Original Article

Navigated pedicle screw placement using computed tomographic data in dorsolumbar fractures

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Abstract

Background: Computed tomographic (CT) based navigation is a technique to improve the accuracy of pedicle screw placement. It is believed to enhance accuracy of pedicle screw placement, potentially avoiding complications arising due to pedicle wall breach. This study aims to assess the results of dorsolumbar fractures operated by this technique.

Materials and Methods: Thirty consecutive skeletally mature patients of fractures of dorsolumbar spine (T9–L5) were subjected to an optoelectronic navigation system. All patients were thoroughly examined for neurological deficit. The criterion for instability were either a tricolumnar injury or presence of neurological deficit or both. Patients with multilevel fractures and distorted spine were excluded from study. Time taken for insertion of each pedicle screw was recorded and placement assessed with a postoperative CT scan using Laine's grading system.

Results: Only one screw out of a total of 118 screws was misplaced with a Laine's Grade 5 placement, showing a misplacement rate of 0.847%. Average time for matching was 7.8 min (range 5-12 min). Average time taken for insertion of a single screw was 4.19 min (range 2-8 min) and total time for all screws after exposure was 34.23 min (range 24-45 min) for a four screw construct. No neurovascular complications were seen in any of the patients postoperatively and in subsequent followup of 1-year duration.

Conclusion: CT-based navigation is effective in improving accuracy of pedicle screw placement in traumatic injuries of dorsolumbar spine (T9-L5), however additional cost of procuring CT scan to the patient and cost of equipment is of significant concern in developing countries. Reduced radiation exposure and lowered ergonomic constraints around the operation table are its additional benefits.

Key words: Dorso lumbar spine, Laine's grading, navigation, paired point matching
MeSH terms: Spine, spinal fractures, bone screws, neuronavigation, tomography

Introduction

Pedicle screw fixation is the current gold standard for internal fixation of lower thoracic and lumbar spine,[1] providing stable and adequate fixation for all the three columns of spine, as described by Denis through a comparatively easy posterior approach.[2] Indications for the pedicle screw fixation are numerous and varied – degenerative spondylolisthesis, scoliosis, disc disease, spinal stenosis, spondylolysis, tumors, infections and trauma including fractures and fracture dislocations.[3] For optimal results a pedicle screw has to be accurately placed in the pedicle without violating its confines. If a pedicle screw perforates the walls of the pedicle, the complications can be disastrous.[4] Medially, it may injure the cord tissue and inferiorly the nerve root. The length of the screw should also be accurate so as to reach the anterior border of the vertebrae, but should not pierce it, or else there can be damage to the vascular and visceral structures.[4] The technique of pedicle screw insertion is demanding and significant rate of screw malplacement resulting in reversible and irreversible neurovascular injuries has been reported. The reported incidence of malposition of pedicle screws using conventional technique varies from 14.3% to 42%.[5-9] Fluoroscopy has been a mainstay for accurate insertion of pedicle screws. Besides radiation hazard to the surgical team, it involves cumbersome time wasting maneuvers for repositioning as well as ergonomic constraints in access to the surgical field. However, due to variable dimensions, inclination and configuration of pedicle in individual vertebrae, even experienced surgeons are liable to make mistakes.[10,11] This has led to search for a device which can help in a more accurate and

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predictable pedicle screw insertion. In the past two to three decades, rapid paced advancements have taken place, enabling the emergence of computer assisted navigation for accurate pedicle screw fixation. The original idea was based on frameless stereotaxis used for brain surgery. By successfully and accurately matching the preoperative and intraoperative images with the intraoperative real image captured by electrooptical methods, the surgeon can retrace the exact trajectory of the pedicle screw.[12-14]

A number of studies have shown improved accuracy with computer-assisted navigation compared with the conventional technique.[12,15-21] A prospective study designed to assess the accuracy of computer-assisted computed tomographic (CT) based passive navigation in placement of pedicle screws was undertaken. It is the first study evaluating CT-based navigation that has been carried out in the Indian subcontinent, to the best of author's knowledge. The accuracy of pedicle screw placement using this technique was studied by postoperative CT scan using the Laine's grading system.[7]

Materials and Methods

30 adult patients of unstable fracture of lower dorsal and lumbar spine (T9-L5) requiring pedicle screw fixation operated between June 2008 and June 2010 were included in the study. Patients with multilevel fractures and those with preexisting distorted spine anatomy were excluded from the study. The criteria for instability were either a tricolumnar injury or presence of neurological deficit, or both together. 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.[22] 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 [Figure 1].

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 [Figure 2].

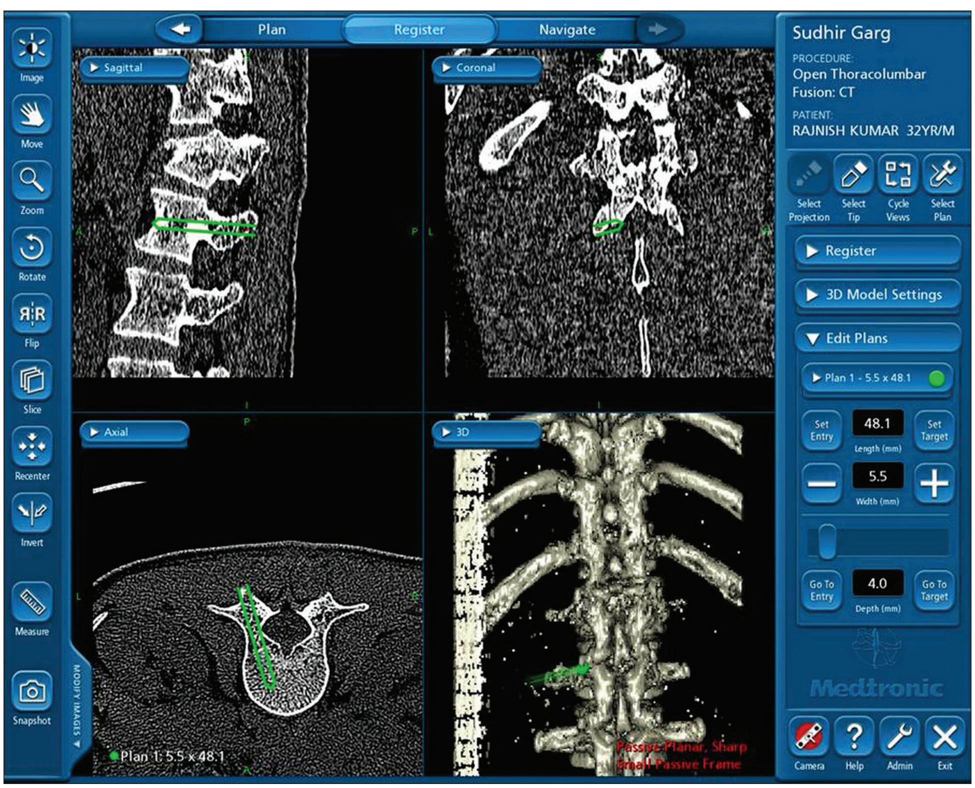


Figure 1: Preoperative planning of screw diameter and trajectory

The electrooptical camera was placed at caudal end of the operation room table, at a distance of 1.5 m 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 [Figure 3]. 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.

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 [Figure 4]. 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. In one case only two screws could be put instead of four because of inadvertent alteration in the position of dynamic reference base resulting in loss of contact with computer workstation.

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

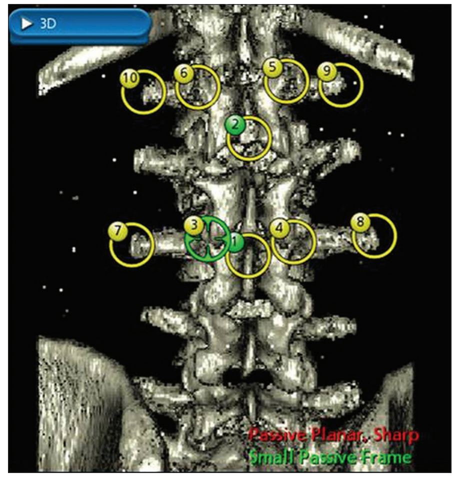


Figure 2: 3-D computer generated image showing single time multilevel registration

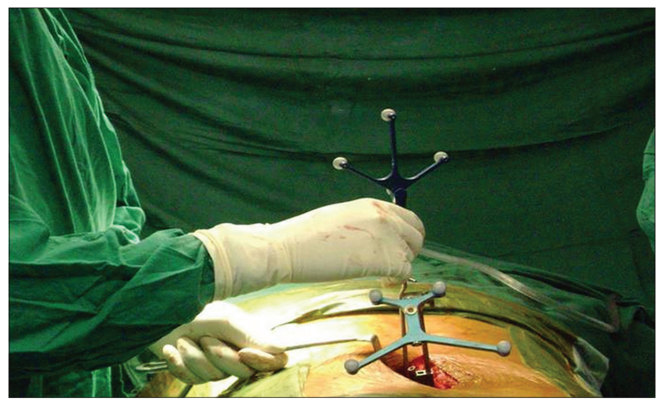


Figure 3: Peroperative clinical photograph showing dynamic reference base attached to the spinous process

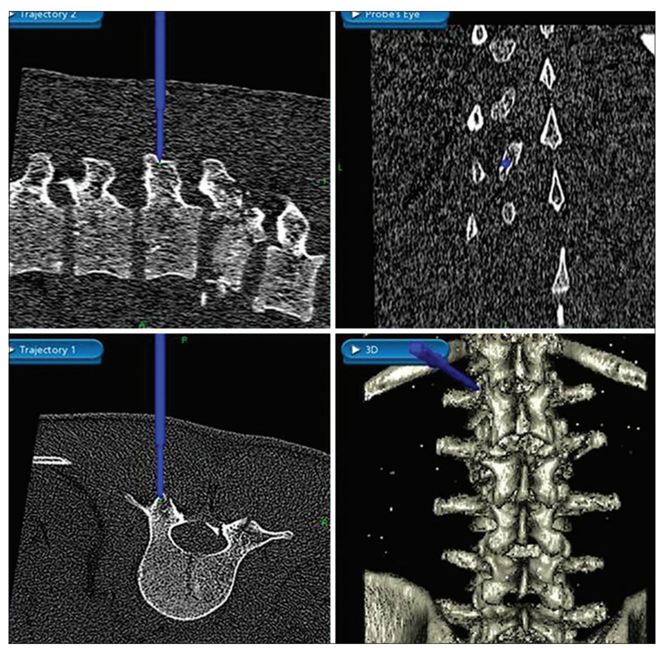


Figure 4: Instruments being tracked in real time on the monitor

determine any breach in the walls of pedicle [Figure 5]. The screw position was then graded as per the staging suggested by Laine *et al*. [Table 1].[7]

All operated patients were followed up regularly at 1, 3, 6, 12 months and were examined clinically and radiographically. The results were analyzed statistically for rate of screw misplacement, average time for matching and screw insertion.

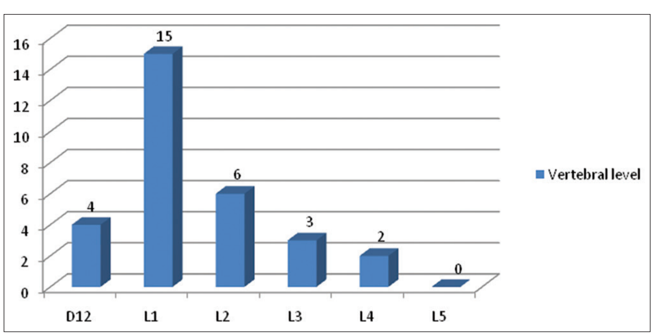
Results

Out of 30 patients included in the study, 22 patients were males and 8 were females. The mean age of patients was 34.53 years (range 17-60 years). Maximum number of patients had a fracture of L1 vertebra (*n* = 15), followed by L2 (*N* = 6), T12 (*n* = 4), L3 (*n* = 3) and L4 (*n* = 2) [Graph 1]. 17 patients had no neurological deficit, 12 had paraperesis and one had complete paraplegia.

Table 1: Laine's grading system

Grade 1	Screw inside the pedicle
Grade 2	Pedicle cortex perforation up to 2 mm
Grade 3	Pedicle cortex perforation from 2.1 to 4.0 mm
Grade 4	Pedicle cortex perforation from 4.0 to 6.0 mm
Grade 5	Screw outside the pedicle

Figure 5: Postoperative computed tomographic scan showing Laine's Grade 1 screw placement



Graph 1: Bar diagram showing vertebral level involvement

Out of 12 patients with paraparesis, one had Grade 4 power (assessed on MRC grading), six had Grade 3 power and five had Grade 2 power distal to the lesion. No improvement in neurological status was observed postoperatively and at subsequent followups. A total of 118 screws were placed in T11 (*n* = 8), T12 (*n* = 28), L1 (*n* = 20), L2 (*n* = 36), L3 (*n* = 16), L4 (*n* = 6) and L5 (*n* = 4) [Graph 2]. In one case, only two pedicle screws could be inserted with navigation as position of dynamic reference base was disturbed resulting in loss of contact with computer work station. Remaining two screws were inserted manually, which were excluded from the study.

There were concerns regarding the extra time that would be required for matching and registration, however as we shall see that this time is within manageable limits. The average time taken for matching was 7.8 min (range 5-12 min) whereas time taken for insertion of a single screw from marking the entry with an awl to complete insertion of the screw was 4.19 min (range 2-8 min). The average total time is taken for screw insertion was 34.23 min (range 24-45 min) after exposure for a four screw construct, which includes time for matching and actual screw insertion. Only one screw out of a total of 118 screws perforated the lateral wall of the right pedicle of L2 vertebra [Figure 6]

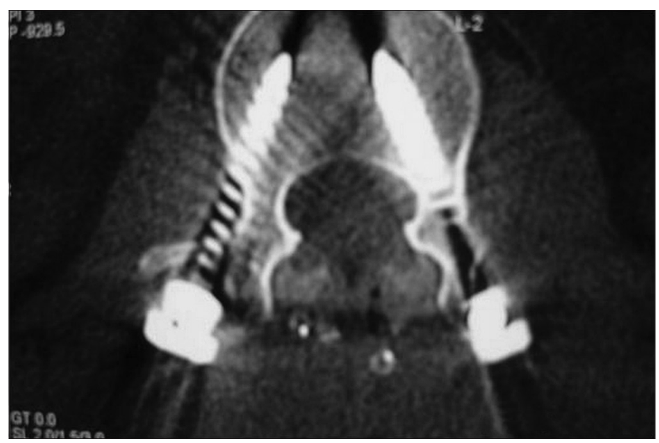
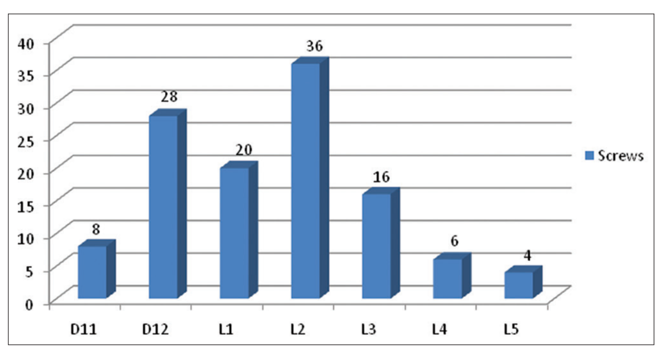


Figure 6: Postoperative computed tomographic scan showing Laine's Grade 5 screw placement



Graph 2: Bar diagram showing screws at different vertebral levels

with a Laine's Grade 5 showing a screw misplacement rate of 0.847% only. All other screws were inside the pedicles with Grade 1 placements. No improvement in neurological status was observed postoperatively and at subsequent followups.

Discussion

Computed tomographic based navigation has been extensively evaluated and its accuracy proven over conventional techniques in different studies.[7,12,15] Various other navigation techniques have been used to enhance accuracy of pedicle screw placement. These include Iso-C based navigation, fluoroscopy based navigation and ultrasound based navigation systems.[14,16-18,21-23] All have reported enhanced accuracy compared to the conventional technique. The reported mal position of pedicle screw with the assistance of conventional radiographic methods (plain radiographs, fluoroscopy) has been variously reported to be 14.3-42%.[5-9] Image guided surgery has also been proved to be effective in difficult C1-C2 transarticular screw fixation for accurate screw placement.[24] The current study evaluates the accuracy of pedicle screw placement using CT-based navigation in fractures of lower thoracic and lumbar spine. Kalfas *et al*. in 1995 reported a study using CT-based computer assisted navigation on 30 patients with varied indications including 23 patients with spondylolisthesis, vertebral body fracture in three patients, degenerative scoliosis in two patients and vertebral body neoplasm in two patients. A total of 150 screws were inserted including 6 at L1, 10 at L2, 18 at L3, 45 at L4, 49 at L5, 20 at S1 and 2 into the sacral ala. Their screw misplacement rates were 0.666%, and they inserted 149 screws out of 150 screws correctly.[15] A similar study carried out in 1997 by Laine *et al*. on 30 patients, in whom 139 screws were inserted using CT based navigation reported screw misplacement rate of 4.3%.[7] Merloz *et al*. in 1998 reported the screw misplacement rate of 8% with CT based navigation as compared to 42% with manual insertion performed for varied indications including fractures, spondylolisthesis, pseudoarthrosis and scoliosis.[12] Current study has been carried out in 30 patients with fractures of lower dorsal and lumbar Spine (T9-L5). A total of 118 screws were placed with eight screws in T11, 28 in T12, 20 in L1, 36 in L2, 16 in L3, 6 in L4 and 4 in L5. Only one screw perforated the lateral wall of the pedicle with a Laine's Grade 5 (screw outside the pedicle). The rate of screw misplacement in the current study is 0.847% which is much less than that reported with a conventional technique and compares favorably to the ones reported in the literature for computer assisted techniques. The cause for this gross misplacement most probably was the fact that although the tract made by the instruments was navigated, the screw placed wasn't. Hence, if in case multiple passages exist the screw can very well take the wrong passage. Time is taken for registration and matching in current study averages 7.8 min (range 5-12 min). The time required for the registration procedure on 1-level instrumentation was 5-20 min in a study done by Wang *et al*. (2008).[25] The average time for screw insertion was 4.19 min (range 2-8 min) in the current study.

Girardi *et al*. in a review of 62 patients who underwent pedicle screw fixation reported mean time required inserting each screw to be 6.6 min (range 3.3-12.5 min).[26] Mean insertion time per screw as reported by Laine *et al*. (1999) in a study using CT based navigation averaged 9.5 min, however the overall time spent in surgery was almost same in the computer assisted and conventional group.[19] Time taken for screw insertion in a study done by Rajasekaran *et al*. was 2.37 ± 0.72 min (range 1.16-4.5 min) using the Iso-C based navigation system.[17] Han *et al*. (2010) in their study using CT based navigation for pedicle screw fixation reported average screw insertion time (from start of the insertion to getting the perfect position) of 4.56 ± 1.03 min (range 3.53-5.59 min) in the conventional group and 2.54 ± 0.63 min (range 1.91-3.17 min) per screw in the computer group indicating shortened screw insertion time with computer assistance.[27] Thus, the time spent in insertion of screws through computer guidance doesn't contribute significantly to prolongation of surgical time, as feared by few workers. In our experience, as the surgeon becomes better versed with using this technique, he uses lesser time to insert screws with computer assistance. In a similar study reported by Laine *et al*. (2000),[28] total time for screw insertion after exposure was reported to be 40 ± 22 min (range 23-77 min). Average time for screw insertion after exposure in the current study was 34.23 min. This compares well with reported screw insertion times. CT based navigation has an inherent advantage of reduced radiation exposure to the surgeon and OT staff as compared to fluoroscopy based technique. Only two images were taken in our study, one before the incision was given to confirm the level and other at the end to visualize the screw placement. Various studies have substantiated this definite advantage of computer assisted navigation. Rampersaud *et al*. (2000) reported that radiation exposure to spine surgeons during pedicle screw placement surgeries. They concluded that fluoroscopically assisted thoracolumbar pedicle screw placement exposes the spine surgeon to significantly greater radiation levels than other, nonspinal musculoskeletal procedures by up to 10-12 times greater.[29] Smith *et al*. (2008) reported a study comparing C-arm fluoroscopy and computer assisted image guidance in terms of radiation exposure to the operating surgeon when placing pedicle screw rod constructs in cadaver specimens. They concluded that computer assisted image guidance systems allow for the safe and accurate placement of pedicle screw rod constructs with a significant reduction in exposure to ionizing radiation to the torso of the operating surgeon.[30]

CT based navigation; however has the disadvantage of extra cost to the patient. There is also a realistic chance of losing contact with computer workstation if dynamic reference base is moved inadvertently during surgery. This would require repetition of the entire procedure and should be guarded against carefully.

The frequent presence of the C-arm in the surgical field, increases radiation exposure to the surgeon, increases surgical time, and also increases the rate of infection.[29,31] CT based navigation by eliminating the need for C-arm reduces radiation exposure, ergonomic constraints and possible breaches in sterility. As the technology is advancing, newer three dimensional intraoperative navigation systems which skip some of the steps of conventional CT based navigation have emerged.[32] These make the entire process fast but retain the inherent accuracy of navigation. The best use of CT based navigation is in deformities and pathologies where the anatomy is distorted. However, we should first use navigation and assess its feasibility in simple and straightforward cases.

Conclusion

Computer assisted CT based navigation is effective in reducing screw misplacement rates. Learning to use CT based navigation involves a steep learning curve and a spine surgeon should have a considerable expertise in a conventional technique of pedicle screw placement for its effective and safe use.

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