anterior Lumbar Interbody Fusion Surgery? World Neurosurg; c2019. p. 11-15.
20. Tan LA, Yerneni K, Tuchman A, Li XJ, Cerpa M, Lehman RA, Jr., *et al*. Utilization of the 3D-printed spine model for freehand pedicle screw placement in complex spinal deformity correction. J Spine Surg. 2018;4:319-327.
21. Xiao JR, Huang WD, Yang XH, Yan WJ, Song DW, Wei HF, *et al*. En Bloc Resection of Primary Malignant Bone Tumor in the Cervical Spine Based on 3-Dimensional Printing Technology. Orthop. Surg. 2016;8:171-178.
22. Sugawara T, Kaneyama S, Higashiyama N, Tamura S, Endo T, Takabatake M, *et al*. Prospective Multicenter Study of a Multistep Screw Insertion Technique Using Patient-Specific Screw Guide Templates for the Cervical and Thoracic Spine. Spine (Phila Pa 1976). 2018;43:1685-1694.
23. Garg B, Gupta M, Singh M, Kalyanasundaram D. Outcome and safety analysis of 3D-printed patient-specific pedicle screw jigs for complex spinal deformities: A comparative study. Spine J. 2019;19:56-64.
24. Lu J, Chen W, Liu H, Yang H, Liu T. Does pedicle screw fixation assisted by O-arm navigation perform better than fluoroscopy-guided technique in thoracolumbar fractures in percutaneous surgery?: a retrospective cohort study. Clinical spine surgery. 2020;33:247-253.
25. Sun J, Wu D, Wang Q, Wei Y, Yuan F. Pedicle screw insertion: Is o-arm-based navigation superior to the conventional freehand technique? A systematic review and meta-analysis. World Neurosurgery. 2020;144:e87-e99.
26. Kapoor S, Sharma R, Garg S, Jindal R, Gupta R, Goe A, *et al*. Navigated pedicle screw placement using computed tomographic data in dorsolumbar fractures. Indian J Orthop. 2014;48:555-561.
27. Salama AA, Amin MA, Soliman AY, El-Tantaway A. Postoperative 320 multi-slice computed tomography in assessment of pedicle screw insertion in thoraco-lumbar fixation. EJRNM. 2019;50:57.
28. Lieberman IH, Kisinde S, Hesselbacher S. Robotic-assisted pedicle screw placement during spine surgery. JBJS Essent. Surg. Tech. 2020;10:20-147.
29. van Dijk JD, van den Ende RP, Stramigioli S, Köchling M, Höss N. Clinical pedicle screw accuracy and deviation from planning in robot-guided spine surgery: robot-guided pedicle screw accuracy. Spine (Phila Pa 1976). 2015;40:986-991.
30. Schatlo B, Martinez R, Alaid A, von Eckardstein K, Akhavan-Sigari R, Hahn A, *et al*. Unskilled unawareness and the learning curve in robotic spine surgery. Acta Neurochir (Wien). 2015;157:1819-1823; discussion 23.
31. Molliqaj G, Schatlo B, Alaid A, Solomiichuk V, Rohde V, Schaller K, *et al*. Accuracy of robot-guided versus freehand fluoroscopy-assisted pedicle screw insertion in thoracolumbar spinal surgery. Neurosurg. Focus. 2017;42:14-100.
32. Roser F, Tatagiba M, Maier G. Spinal robotics: current applications and future perspectives. Neurosurgery. 2013;72:12-18.

How to Cite This Article
Arakeep OM, El-Noor TIA, El-Tantawy AES, El-Daw SES. Thoracolumbar pedicle screw instrumentation: Different types & insertional techniques. International Journal of Orthopaedics Sciences. 2024;10(2):241-245.