Accuracy and Safety of the Free Hand Technique for Thoracic Pedicle Screw Placement in Spinal Deformity

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ABSTRACT:

BACKGROUND:

Pedicle screw construct has become widely accepted method for correction of spinal deformities. Better correction, higher rates of fusion as well as low complication rates have been reported. Free hand technique for placement of pedicle screw has been shown to be associated with low complication rate when performed by experienced surgeon. Low dose CT scan was used for postoperative assessment of screw placement and shown to be safe and effective method.

OBJECTIVE:

To determine the accuracy and safety of malpositioned screws in the thoracic spinal deformities using the free hand technique and to determine the effectiveness of the low dose CT scan regarding this issue

METHODS:

502 pedicle screws were used in 21 patients with adult idiopathic and congenital scoliosis using the free hand technique, screws positions were estimated one week postoperatively using low dose CT scan.

RESULTS:

Of the 502 screws inserted 262 (52.19%) were well placed inside the pedicle while 110 (21.91%) were medially misplaced and 108 screws (21.51%) were misplaced laterally, 16(3.19%) anterior perforation, 5 (1%) perforated the underlying neural foramen and 1(0.2%) perforated the upper end plate; without any significant neurological or visceral complication.

CONCLUSION:

Placement of the thoracic pedicle screws in the surgical correction of the deformed spine using the free hand technique is a safe, cost effective and non-time consuming and that the low dose CT scan used postoperatively is effective and safe method in detecting malpositioned screws.

KEY WORDS: Thoracic pedicle screw, malpositioned screw, low dose CT scan.

INTRODUCTION:

Posterior spinal instrumentation with pedicular screws is the current gold standard in the treatment of spinal deformity[1]. It has led to significant improvement in deformity correction even in large magnitude curves. The original correction with the Harrington rod system has evolved to segmental instrumentation: first with sublaminar wires according to Luque, then multiple hooks, hybrid nstrumentation, and now all pedicle screw constructs.

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Lenke et al[1] claim that pedicle screw fixation is the state of the art in spinal deformity correction. Others have questioned the benefits of pedicle screw fixation in thoracic curves because of potential risks of placement in morphologically abnormal vertebral bodies or even the questionable benefits of increased curve correction[2]. In 1995, Professor Suk et al provided their initial results of thoracic pedicle screw placement in the correction of idiopathic scoliosis.[3] They achieved better correction of major curve, compensatory curve, restoration of kyphosis with the use of segmental pedicle screw fixation compared with hooks and hybrid construct. Also the screw malposition rate was low, with no neurological impairment or adverse effect on the results of treatment. Many other scoliosis surgeons became interested in this technique as well, but much work was needed to confirm first the safety and second the efficacy of this technique.[3-9] Through multiple publications, the ability to safely place thoracic pedicle screws in any degree of idiopathic scoliosis and even revision cases has been confirmed.[10-15]

The hook or sublaminar wire fixation is not risk free.[16] Pedicle hooks, sublaminar hooks and wires all expose the spinal canal and place the thoracic neural elements at risk during anchor placement and rod manipulation. Once the screws are placed completely intraosseous, deformity correction techniques should be quite safe by minimizing direct implant impingement on neural elements, this is a significant advantage. Other advantages of pedicle screw constructs for scoliosis and related deformity correction include saving fusion levels compared with other techniques, obviating an anterior release and fusion in large and/or sagittally malaligned curves, providing a lower revision rate both in the short- and long-term, and maximizing pulmonary function with improved chest wall deformity correction afforded by screw derotation techniques while avoiding a thoracoplasty.[17-20]

The greatest point of discussion in the pedicle screws debate remains related to their potential complications. In the thoracic spine, the benefits of pedicle screws have been tempered by its potential risks, such as,: spinal canal violation, pedicle fracture, nerve root compression, and vascular lesions. Furthermore, the narrow and inconsistent shape of the thoracic pedicles, especially in spinal deformity, altered pedicle morphology, and shift of surrounding structures by rotation make pedicle screw placement technically challenging at this level.[21] Despite these concerns, there are only a limited number of severe complications reported in the adolescent patient resulting from the use of pedicle screws.[22] The most severe complications of pedicle screw malpositioning, such as neurologic, vascular or pleuro-pulmonary complications, have been described in some rare case reports.[23-30] The exact incidence and clinical relevance of screw malpositioning is still unclear.

Assessment of malpositioned pedicle screws in patients with spinal deformities has been reported in many studies.[31-34] The use of low dose CT Scan in the detection of screw malposition has been widely accepted as a diagnostic tool. In addition to its safety comparable to the standard X-Ray.

In this study, we evaluated the position of the screws postoperatively using low dose CT scan to estimate the rate of screw misplacement, to determine the accuracy and safety of screw insertion for treatment of spinal deformity using free hand technique, and to determine the effectiveness of low dose CT scan in follow up the patients treated by this technique.

PATIENTS AND METHODS:

Twenty one patients with spinal deformities(seven idiopathic and fourteen congenital scoliosis) underwent correction with posterior spinal instrumentations and fusion. All the operations were performed in the Medical City complex in Baghdad, by two surgical teams. 502 Titanium poly axial pedicular screws have been inserted using free hand technique, and connected through rods. Fusion was performed to all of the curve using bone graft (autogenous and allograft). Postoperatively patients were observed for any symptoms and signs of injuries to the spinal cord, nerve roots, blood vessels, pleural cavities and other viscera.

Surgical procedure:

Under general anesthesia (total intravenous anesthesia) and hypotensive technique, through posterior midline approach, the vertebrae from upper to lower ends of the curve were exposed. The posterior vertebral elements were exposed to the tip of the transverse processes. The entry points were identified as a point just inferior to the intersection of a line drawn along the superior boarder of the transverse process with one drawn along lateral boarder of the superior articular process. After decortication, the pedicle was entered using a thoracic ball handle probe, and the walls were palpated with a feeler probe. The length from the entry point to the anterior cortex of the vertebral body was measured, and screw inserted. The vertebral rotation and the distorted anatomy were taken into consideration during free hand insertion of the screws. The rods are prepared so as to correct spinal deformity and attached to the screws. Global and segmental derotation was done followed by distraction on the concave side, and compression on the convex side. Neurophysiological intraoperative monitoring using motor and somatosensory evoked potential has been performed during the procedures. Bone graft both autogenous and allograft were applied to the decorticated posterior vertebral elements. The wound is closed after leaving suction drains.

Postoperatively:

Patients were closely observed in the intensive care unit in order to detect any symptoms or signs that may develop. Specifically, we looked for evidences of nerve root injury, spinal cord or cauda equina injury, vascular injury, dyspnea, dysphagia, abdominal pain, or else.

CT Scan examination:
All patients underwent low dose CT Scan examination for the dorsal, lumbar spine as well as the thorax and abdomen.
In the axial view, the screws were checked for any misplacements, medially (inside the spinal canal), laterally (outside the pedicle), or anterior penetration of the anterior cortex of the vertebral body. Any anterior penetration was recorded by the distance from the anterior cortex to the tip of the screw, and the distances from the adjacent structures were also recorded. In the sagittal view, the screws were investigated for upward or downward misplacements with any violation of the intervertebral foramina or penetration of the vertebral end plates. A screw that was completely contained inside the pedicle with its longitudinal axis parallel to that of the pedicle had been considered as a well-placed screw (Fig. 1). Medial misplacement has been measured as the distance between the medial wall of the pedicle, to the medial boarder of the screw and was measured in millimeters. Lateral misplacement has been measured from lateral wall of the pedicle, to the lateral boarder of the screw (Fig. 2-4).

Fig.1: Well-placed screws.

Fig.2: Medial and lateral screw misplacements.

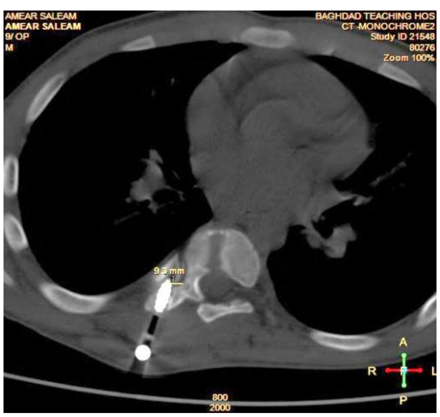

Fig. 3: Lateral misplacement.

Fig. 4: Anterior penetration.

We have used a grading system proposed by Abdul Kazim et al.[34] as a grading tool for misplaced screws (Fig.5).

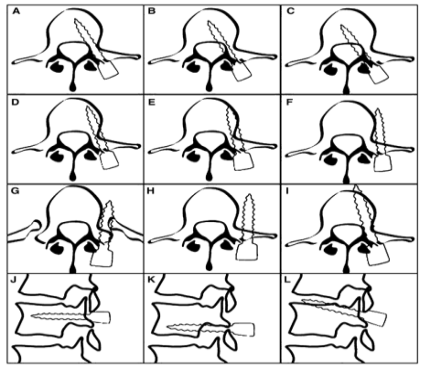

FIG.5 The types of screw placement according to the new grading system and examples of the relationship between different misplaced screws and the surrounding structures. a Normally placed screw. b Grade 1 MCP. c Grade 2 MCP. d Grade 1 LCP. Screw anchors in the vertebral body. e Grade 1 LCP. Screw passes within the vertebral body and abuts its inner cortex. f Grade 2 LCP. Screw abuts outer cortex of the vertebral body and does not anchor in the vertebral body. g Grade 2 LCP. Screw passes through the PRU and does not anchor in the vertebral body. h Grade 2 LCP. Screw with paravertebral passage. i ACP. j Normally placed screw on sagittal plane. k FP: perforation of underlying neural foramen. l EPP: perforation of upper endplate.

In this grading system, five types of misplacement have been evaluated: lateral, medial, anterior cortical perforation, endplate perforation, and foraminal perforation.

RESULTS:

A total number of 502 pedicle screws has been used in surgical correction of spinal deformities in twenty one Iraqi patients (seven Adolescent Idiopathic Scoliosis, fourteen congenital scoliosis) , 4 (19.05%) males and 17 (80.95%) females, age ranging from 14-22 (mean 17.29) years. All were convex to the right. The number of screws which were inserted in each level in the thoracic and lumbar vertebrae from T1 to L4 are shown in table 1.

Table 1: Number of screws in each vertebral level from T1 - L4.

Level	Concave	Convex	Total
T1	1	1	2
T2	7	6	13
T3	13	12	25
T4	19	19	38
T5	19	19	38
T6	20	20	40
T7	17	17	34
T8	22	19	41
T9	15	22	37
T10	21	19	40
T11	20	22	42
T12	22	22	44
L1	19	20	39
L2	19	18	37
L3	10	10	20
L4	6	6	12
Total	250	252	502

Using the above grading system of Abdul Kasim et al., analysis of CT scans of these 21 patients showed that of the 502 screws, 262 screws (52.19%) were well placed inside the pedicle, 110 screws (21.91%) were medially misplaced, 108 screws (21.51%) were laterally misplaced, anterior perforation 16 screws (3.19%), perforation of the underlying neural foramen 5 screws (1%), and perforation of the upper endplate 1 screw (0.2%). The grade J in the grading system has been omitted as we found overlap with grade A, B, C, D, E, F, G and H.

Medial misplacement was found to range from 1.0-7.3 mm, with an average of 3.44 mm. For lateral misplacement, the range was from 1.3-9.3 mm, with an average of 3.88 mm. The maximum medial displacement in the thoracic vertebrae was found to be 6.6 mm in 12th thoracic vertebra. And the maximum lateral displacement was found to be 9.3 mm in the 7th thoracic vertebra. (Fig.7 and 8).

Fig. 7: Maximum medial misplacement.

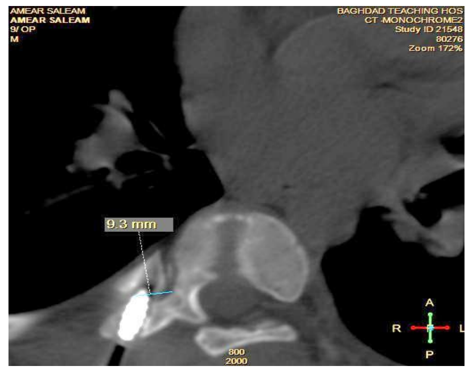

Fig. 8: Maximum lateral misplacement.

On the concave side:

Well placed screws were 121 from 250 (48.40%), Grade 1 MP 40 (16%), Grade 2 MP 31 (12.40%), Grade 1LP (screw anchors in the vertebral body) 19 (7.60%), Grade 1 LP (Screw passes within the vertebral body and abuts its inner cortex) 12 (4.80%), Grade 2 LP (Screw abuts outer cortex of the vertebral body and does not anchor in the vertebral body) 13 (5.20%), Grade 2 LP (Screw passes through the PRU and does not anchor in the vertebral body) 1 (0.40%), Grade 2 LP (Screw with paravertebral passage) 0 (0%), Anterior penetration 9 (3.60%), FP (perforation of the underlying foramen 3 (1.20%), EPP (perforation of upper end plate 1 (0.40%).(Table2).

Table 2: The concave side

Class	No.	Percent
A	121	48.40%
B	40	16.00%
C	31	12.40%
D	19	7.60%
E	12	4.80%
F	13	5.20%
G	1	0.40%
H	0	0
I	9	3.60%
J	0	0
K	3	1.20%
L	1	0.40%
Total	250	100.00%

A: well placed screw. B,C: medially placed screw. D,E,F,G, H: laterally placed screws. I: anterior perforation. J: normally placed screw on sagittal plane. K: perforation of underlying neural foramen. L: perforation of upper end plate.

On the convex side:
Normally placed screws were 141 from 250 (56%), Grade 1 MP 22 (9%), Grade 2 MP 15 (6%), Grade 1LP (screw anchors in the vertebral body) 25 (10%), Grade 1 LP (Screw passes within the vertebral body and abuts its inner cortex) 16 (6%), Grade 2 LP (Screw abuts outer cortex of the vertebral body and does not anchor in the vertebral body) 19 (8%), Grade 2 LP (Screw passes through the PRU and does not anchor in the vertebral body) 3 (1%), Grade 2 LP (Screw with paravertebral passage) 0 (0%), Anterior penetration 7 (3%), FP (perforation of the underlying foramen 2 (1%), EPP (perforation of upper end plate 0 (0%) (Table 3).

Table 3: The convex side.

Class	No.	Percent
A	141	55.95%
B	24	9.52%
C	15	5.95%
D	25	9.92%
E	16	6.35%
F	19	7.54%
G	3	1.19%
H	0	0.00%
I	7	2.78%
J	0	0.00%
K	2	0.79%
L	0	0.00%
Total	252	100.00%

A: well placed screw. B,C: medially placed screw. D,E,F,G, H: laterally placed screws. I: anterior perforation. J: normally placed screw on sagittal plane. K: perforation of underlying neural foramen. L: perforation of upper end plate.

Table 4: Overall number of each class.

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Class	No. of Screws	Percent
A	262	52.19%
B	64	12.75%
C	46	9.16%
D	44	8.76%
E	28	5.58%
F	32	6.37%
G	4	0.80%
H	0	0.00%
I	16	3.19%
J	0	0.00%
K	5	1.00%
L	1	0.20%
Total	502	

A: well placed screw. B,C: medially placed screw. D,E,F,G, H: laterally placed screws. I: anterior perforation. J: normally placed screw on sagittal plane. K: perforation of underlying neural foramen. L: perforation of upper end plate.

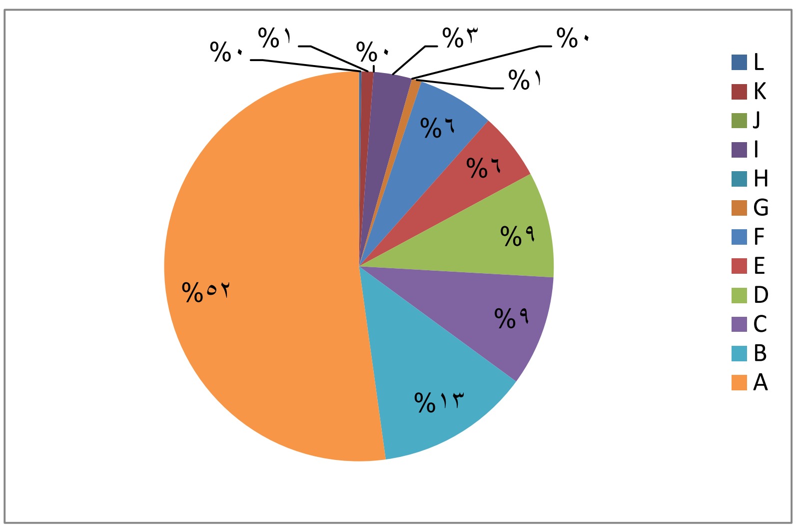

Fig. 9: Percent of screws according to Abdulkasim et al. grades. A: well placed screw. B,C: medially placed screw. D,E,F,G, H: laterally placed screws. I: anterior perforation. J: normally placed screw on sagittal plane. K: perforation of underlying neural foramen. L: perforation of upper end plate.

In our study, no complication was detected clinically in all of the patients. During CT Scan examination the structures which were found to be at risk from the misplaced screws are shown in Table 5.

Table 5: Relation of the malpositioned screws to the surrounding structures. (* indicates screw inside the pleural cavity).

Structure	Level	Side	Distance
Aorta	T8	Concave	5.6 mm
	T9	Concave	1.8 mm
	T10	Concave	5.6 mm
	T10	Concave	6.2 mm
	T11	Concave	6.0 mm
Trachea	T2	Concave	1.8 mm
	T2	Convex	1.3 mm
	T3	Convex	2.2 mm
	T4	Concave	1.5 mm
	T4	Concave	1 mm
	T4	Convex	3 mm
Pleural cavity*	T3	Concave	1.5 mm
	T3	Concave	2.5 mm
	T4	Concave	1 mm
	T5	Convex	1.5 mm
	T10	Convex	2 mm
Esophagus	T2	Concave	3.2 mm
	T2	Concave	4.3 mm
	T3	Concave	3.5 mm
Left Bronchus	T5	Concave	4.3 mm
Liver	T11	Convex	2 mm

Fig. 10

Fig. 11

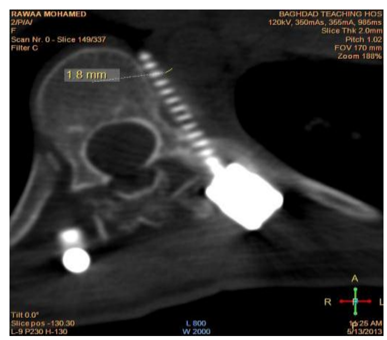

Fig.12

Fig 10: Screw 5.6mm close to aorta
Fig 11: Screw 1.3mm close to trachea
Fig 12: Screw 1.8mm to aorta.

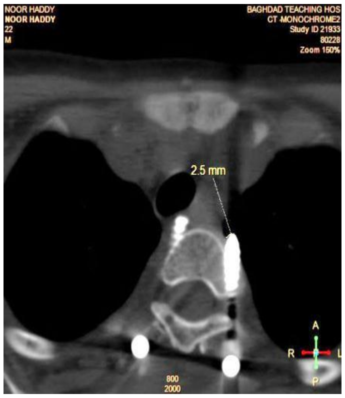

Fig. 13

Fig.14

Fig. 15

Fig. 13: 2.5mm inside pleural cavity
Fig.14: A screw found to be well placed in axial view.
Fig. 15: Sagittal view in the same patient in Fig.16. Two screws were found to penetrate the end plates.

DISCUSSION:

The use of thoracic pedicle screw for spinal deformity correction has become a common method of instrumentation in the developed countries , as it provides a stronger biomechanical anchoring strength compared to the hook and wire construct. However, the concern of potentially life threatening complications resulting from thoracic pedicle screw fixation has yet limited its widespread use in the developing countries because of the low learning curve and lack of the doctors' protection laws. Recent studies have brought more light to this issue and showed that the complication rate of posterior instrumentations using pedicle screws is not higher than that of other instrumentations, such as Luque's, hooks or hybrids, in the treatment of thoracic spinal deformity.[35]

On the other hand, misplaced screws diminish the pull-out strength of implants and increase the chance of implant failure. In order to improve the accuracy of the thoracic pedicle screws various insertion techniques like the freehand technique, fluoroscopy and computer-assisted surgery(navigation),[36-38], motor and somatosensory evoked potential monitoring have been described.[4-11]

Image-guided techniques are expensive and time consuming. We have used the freehand pedicle screw insertion technique as it is simple, cheap, less time consuming and exhibits similar accuracy in experienced hands as compared to image guided techniques[4,11]. The freehand technique relies on an accurate entry point, correct screw trajectories in transverse and sagittal planes and palpation of all walls of thoracic pedicles during each step of insertion taking into consideration the disturbed anatomy in spinal deformity.

A well placed screw is defined as a screw that is completely contained within the pedicle with its axis parallel to the longitudinal axis of the pedicle both in sagittal and axial planes. We reviewed the grading systems used for the assessment of malpositioned screws and we have found that the grading system of Abdul kasim et al is superior to other systems, as it is more comprehensive anatomically and it includes both axial and sagittal position unlike the other systems that only include the axial one (Fig. 14 and 15). Other grading systems divided the misplaced screws into four grades: grade 1 (<=2.0 mm), grade 2 (2.1–4.0 mm), grade 3 (4.1–6.0 mm) and grade 4 (6.1–8.0 mm) displacement. [32,36,39]They considered those screws as within the safe zone which were within the pedicle, grade 1 (<=2.0 mm) on the medial aspect or grade 1–2(<=4 mm) on the lateral aspect, while the rest of the screws were considered as potentially at risk. . Gertzbein and Robbins[32] in their study of 71 thoracic screws between T8 and T12 had a 26% incidence of medial cortical penetration of up to 8 mm with only two minor neurological injuries. They postulated a 4-mm safe zone for medial encroachment. Lateral wall penetration or lateral extrapedicular screw placement of up to 6 mm was also considered acceptable, especially in the upper and middle thoracic spine where pedicle diameters typically measure only 4–5 mm.

In our study, we found that 82 screws out of 110 (74.5%) of the medially misplaced screws were more than 2 mm, (maximum 6.6 mm). And 31 screws out of 130 (23.9%) of the laterally misplaced screws were more than 4 mm (maximum 9.3 mm) without any significant neurological or visceral complications which increases the safety zone more than what was written in the literature.

Most of the studies have shown the rates of misplacement to be (28 - 43%) and only few studies have shown rates less than 5% [39]. In our study, the rate was 47.81% which is consistent with these studies.

Various post-operative investigations like radiogram, CT scan or magnetic resonance imaging (MRI) have been described to measure the accuracy of pedicle screw placement and CT scans have been found to be more reliable than radiograms [39]. Low dose Computed tomography (CT) is the best method of performing such an assessment and in one study showed ten times as many pedicle violations as did plain radiography [40]. Furthermore, the radiation dose of plain radiography of spine varies in different reports and in some studies is reported to be as high as 26 mSv [41]compared with 0.37 mSv for the low-dose spine CT in that study[42]. Beside the higher diagnostic accuracy, patients undergoing low dose CT of spine carry at least 70 times lower risk of developing lethal cancer than those examined with plain radiography[39]. Hence we have analyzed our study with post-operative low dose CT scans. Although, there are few studies concerning the evaluation of screw position after pedicle instrumentation in deformed spine by free hand technique using low dose CT scan. [36,43-44].

CONCLUSION AND RECOMMENDATION:

Pedicle screw fixation with the freehand technique augmented with motor and somatosensory monitoring in the thoracic spine appears to be a safe and reliable method, showing acceptable accuracy for the treatment of scoliosis and it should be considered by surgeons during thoracic pedicle screw instrumentation. Also there is a wider zone of safety for the medially and laterally misplaced screws compared with other literature; and that postoperative low dose CT scan is effective, reliable and safer than other imaging techniques including conventional radiography in detecting malpositioned screws.

As we have a lot of neglected scoliotic patients that need effective surgical intervention, and because of the emergence of scoliosis surgery in Iraq recently with lack of the doctors' protection laws and the low learning curve which needs time, effort, and a well-planned training programs, we recommend to have special regulations to protect the doctors who are willing to initiate and push forward this work in Iraq.

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