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Evaluation of efficacy and accuracy of free hand pedicle screw insertion technique in thoracic spine

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Abstract

Introduction: Advanced internal fixation techniques, including pedicle screws, have been developed and used extensively in spine surgery, not only for traumatic injuries but also for degenerative conditions. Free hand pedicle screw fixation technique have the advantage of universal application, fixation strength, and stabilization of all three mechanical columns of the spine. Free hand pedicle screw placement based on external anatomy alone can be performed with acceptable safety and accuracy and avoids excessive radiation exposure.

Materials and Method: This was a prospective study done in Department of Orthopaedics at our institute. 30 consecutive patients who underwent posterior thoracic instrumentation from May 2015- May 2016 were analysed. The mean age was 39 years. The etiologic diagnoses were - spinal trauma-22, spinal tuberculosis-05, spinal deformity-02, and spinal tumour-01. Titanium pedicle screws used in all these vertebrae were polyaxial in nature and of 4.5mm or 5.5mm diameter with length ranging from 25mm to 50mm. 168 screws were inserted in 84 thoracic vertebra (T1-T12) by free hand technique as described by Kim et al. Informed consent was taken. Clearance from ethical committee of the institute was taken. The patients were followed-up with X-ray, CT Scan at immediate postoperative and reviewed at 1 month and 3 months postoperative with radiograph.

Results: 168 screws were inserted in 84 thoracic vertebra (T1-T12) with number of screws inserted at each level as follows T1 =0, T2=4, T3=6, T4=8, T5=14, T6=14, T7=16, T8=16, T9=18, T10=18, T11=24, T12=30. All the screw were evaluated post operatively. Of 168 screws 144 screws (85.70%) were intraosseous and accurately placed. 24 screws (14.28%) in patients were malpositioned. Of 24 perforations 3 screws (1.78%) had critical medial breach of more than 2 mm perforation, however no neurological worsening was noted post operatively in any case. Rest 21screws (12.50%) perforations were non-critical. In 3 patients (deformity 1, trauma 1 and infection 1) sudden give away was felt during gear shift probing, and a breach confirmed on palpation/probing and the screw was re directed. None of the patients had any incident of CSF leak or excessive bleeding during screw insertion.

Conclusion: The free hand technique of thoracic pedicle screw placement performed in a stepwise, consistent, and compulsive manner is an accurate, reliable, efficient and safe method of insertion to treat a various spinal conditions, with almost same rate or less number of complications as performed with fluoroscopy guided pedicle screw insertion. Our results with less than 2 percent of critical breach, document that we have been able to create a safe method of thoracic pedicle screw placement without use of other intra operative imaging modalities. One must have a thorough knowledge of spine and vertebral anatomy, follow and use deligent and repetitive confirmatory steps to compulsively assure interosseous screw placement.

Keywords: Free Hand Technique, Pedicle Screw Fixation, Thoracic Spine, Thoracic Pedicle

Introduction

Over the years pedicle screw fixation in spine has gained a lot of importance and popularity as it being a stable and superior fixation modality over its predecessors.[1,2] The advantages of pedicle screws over hooks is that pedicle screws provide better pull-out strength, three dimensional control of deformity correction,it allows application of significant corrective forces and they do not routinely violate the spinal canal if placed precisely.[3,4] Pedicle screw insertion with the free hand technique though has a steep learning curve and depends upon the skills and expertise of the operating surgeon and also requires a thorough knowledge of the anatomy of spine.

Pedicle screw fixation in thoracic spine is especially done for various reconstructive spine surgeries, spinal fusion and stabilization of spine in traumatic, degenerative, scoliotic, and neoplastic spinal diseases. All the above conditions require stabilization of the spine or correction of the deformity to restrict its progression and a critical intraoperative assessment of pedicle screw placement to prevent any further neurological and vascular complications.[5-12] A stable and superior three column fixation is required.[13] Thoracic pedicle screws are now recently used over wires and hooks.[8,14-23]

The thoracic spine has a very unique vascular and neurologic anatomy. There are variations in the anatomy of each pedicle at different levels from T1-T 12.[20,24-26] The presence of shoulder girdle and ribcage in upper thoracic region makes it difficult to use intra-op fluoroscopy. So accurate and optimal placement of the screw is of prime importance to obtain stable fixation and good results.[27-30]

In Thoracic Spine, with superimposed bony architecture (Shoulder girdle And Rib Cage) and variations in the anatomy of each pedicle at different levels, in bulky patients, in patients with deformity, rotation and osteoporosis, it becomes further difficult to rely on intra-operative Fluoroscopy and imaging techniques. So they remain of limited use and free hand technique has promising results. The aim of this study

was to evaluate the efficacy and accuracy of Free Hand Pedicle Screw Insertion technique In Thoracic Spine (T1-T12).

Materials and Method

Source of data: 33 Patients getting treated with posterior spinal instrumentation at level T1-T12 by the same surgeon during the period May 2015- May 2016 and operated at our centre were included in the study.3 patients did not follow-up, hence were excluded. In the end,final analysis was done on 30 patients.

Inclusion Criteria:

1. Thoracic spinal instrumentation
2. Free hand pedicle screw insertion technique
3. T1-T12 vertebrae included
4. Patients with post-op CT scan included

Exclusion Criteria:

1. Lumbar screws (L1-L5)
2. Fluoroscopy guided screws
3. Patients in whom CT scan not done post-operatively
4. Patients medically unfit for surgery

Surgical technique of "free hand" pedicle screw insertion

The surgical technique of "free hand" thoracic pedicle screw placement is the one described by Kim et al[(11)] in scoliosis was used for all the cases.

1. **Incision and Exposure:** The first important component is meticulous exposure of the posterior elements. The spine is exposed to the tips of the transverse processes bilaterally, staying strictly subperiosteal to reduce bleeding.

Fig. 1: Complete exposure and facetectomy

2. The cortical burring of starting point

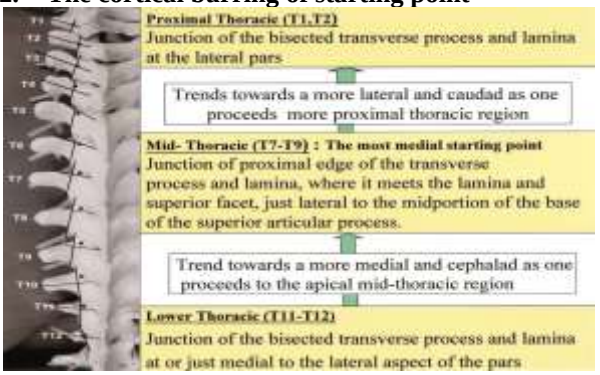


Fig. 2: Shows the ideal pedicle entry point for pedicle screw insertion by Kim et al[(11)]

Usually the supine preoperative film is very illustrative to find the ideal starting point because of prone positioning during the operation usually it is at the junction of the proximal edge of the transverse process and just lateral to the mid portion of the base of the superior articular process. It is advantageous to note these trends when placing a screw at each level in succession, working from distal to proximal in the thoracic spine, to make fine adjustments to the trajectory of the next screw base on the previous level screw or contralateral screw.

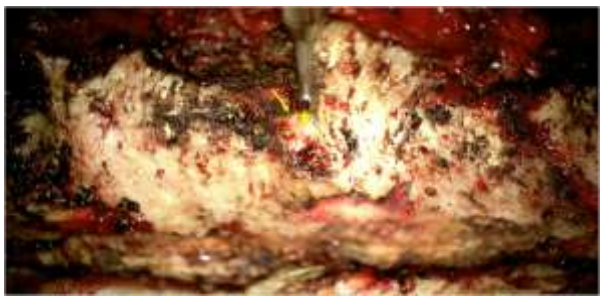


Fig. 3: Arrow showing the entry point with burr tip

3. **Gearshift Probing:** A pedicle "blush" may be visualized suggesting entrance into the cancellous bone at the base of the pedicle. This may not be seen in smaller pedicles because of very limited intrapedicular cancellous bone. The thoracic gearshift (2 mm blunt-tipped, slightly-curved pedicle finder) is placed in the base of the pedicle searching for a cancellous "soft spot" indicating entrance to the pedicle. The gearshift is initially pointed lateral as a safety measure to avoid medial wall perforation. The 2mm tip will go down the cancellous portion of the pedicle even if it is quite small. After inserting the tip approximately 15–20 mm (to beyond the medially based spinal canal), the gearshift is removed and the tip turned to face medial. Before advancing the pedicle finder, place the tip carefully into the base of the hole. Feel the entire length of the pedicle and body. Probing of

the pedicle with the thoracic gearshift should proceed in smooth and consistent manner with a snug feel because of the small size of the thoracic pedicles. Any sudden advancement of the gearshift suggests penetration into soft tissue and thus a pedicle wall or vertebral body violation and should be investigated immediately to avoid complications.

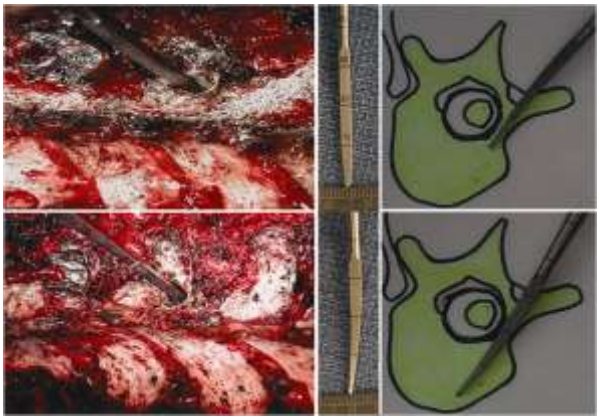


Fig. 4: Gearshift probing: initially, direct the gearshift laterally to the depth of 20 mm (the approximate depth of the pedicle) to diminish the likelihood of medial pedicle perforation. Then, remove the gearshift and redirect it medially. Use the non-dominant hand to brace the gearshift from sudden advancements

Fig. 5: The figure shows entry point with a pedicle seeker and gearshift probing

Palpation and Pedicle Length Measurement: The pedicle seeker is removed, the tract is visualized to make sure that only blood is oozing and not cerebrospinal fluid (CSF). Next, a flexible ball-tipped pedicle sound is utilized to palpate five distinct bony borders: a floor and four walls (medial, lateral, superior, and inferior). With the sound in the base of the pedicle tract after confirming five intraosseous borders, measure it.

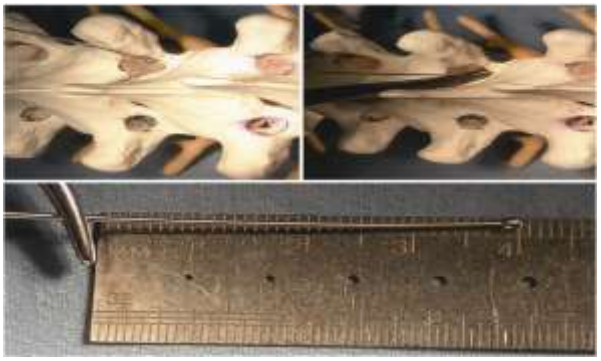


Fig. 6: Palpation and pedicle length measurement

5. **Tapping, Repalpation, and Screw Placement:** The pedicle tract is undertapped with a 0.5 mm less diameter tap than the intended screw. Following this, the pedicle tract is palpated again to make sure that the five osseous borders are intact. Place the screw slowly down the pedicle into the body in the same alignment.

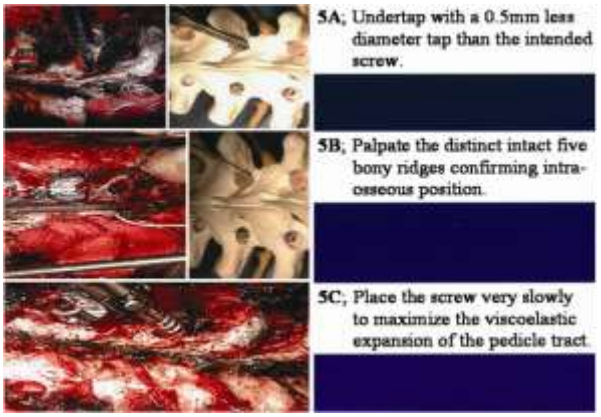


Fig. 7: Tapping, repalpation, and slow screw placement

Titanium pedicle screws were used. All pedicle screws were inserted with the above mentioned free hand technique which uses established surface landmarks and direct palpation of the internal pedicle and vertebral structure.

Post-operative Assessment: Post-operative radiographs in erect PA and Lateral view were taken and CT scans were obtained for all **30 patients** in order to assess screw position. The imaging series consisted of 2.5 mm thick CT sections reconstructed at 2 mm intervals.

The screws were reported to be:

Through-In: if they were completely surrounded by bony margins in all views,

Questionable / Suspicious: if the screw in more than one view seems to be perforating the bony margins, but being in the bony margins in rest of images, or if there is no consensus between the reporting radiologist and

orthopedician.

Out: was reported for pedicle screw when there was definite breach of bony margins reported in either anterior / lateral / medial perforation was noted.

Types of Perforation

Fig. 8: Medial perforation

Fig. 9: Lateral perforation

Fig. 10: Anterior perforation

Critical vs. Non-Critical Breach

Fig. 11: Critical perforation

Fig. 12: Non-critical perforation

Xu & Poley et al Criteria was used to assess Accuracy of Placement of pedicular screws to assign whether the osseous breach noted has been Critical or Non-critical.

Critical breach were those with either 3 mm or more of medial/inferior/lateral perforation or with more than half the diameter of the screw being medial perforation.

All the other breaches were considered non-critical.

Relation of critical versus non-critical breach to neurological complications was noted

Complications - Dural Leak, Visceral/Vessel Injury, Neurological Deterioration, if any Were Documented Immediate Postoperative.

Follow-Up: The patients were followed-up with X-ray, CT Scan at immediate postoperative, 1 month postoperative with X-ray and 3 months postoperative with X-ray.

Observation and Results

Table 1: Number of pedicle screws inserted

Pedicle	Number of Screws Inserted	Percentage
T1	0	0.00
T2	4	2.38
T3	6	3.57
T4	8	4.76
T5	14	8.33
T6	14	8.33
T7	16	9.52
T8	16	9.52
T9	18	10.71
T10	18	10.71
T11	24	14.29
T12	30	17.86
Total	168	100.00

Most of the pedicle screws were inserted in pedicle T7 and above.

Table 2: Number of perforations in relation to number of pedicle screws inserted

Pedicle	Number of Screws Inserted	Perforations	
		No.	%
T1	-	0	0.0
T2	4	1	4.16
T3	6	0	0
T4	8	1	4.16
T5	14	3	12.5
T6	14	2	8.33
T7	16	6	25.00
T8	16	2	8.33
T9	18	7	29.10
T10	18	2	8.33
T11	24	0	0.00
T12	30	0	0.00
Total	168	24	100.00

Majority 7 (29.10%) perforations were done in pedicle T9, followed by 6 (25.00%) in pedicle T7, while few perforations were done in other pedicles.

Table 3: Distribution of perforations

Pedicle	Number of Screws Inserted	Number of perforations	Medial	Lateral	Anterior	In-Out-In
T1	0	0	0	0	0	0
T2	4	1	0	1	0	0
T3	6	0	0	0	0	0
T4	8	1	0	1	0	0
T5	14	3	1	1	1	0
T6	14	2	1	1	0	0
T7	16	6	4	1	0	1
T8	16	2	0	2	0	0
T9	18	7	2	3	0	2
T10	18	2	0	1	0	0
T11	24	0	0	0	0	1
T12	30	0	0	0	0	0
Total	168	24	8	11	1	4

Maximum perforations were in lateral position, followed by medial, then In-Out-In position and only 1 was done in anterior position.

Table 4: Distribution of perforations as Critical / Non-Critical

Pedicle	Number of Screws Inserted	Number of perforations	Critical		Non-Critical	
			No.	%	No.	%
T1	0	0	0	0.00	0	0.00
T2	4	1	0	0.00	1	4.76
T3	6	0	0	0.00	0	0.00
T4	8	1	0	0.00	1	4.76
T5	14	3	1	33.33	2	9.52
T6	14	2	1	33.33	1	4.76
T7	16	6	1	33.33	5	23.81
T8	16	2	0	0.00	2	9.52

T9	18	7	0	0.00	7	33.33
T10	18	2	0	0.00	2	9.52
T11	24	0	0	0.00	0	0.00
T12	30	0	0	0.00	0	0.00
Total	168	24	03	100.00	21	100.00

The above table shows the distribution of perforations as categorized as Critical and Non-Critical perforations. There were 3 critical and 21 non-critical perforations in the present study.

30 consecutive patients with mean age 39 years (14-70) with various indications (spinal trauma-22, spinal tuberculosis-05, spinal deformity-02, and spinal tumour-01) underwent posterior spinal instrumentation in thoracic spine. The pedicle screws used in all these vertebrae were polyaxial in nature and of 4.5mm or 5.5mm diameter with length ranging from 25mm to 50mm. 168 screws were inserted in 84 thoracic vertebra (T1-T12).

In 3 patients sudden give away was felt during gear shift probing, and a breach confirmed on palpation/probing and the screw were re-directed. None of the redirected screws showed any breach. None of the patients had any incident of CSF leak, excessive bleeding indicating an osseous breach during screw insertion.

Of 168 screws 144 (85.70%) were intraosseous and accurately placed. 24 screws (14.28%) in patients were malpositioned. As per evaluation criteria 144 screws were considered IN, however 4 were considered Questionable/suspicious. 20 screws were considered OUT with consensus by both the observers.

Out of twenty four screw perforations, 11 (6.54%) had lateral wall perforation, 8 (4.76%) had medial wall perforation and 1 (0.59%) had anterior wall perforation. Though osseous in location, 4 interosseous screws (2.38%) placed In-Out-In were also considered misplaced, described in Table no.3.

Of 24 perforations 3 screws (1.78%) had critical medial breach of more than 2 mm perforation, which meant the central line of the pedicle screw was out of the inner cortex of the pedicle wall, however no neurological worsening was noted post operatively in any case. Rest 21screws (12.50%) perforations were non-critical and where minimal breach was noted medially, laterally or anteriorly as in Table 4.

By performing multiple regression analysis we found:

Commonest perforation: Lateral wall perforation (6.54%)
Commonest pedicle having perforation: T9
Incidence of perforation: (24/168)*100= 14.28%
Incidence of critical breach: (3/168)*100= 1.78%
Incidence of non-critical breach: (21/168)*100= 12.50%

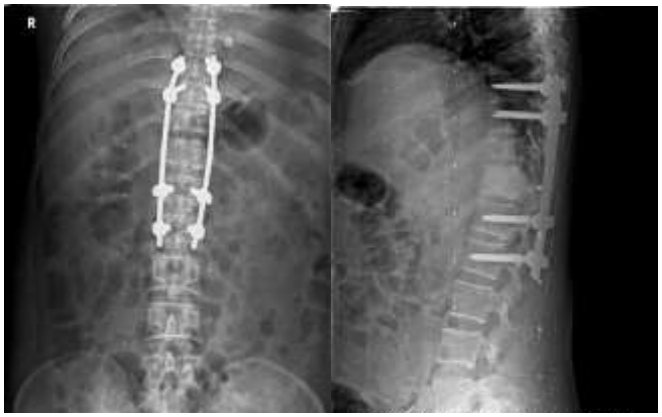
Case no 1

Pre operative X ray (AP view) **pre operative x ray (lateral view)**

Post operative x ray (AP view) **post operative x ray (Lateral view)**

Case no. 2

Pre operative x ray (AP view) **pre operative x ray(lateral view)**



Post operative x ray (AP view) **post operative x ray (Lateral view)**

Discussion

A major advance provided by spinal systems was the exploitation of the pedicle as a site for segmental fixation. In 1985**, Roy-Camille** applied the first pedicle screw plate system for the lumbar spine, known to treat spinal disorders by providing stable fixation and correcting spinal deformities.[2,31-34] Pedicle screws are biomechanically superior as a point of fixation compared with hook- or wire-rod constructs and can be placed into the sacrum.

In recent years, there has been an interest in developing dynamic stabilization systems for degenerative diseases.When comparing the advantages of pedicle screws over hooks, pedicle screws provide a better pull-out strength, three dimensional control of deformity correction, and routinely do not violate the spinal canal if placed properly.[3,4] The anatomical approach provides the largest possible bone channel for screw placement, but it requires the use of a polyaxial screw. The straight-forward approachis a slightly

modified Roy-Camille approach that was popularized by Suk and Lenke.[11]

The major limitation associated with the insertion of thoracic pedicle screws is potential risk of damage to neurovascular structures.

The free hand technique of thoracic pedicle screw placement performed in a stepwise, consistent, and compulsive manner is an accurate, reliable, and safe method of insertion to treat spinal conditions, with almost same rate or less complications as performed with fluoroscopy guided pedicle screw insertion.

Kim et al (2004)[11] conducted a study for safety of free hand pedicle screw placement in which had a 6.2% moderate cortical perforation as compared to 12.5% in our study and 1.7% critical medial wall perforation which was same as in our study.

Fisher et al (2006)[35] evaluated accuracy and safety of pedicle screw placement in the treatment of unstable thoracic spine fractures in which 201 pedicle screws were inserted in 23 patients from T1-T12. Post-operative CT scan analysis confirmed 133(66.20%) screws were fully contained and the remaining 68(33.8%) screws violated the pedicle wall.

Modi et al (2008)[36] evaluated the accuracy and safety of pedicle screw placement in neuromuscular scoliosis with free hand technique. In a retrospective study of 37 patients of neuromuscular scoliosis in whom 1009 transpedicular screws were inserted, 273 (27%) screws were displaced medially, laterally or anteriorly and 73% screws were accurately placed in the pedicle. 92.4% thoracic screws were in safe zone. They concluded that pedicle screw placement in neuromuscular scoliosis with free hand technique is an accurate and safe method.

Yalniz et al (2009)[37] studied the safety of pedicle screw fixation in the thoracic spine out of 827 screws 780 (94.3%) showed containment as compared to (85.70%) in our study and 47(5.7%) showed incorrect placement as compared to (14.3%) and concluded that high accuracy of thoracic pedicle screw placement using the free hand technique suggests that pedicle screw fixation of thoracic spine is safe and reliable in the treatment of all spinal diseases.

Parker et al (2011)[38] evaluated the placement of pedicle screws in the thoracic and lumbar spine using a free hand technique. A total of 964 patients received 6816 free hand placed pedicle screws in the thoracic spine out of which 115 (1.7%) screws were identified as breaching the pedicle. Thus free hand pedicle screw placement based on external anatomy alone can be performed with acceptable safety and accuracy.

Gelalis et al (2012)[39] conducted a systematic review of prospective in vivo studies comparing free hand, fluoroscopy guidance and navigation techniques. In a study of 1105 patients 6617 screws were inserted in which free hand technique showed 69-94% screws contained, fluoroscopy 28-85%, CT navigation 89-100% and fluoroscopy based navigation 81-92% which is similar to 85.70% in our study.

Seo et al (2013)[40] studied the accuracy and safety of free-hand pedicle screw fixation in 31 patients aged less than 10 years. The accuracy of pedicle screw placement in pedicles was 94.6% without any complications. These results suggest that free hand pedicle screw fixation can be safely used in patients younger than 10 years to treat a variety of spinal disorders.

Fennell et al (2014)[41] studied the free hand thoracic pedicle screw technique using a uniform entry point and sagittal trajectory for all levels. A total of 219 thoracic pedicle screws were placed with 96% accuracy rate. No any medial breachesfound. Only 9 screws (4%) showed lateral breach and no any neurological complications were noted. The study concluded that it is feasible to place thoracic pedicle screws with free hand technique using a uniform entry point and sagittal trajectory at all levels.

The incidence rate of perforation of screws in our study is similar or matching other studies where radiography or intraoperative fluoroscopy was used. This very fact that the incidence is nearly matching, also highlights the fact that margin of error in interpretation of the intraoperative findings is very high. Also subjective intra - observer variations in reporting the perforation on these images intraoperatively has a high degree of variability reducing the reliability.

Our results with less than 2 percent of critical breach, document that we have been able to create a safe method of thoracic pedicle screw placement without use of other intraoperative methods/devices, but we acknowledge that this method may not be the best for many surgeons to start with. Infact, it is recommended to master the skills of intraoperative assistance which may sometime be the only bail out procedure at times of need. Surgeons must use their best judgment for creating the safest environment possible when placing thoracic pedicle screws.

Conclusion

Free hand technique for pedicle screw insertion in the thoracic spine appears to be an accurate, safe and reliable procedure done without any intraoperative radiographic assistance.

Intraoperative fluoroscopy is not reliable especially in higher thoracic spine (T1-T6) because of superimposed bony architecture and shadows of ribcage, shoulder, scapula, humeral head.

Thus for placing the screw in thoracic pedicle, one must have a thorough anatomical knowledge of the thoracic pedicles and spine. Although it has a steep learning curve but if done in a stepwise, compulsive manner with repetitive confirmatory steps may achieve assured intraosseous placement of the screws.

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