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Comparison of accuracy of conventional and navigation pedicle screws in spine surgery

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Abstract
Introduction: Use of pedicle screw (PS) systems for spinal stabilization has become increasingly common in spine surgery. The technique and principle for pedicle screw instrumentation as well as anatomical landmarks of screw placement, however are common to all systems. The purpose of this study is to compare accuracy of pedicle screw placement with conventional and navigation techniques.
Aim: To compare the accuracy of pedicle screw positioning between conventional and a new navigation system for the spine.
Materials and Methods: It was a retrospective study in which 40 patients were randomly selected during the period between Jun-2014 to Jun-2016, operated for posterior fixation either through conventional and navigational spine surgery. Two independent observers analysed digital axial CT slices of all instrumented pedicles, with individual and consensus interpretation for each screw. A simple grading system (LAINE's grading) was devised for evaluation of screw position.
Results and Discussion: Overall accuracy of navigation technique is 95.89% (140/146) with 6 PS breach with laine's grade 1 error all occurs in thoracic level, doesn't results into any type of complications in manner of neurologic deficit or CSF leakage or dural tear etc. Overall accuracy of conventional PS placement is 89.84% (113/128) with 4 PS having grade 2 error and 11 PS having grade 3 error mainly occurs in thoracic level but none causes complication in any form i.e.; neurologic deficit, CSF leak, revision surgery etc.
Conclusion: From our study, despite of high cost, preoperative registration and matching, more steep learning curve, needful of technician throught surgery, navigation surgery is better option in thoracic PS placement and spinal deformities due to complex morphology and anatomy of thoracic pedicles with rib cage obscuring fluoroscopic visualization making conventional surgery difficult with high rate of pedicle breach.

Keywords: Navigation pedicle screws, spine surgery, instrumented pedicles

Introduction
Use of pedicle screw (PS) systems for spinal stabilization has become increasingly common in spine surgery. The technique and principle for pedicle screw instrumentation as well as anatomical landmarks of screw placement, however are common to all systems.
The history of vertebral screw fixation dates back to 1944. King [1] first described the placement of screws (three-quarters of an inch for women; one inch for men) parallel to the inferior border of the lamina and perpendicular to the facet joints of lumbar vertebrae in an attempt to avoid postoperative external immobilization and prolonged bed rest. 2627 However, patients were encouraged to stay in bed for three weeks following surgery. A pseudarthrosis rate of approximately 10% was reported in patients fixed with screws and grafted from L5-S1. One (2.3%) patient experienced "nerve-root irritation" as a result of a poorly positioned screw which was subsequently removed.
Pedicle screws are currently placed in the thoracolumbar spine via three main techniques: free hand technique, fluoroscopy guidance, and stereotactic navigation. The correct position of the screws ensures good pullout strength in the bone, and good control of rotation and possibility of repositioning the respective vertebral body. The precondition for this is the correct position of the pedicle screws. From a biomechanical point of view, the PS should ideally be placed along the pedicle axis. The stability of the PS in the bone is determined by a greater screw diameter and insertion depth. In addition to the biomechanical aspect of stability, the ideal position also ensures optimal protection of adjacent structures [2].

Faulty positioning can lead to injury in the chest and abdominal region. typical clinical manifestation of this radiculopathies, neuropathies, and epidura hematomas. A faulty position also poses an increased risk of instability. So utmost accuracy in positioning the screws is important.

FREE-HAND technique [3] of pedicle screw placement based on anatomical landmarks and intraoperative, fluoroscopic-guided placement. The disadvantage of the intraoperative fluoroscopic free hand technique is the higher rate of faulty placements and increased radiation dose to patient and surgeon. Intraoperative fluoroscopy has the benefit of increased visualization of pedicle's trajectories, but can result in increased morbidity associated with radiation exposure and possible workflow interruption.

In patients with severe scoliosis having altered morphology of vertebrae poses challenge in screw placement due to altered trajectory of non-anatomic pedicles and also in midthoracic level pedicle screw placement posses challenge due to their inherent anatomical characteristics which is characterized by narrow pedicles. Usage of PS at the T4-T9 vertebral levels has an increased risk of injury to both the cord and the aorta [4].

Both morbidity rate and revision rates are higher in free hand technique. Screw revision can be difficult and time consuming, as the faulty screw track often hinders effective screw repositioning [5].

When considering screw revision time and possible decrease in biomechanical stability,

NAVIGATION – guided [6] pedicle screw placement is helpful. Pedicles of vertebrae within the mid-thoracic spine and vertebrae that have altered morphology due to scoliosis or other deformities are the most difficult to cannulate, so navigation guided screw placement have more benefit when cannulating midthoracic vertebral levels and vertebrae that have altered morphology due to deformation from complex pathologies.

The purpose of this study is to compare accuracy of pedicle screw placement with conventional and navigation techniques. The primary end point of study is pedicle perforation, while the secondary end points are operative time, blood loss, and complications. The most common indications for surgery are degenerative disease, spinal deformities, myelopathy, tumour, tuberculous spine and trauma.

Aim

The aim of this study was to compare the accuracy of pedicle screw positioning between conventional and a new navigation system for the spine.

Materials and Methods

It was a retrospective study in which 40 patients were randomly selected during the period between Jun-2014 to Jun-2016, operated for posterior fixation either through conventional and navigational spine surgery at B.J Medical college, Ahmedabad done by expert surgeons. 40 adult patients of dorsal and lumbar spine (T1-S1) requiring pedicle screw fixation operated between June 2014 to Jun-2017 were included in the study. Patients with multilevel fractures and those with preexisting distorted spine anatomy were excluded from the study. History and clinical examination was recorded in all patients. Besides the routine blood investigations and plain radiographs of involved spine, a CT scan was done with specialized protocol. A written and informed consent was taken from all patients explaining them the procedure as well as CT scan protocol and its hazards. The CT scan included the region of two vertebrae above and below the fractured vertebrae having 1 mm consecutive cuts with 150° field of view, nonoverlapping and contiguous with a recorded computer disc (CD). Such protocol did not expose patients to any extra radiation as CT scanning is now considered essential for assessment of vertebral fractures. This CD was then fed to the navigation computer which provided preoperative complete projections of the spine in different planes and three dimensional reconstruction. The pedicle morphology including diameter, inclination and configuration was studied as part of preoperative planning. The points of entry of the pedicle screws, screw size and their trajectory were identified in different projections of the spine.

Registration and matching

The process of registration started with marking 10 most accessible bony landmarks on the computer generated image which would later be matched on to the patient's exposed spine which is single time multilevel registration.

The electrooptical camera was placed at caudal end of the operation room table, at a distance of 1.5 meter from the foot end of the patient to be operated. The optoelectronic camera system would send infra red rays, which were reflected back by infra red reflecting gleons attached to the various instruments. The reflected infra red rays would be picked up by the computer workstation to show the coordinates of the various instruments inside the patient's body.

Under general anesthesia, the patient was positioned prone and the level of the vertebra confirmed with a metallic marker using a fluoroscope. A posterior midline incision was used to expose the spine. The paraspinal muscles were elevated till the tip of the transverse processes of the vertebrae to be operated, on both sides of the midline. After exposure dynamic reference base was firmly fixed to the spinous process. A probe with gleons was sequentially placed to the selected points on the posterior surface of the vertebrae (already marked on the computer generated CT image in the initial part of the registration process). The computer workstation verifies the accuracy of paired point matching and displays the area of the spine in real time that can be safely navigated with an accuracy of 1 mm. This completed the process of registration and matching [7].

Inclusion criteria

All pathologies requiring pedicle screw placement for fixation are included in this study fulfilling following criterias:9-65 year age group, thoracolumbar level of injury with instability, T.B. spine, tumour, spinal deformities

Exclusion criteria: Patients falling in the following exclusion criteria were excluded from the study: Revision surgery, recent infections, laminectomies that will not cause instability, fusion which are normally successful without fixation, thoracolumbar level of injury with instability with pre- existing deformities, severe osteoporotic spine

Pre-Op Evaluation

Patients were evaluated clinically for their symptoms which mostly included Backache and detailed neurological assessment was done.Radiological investigations were done in the form ofX-ray cervical spine AP/lateral Dorsal Lumber spine AP/Ltaeral Lumber spine AP/Lateral. Corresponding MRI with whole spine screening, CT SCAN with AXIAL and CORONAL CUTS: The CT scan included the region of two

vertebrae above and below the fractured vertebrae having 1 mm consecutive cuts with 150° field of view, non-overlapping and contiguous with a recorded computer disc (CD). Routine blood investigations in the form of CBC/RFT/HIV/HBsAg were done. Methylprednisolone was given to reduce cord edema for three days approximately 1 gm in 500ml NS over 24hr. 2nd generation cephalosporins were administered intravenously, one night before and 1 hour before operation.

Intraoperative assistance

The pedicle screw entry point was localized and decided. The screw track was then made with pedicle seeker and other instruments whose location could be tracked on a computer workstation monitor in real time. A screw of accurate length, as measured preoperatively and confirmed by intraoperative intervention was inserted. The time required for registration and matching and the time taken for actual insertion of each screw was noted down. In a similar fashion, all the screws were inserted, and the final assembly constructed. In 12 patients with paraparesis and one patient with paraplegia, laminectomy at the level of cord injury was performed as the decompressive procedure coupled with mild distraction to restore vertebral body height. While, in other 12 patients with complete paraplegia only distraction was done as magnetic resonance imaging showed complete cord transection. In patients with intact neurology, only distraction was done following instrumentation.

Post-operatively

Patients were given IV antibiotics for 24-48 hours. Physiotherapy in the form of Back Extension Exercises, pelvic floor raising were taught. Single stitch line dressing was done on POD-1 and patients were given discharge on POD-2/3. Stitch removal was done 14 days after surgery. Post operatively CT SCAN with AXIAL and CORONAL cuts with 1mm slice thickness was noted on POD-1.

Postoperative evaluation

In the immediate postoperative period, CT scan of the operated spine was done showing position of the screws in all three planes. The position of each screw was studied to determine any breach in the walls of pedicle. The screw position was then graded as per the staging suggested by Laine *et al*.

Evaluation of Screw Position

Two independent observers analysed digital axial CT slices of all instrumented pedicles, with individual and consensus interpretation for each screw. A simple grading system (LAINE's grading) was devised for evaluation of screw position [8].

Pedicle Breach Classification

Laine's grading of screw violation

Grade 0	Screw inside the pedicle (good screws)
Grade 1	Screw cortex perforation up to 2 mm
Grade 2	Screw cortex perforation from 2.1 mm to 4.0 mm
Grade 3	Screw cortex perforation from 4.1 mm to 6.0 mm
Grade 4	Screw outside the pedicle

Observation and Results

Sex-Wise Distribution

In our study out of 40 patients, 30 were males and 10 were females.

Sex of Patient	Number of Patients(C/N)	% of Patients
MALE	25(13/12)	62.5%
FEMALE	15(7/8)	37.5%
TOTAL	40 (20/20)	100%

Age-Wise Distribution

Out of 40 patients, 10 belonged to 9- 20 years age group, 18 patients were between 21 and 40 years of age and 12 patients were 41-65 years.

Indication

Pathology	No. of patients (c/n)
Degenerative	13(7/6)
Spinal deformity	7(2/5)
Traumatic	10(6/4)
Infection	9(6/4)
Metastatic	1(0/1)

Average blood loss during surgery

Average blood loss during Conventional was 300 ml and during Navigation was 350 ml.

Surgery	Average blood loss (ml)
Conventional	300
Navigation	350

Duration of surgery

Average duration of surgery of conventional has 120 minutes while that of Navigation patients was 134 minutes

Surgery	Duration(min)
Conventional	120 min
Navigation	134 min

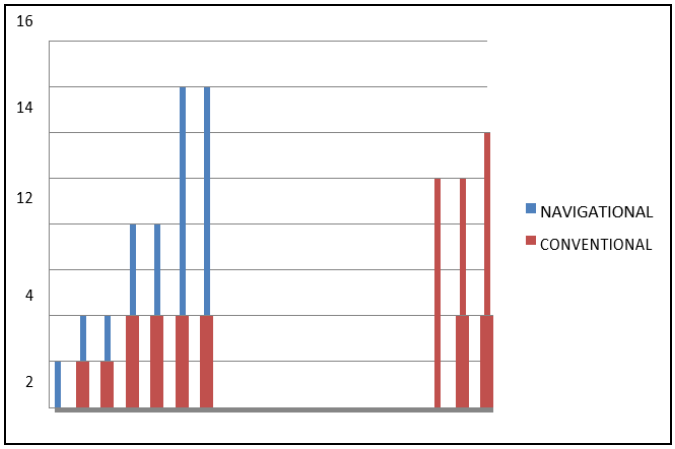
Duration of hospitalization

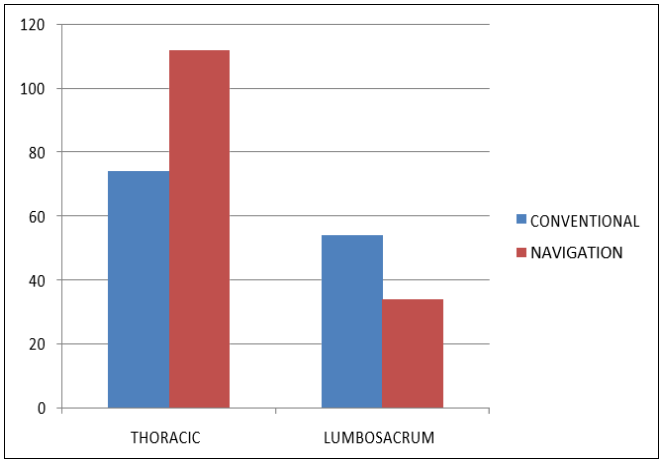
As per our standard protocol, patients were admitted approximately 2 days prior to the operation and discharged within 3 to 5 days after operation depending upon the operative technique. All the patients were discharged within 2 days of surgery in Navigation technique but in Conventional Procedure it takes around 4 days.

Method	Days
Navigation	2 Days
conventional	4 Days

There is no significant difference in conventional and navigation PS placement surgery in regard to total blood loss during surgery, duration of surgery and duration of hospitalization.

Number of Pedicle Placement at Each Vertebral Level





Level of PS placement

	Thoracic	Lumbosacral	Total
Conventional	74	54	128
Navigation	112	34	146

In this study, total 128 PS inserted by conventional surgery from T1 to S1 Vertebre from which 74 in thoracic level and 54 in lumbosacrum level. From total 146 PS placement in navigation surgery, 112 PS placed in thoracic vertebrae and 34 PS in lumbosacrum vertebrae.

More PS placement in thoracic under navigation surgery taken as compared to convention due to more complex anatomy of thoracic pedicles than lumbosacral pedicles.

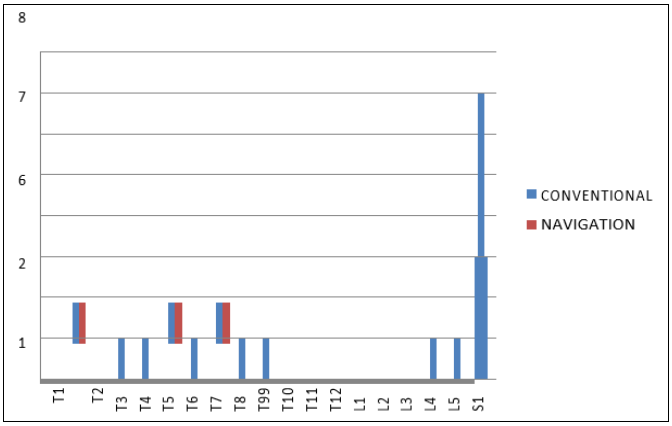
Medial and lateral screw errors at pedicle level and length errors.

	Medial errors by categories								Lateral errors by categories								Total screws	
Errors	**Good screw**		**0.1-2.0mm**		**2.1-4.0mm**		**4.1 or more**		**Good screw**		**0.1-2.0mm**		**2.1-4.0mm**		**4.1 or more**			
	N	**C**	**N**	**C**	**N**	**C**	**N0**	**C**	**N**	**C**	**N**	**C**	**N**	**C**	**N**	**C**	N	C
T1	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0
T2	3	2	1	0	0	0	0	1	4	2	0	0	0	0	0	0	4	2
T3	4	2	0	0	0	0	0	0	4	2	0	0	0	0	0	0	4	2
T4	8	4	0	0	0	0	0	0	8	4	0	0	0	0	0	0	8	4
T5	8	4	0	0	0	0	0	0	8	4	0	0	0	0	0	0	8	4
T6	13	4	1	0	0	0	0	0	14	4	0	0	0	0	0	0	14	4
T7	14	4	0	0	0	0	0	0	14	4	0	0	0	0	0	0	14	4
T8	11	7	1	0	0	1	0	0	12	8	0	0	0	0	0	0	12	8
T9	12	11	0	0	0	1	0	0	12	12	0	0	0	0	0	0	12	12
T10	12	11	0	0	0	1	0	0	12	12	0	0	0	0	0	0	12	12
T11	12	12	0	0	0	0	0	0	12	12	0	0	0	0	0	0	12	12
T12	10	10	0	0	0	0	0	0	10	10	0	0	0	0	0	0	10	10
L1	10	10	0	0	0	0	0	0	10	10	0	0	0	0	0	0	10	10
L2	6	6	0	0	0	0	0	0	6	6	0	0	0	0	0	0	6	6
L3	6	6	0	0	0	0	0	0	6	6	0	0	0	0	0	0	6	6
L4	4	10	0	0	0	0	0	0	4	10	0	0	0	0	0	0	4	10
L5	4	10	0	0	0	1	0	0	4	10	0	0	0	0	0	0	4	10
S1	4	12	0	0	0	0	0	1	4	12	0	0	0	0	0	0	4	12
Total	143	122	3	0	0	4	0	2	146	128	0	0	0	0	0	0	146	128

Superior and Inferior errors at pedicle level

	Superior errors by								Inferior errors by								Total	
	Good screw		**0.1-2.0mm**		**2.1-4.0mm**		**4.1 or more**		**Good screw**		**0.1-2.0mm**		**2.1-4.0mm**		**4.1 or more**			
	N	C	N	C	N	C	N	C	N	C	N	C	N	C	N	C	N	C
T1	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0
T2	3	2	1	0	0	0	0	0	4	1	0	0	0	1	0	0	4	2
T3	4	2	0	0	0	0	0	0	4	1	0	0	0	1	0	0	4	2
T4	8	4	0	0	0	0	0	0	8	3	0	0	0	0	0	1	8	4
T5	8	2	0	0	0	1	0	1	8	4	0	0	0	0	0	0	8	4
T6	13	2	1	0	0	1	0	1	13	4	1	0	0	0	0	0	14	4
T7	13	4	1	0	0	0	0	0	14	4	0	0	0	0	0	0	14	4
T8	11	7	1	0	0	0	0	1	12	8	0	0	0	0	0	0	12	8
T9	11	11	1	0	0	1	0	0	12	12	0	0	0	0	0	0	12	12
T10	12	11	0	0	0	1	0	0	12	12	0	0	0	0	0	0	12	12
T11	12	12	0	0	0	0	0	0	12	12	0	0	0	0	0	0	12	12
T12	10	9	0	0	0	0	0	1	10	10	0	0	0	0	0	0	10	10
L1	10	10	0	0	0	0	0	0	10	10	0	0	0	0	0	0	10	10
L2	6	6	0	0	0	0	0	0	6	6	0	0	0	0	0	0	6	6
L3	6	6	0	0	0	0	0	0	6	5	0	0	0	1	0	0	6	6
L4	4	10	0	0	0	0	0	0	4	9	0	0	0	0	0	1	4	10
L5	4	8	0	0	0	0	0	2	4	10	0	0	0	0	0	0	4	10
S1	4	10	0	0	0	0	0	2	4	12	0	0	0	0	0	0	4	12
Total	141	116	5	0	0	4	0	8	145	123	1	0	0	3	0	2	146	128

Medial Error



Medial PS accuracy and breach rate

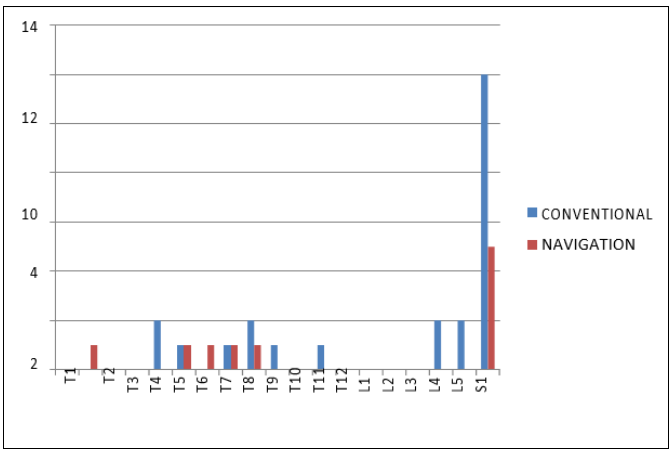
	Accuracy rate	Breach rate
Conventional	94.53% (121/128)	5.47% (7/128)
Navigation	97.94% (143/146)	2.05% (3/146)

Lateral PS accuracy and breach rate

	Accuracy rate	Breach rate
Conventional	100% (128/128)	0% (0/128)
Navigation	100%(146/146)	0% (0/146)

In conventional surgery, there is 94.53% (121 /128) accuracy in medial aspect of pedicle with grade 2 error in 4 PS and grade 3 error in 2 PS compared 97.89% (143/146) accuracy in navigation surgery with all 6 PS have grade 1 pedicle breach without any complication and there is 100% accuracy in both conventional and navigation suergery in lateral aspect of pedicle.

Superior PS breach

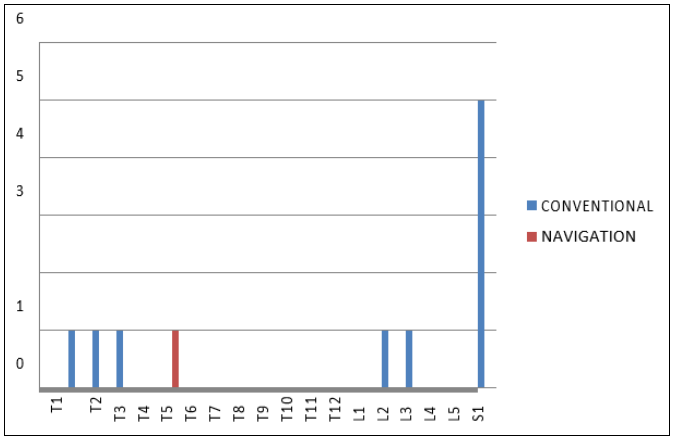


Superior PS accuracy and breach rate

	Accuracy rate	Breach rate
Conventional	90.64%(116/128)	9.36%(12/128)
Navigation	96.57%(141/146)	3.42%(5/146)

In conventional technique, 94.64% (116/128) accuracy in superior aspect of pedicle with grade 2 error in 4 PS and grade 3 error in 8 PS compared to 96.57% (141/146) accuracy of navigation surgery with all 5 PS have grade 1 error without any complication.

Inferior PS breach



Inferior PS accuracy and breach rate

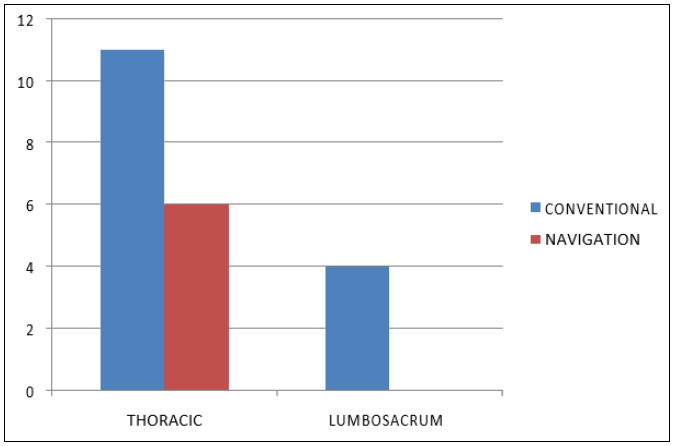
	Accuracy rate	Breach rate
Conventional	94.09% (123/128)	3.91% (5/128)
Navigation	99.39% (145/146)	0.61%(1/146)

In conventional technique, 94.09% (123/128) accuaracy in inferior aspect of pedicle with grade 2 error in 3 PS and grade 3 error in 2 PS compared to 99.39% (145/146) accuracy with only 1 PS error of grade 1 in navigation surgery.

Pedicle level breach

	Thoracic	Lumbosacral	total	% breach
Conventional (128)	11 (8.59%)	4 (3.13%)	15	11.72%
Navigation (146)	6 (4.11%)	0	6	4.11%

Out of total 15 PS placement error out of 128 PS (11.71%) in conventional surgery breach mainly occurs in thoracic vertebrae, 11 PS breach from total 15 PS breach (73.33%).In navigation technique, all 6 PS breach occurs at thoracic level.



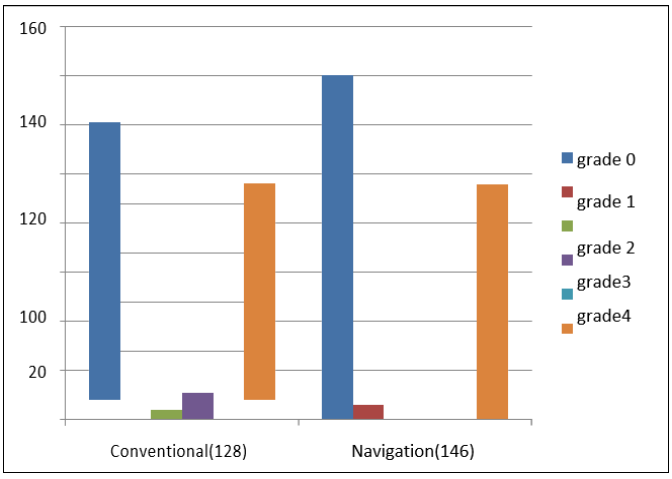
LAINE'S Grade of PS breach

Grade		Grade 1	Grade 2	Grade 3	Grade 4
Technique	Direction of PS breach	(upto 2mm)	(2.1 to 4.0mm)	(4.1 to 6.0 mm)	(more than 6.1mm)
Conventional	Superior	0	4	8	0
	Inferior	0	3	2	0
	Medial	0	2	4	0
	Lateral	0	0	0	0
Navigation	Superior	5	0	0	0
	Inferior	1	0	0	0
	Medial	3	0	0	0
	Lateral	0	0	0	0

Laine's Grading of PS Error

Laine's Grade	Conventional(128)	Navigational (146)
Grade 0(good screws)	123	140
GRADE 1	0	6
GRADE 2	4	0
GRADE 3	11	0
GRADE 4	0	0
Accuracy Rate *	88.28%	95.89%

Accuracy rate = good screws/total screws*100



Overall accuracy of navigation technique is 95.89% (140/146) with 6 PS breach with laine's grade 1 error all occurs in thoracic level, doesn't results into any type of complications in manner of neurologic deficit or CSF leakage or dural tear etc.

Overall accuracy of conventional PS placement is 89.84% (113/128) with 4 PS having grade 2 error and 11 PS having grade 3 error mainly occurs in thoracic level but none causes complication in any form i.e.; neurologic deficit, CSF leak,revision surgery etc.

Discussion

In this study, we included total 40 patients of different pathologies (degenerative, spinal deformity. Traumatic, infections etc) requiring fixation by pedicle screw placement either through conventional or navigational method depending on level of accuracy. Out of total 40, 15 patients are female mainly with degenerative, infections and spinal deformity and rest were male patients with traumatic, degenerative and deformity etc pathologies. Females having excessive lumbar lordosis to adopt centre of gravity over posterior aspect during pregnancy, small facets favours accelerated degenerative changes and relatively less horizontal and vertical diameter of pedicles than males makes difficult task for PS placement.

In this study, we divided 40 patients in 3 age groups i.e. 9-20 years, 21-40 years and 40-65 years with 10, 18 and 12 patients respectively in each groups. Both horizontal and vertical pedicle diameter increase as age increase so PS placement is difficult in younger patients. Navigation surgery requires preoperative preparation of surgery with preoperative CT scan with registration and matching, requires high cost navigation machine, more steep learning curve, needful of technician before and during surgery and altered trajectory of pedicle insertion due to breathing etc are limitations for its routine use.

Both navigation and conventional surgeries takes almost similar time duration after incision, thus blood loss and duration of hospitalization is also almost of same in both surgery with mild differences. Anatomy of thoracic pedicles is more complex than lumbosacrum as thoracic vertebra overcrowding of ribs, small vertebra with smaller pedicle dimensions makes difficult task of PS placement in thoracic vertebra than lumbosacrum. So conventional techniques having high chance of pedicle breach in thoracic level.

Majority of pedicle errors occurs in thoracic level, more specifically in mid-thoracic level (T4-T9) in both conventional and navigational method. Respiratory movements of rib cage may alter the normal trajectory of PS placement and results into misplacement. In conventional surgery there is grade 2 and grade 3 error mostly in thoracic level (11/74) and some are in lumbosacrum level (4/54) with but Out of total 15 PS placement error out of 128 PS (11.71%) in conventional surgery breach mainly occurs in thoracic vertebrae, 11 PS breach from total 15 PS breach (73.33%).In navigation technique, all 6 PS breach occurs at thoracic level. Overall accuracy of navigation technique is 95.89% (140/146) with 6 PS breach with laine's grade 1 error doesn't results into any type of complications in manner of neurologic deficit or CSF leakage or dural tear etc.

Overall accuracy off conventional PS placement is 89.84% (113/128) with 4 PS having grade 2 error and 11 PS having grade 3 error but none causes complication in any form i.e.; neurologic deficit, CSF leak, revision surgery, dural tear etc. PS placement is more at thoracic level in both conventional and navigation technique but more accuracy from navigation technique. No revision surgery indicated in these errors. Indication for most of the thoracic PS placement under navigation are spinal deformity i.e. congenital kyphoscoliosis, sequele of koch's spine etc which totally disrupts the normal alignment of pedicles so for high accuracy and less pedicle breach, navigation method is most suitable.

Many similar studies have been carried out in the past and the results of those studies are comparable with our present study: Laine [9] randomized 91 consecutive patients having pediclescrew fixation, to assess 50 patients with anatomical landmarks and fluoroscopy and 41 patients with CT-based navigation. The pedicle perforation rate was 13.4% in the conventional group (4-6mm errors = 1.4%; medial) and 4.6% with CT-based navigation (4-6mm = 0%; lateral) (P = 0.006).

Amiot [10] compared a historical cohort of patients operated by anatomical landmarks with patients newly operated with navigation. The error rate was 15% for the historical control group) compared to 5% for the navigation group. Errors were quantified by MRI. They cautioned that MRI might overestimate errors compared to CT-Scan.

Assaker [11] compared lateral fluoroscopy to CT-based navigation and found respectively 2 medial and 1 lateral perforations. The author states that CT-based navigation is not absolutely necessary in lumbosacral spine but is very helpful in the thoracic and cervical spine.

Kosmopoulos [12] performed a Meta-analysis of pedicle screw placement accuracy. They reviewed 130 studies on 37,337 pedicle screws and found in the lumbar spine that 864 screws were inserted with navigation and 1674 screws inserted without navigation. A weighted accuracy of 92.1% was found for navigation and 87.3% without navigation for the lumbar spine.

Conclusion

From our study, despite of high cost, preoperative registration and matching, more steep learning curve, needful of technician throught surgery, navigation surgery is better option in thoracic PS placement and spinal deformities due to complex morphology and anatomy of thoracic pedicles with rib cage obscuring fluoroscopic visualization making conventional surgery difficult with high rate of pedicle breach. The limitations of this study include the relatively small number of patients (total 40 patients).

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