Three-Dimensional Frameless Stereotactic-Guided Pedicle Screw Fixation of the Spine: Early Experiences in King Chulalongkorn Memorial Hospital

Chopeow Taecholarn MD*, Peerapong Montriwiwatchai MD*,
Thana Tongkon MD*, Surachai Khaoroptham MD*

** Division of Neurological Surgery, Department of Surgery, Faculty of Medicine, Chulalongkorn University*

Objectives: *To study the accuracy and safety of pedicle screw insertion by three-dimensional frameless stereotactic-guided technique.*
Material and Method: *Twelve patients underwent spinal surgery using three- dimensional frameless stereotactic-guided technique at King Chulalongkorn Memorial Hospital (KCMH) during June - December 2004. In all patients, post-operative CT scan of the operated spinal segments were obtained and evaluated for the position of each screw placed. Medical records were reviewed and all patients were interviewed by telephone to assess clinical outcomes and complications*
Results: *51 pedicle screws were inserted in 12 patients. Postoperative CT scan of the instrumented spine revealed that 50 screws were considered grade I screw while one screw was considered grade II. No patient suffered direct vascular or neurological injury.*
Conclusion: *Three-dimensional frameless stereotactic-guided technique provides additional safety to spinal instrumentation*

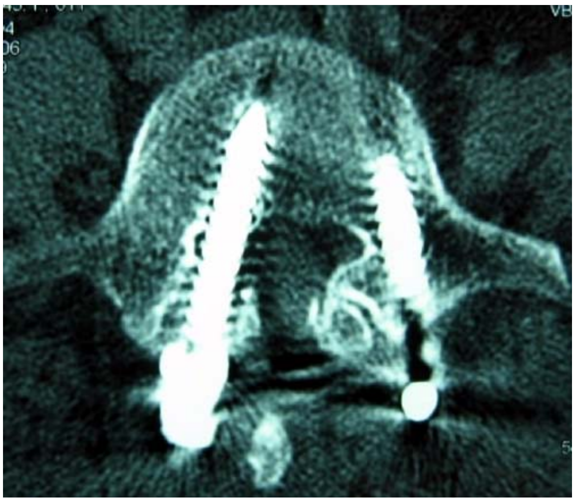
Keywords: *Spinal surgery, Spinal instrumentation, Sterotactic guided*

J Med Assoc Thai 2006; 89 (2): 217-23
Full text. e-Journal: *http://www.medassocthai.org/journal*

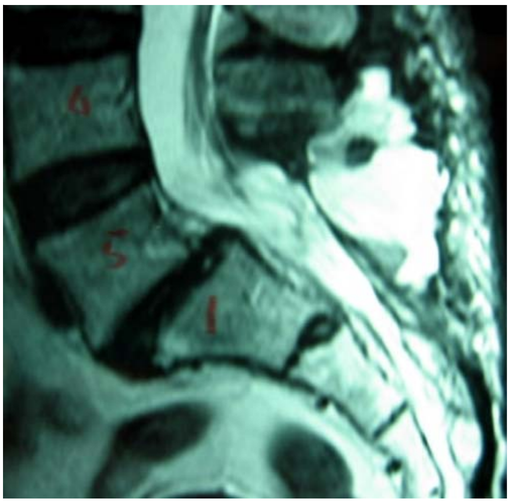
Spinal surgery has been tremendously refined during the past few decades, compared to what it had been for centuries. One of the most important cornerstones was the development of various spinal instrumentations enabling spinal surgeons to deal with more complex diseases. Conventional method of insertion of spinal implant utilizing anatomical landmarks and fluoroscopic guidance demands surgical expertise. Even in the hands of most experienced surgeons, 21-31% of the implants still penetrate the bone cortex[1] and may injure vascular or neural structures (Fig. 1A-B).

The development of image-guided technology for spinal surgery was influenced by the difficulties of intra-operative spatial orientation associated with surgery for complex spinal disorders. The primary components of an image-guided navigational system include an image-processing computer workstation interfaced with a two-camera optical localizer. Customized navigational probes (and later, specialized tools for instrumentation) with three to four small reflective spheres serve as the tools that link the surgeon to the navigational system. The optical localizer camera system emits an infrared beam toward the surgical field, where the beam is captured by the spheres on the probe and reflected back to the camera. The spatial orientation of the reflected light is passed onto the computer workstation, which can then use mathematical principles of localization by triangulation to localize and track the probe's tip position and spatial relationship between the probe's tip and the anatomic structures in the surgical field. Image-based technique has been quoted to improve pedicle screw insertion accuracy, with an error rate of only 5.5%[2]. The authors present here the result of image-guided spinal instrumentation in 12 patients.

Correspondence to : Taecholarn C, Division of Neurological Surgery, Department of Surgery, Faculty of Medicine, Chulalongkorn University, Bangkok 10330, Thailand.



1A



1B

Fig. 1 A 50 year old female patient presented to another hospital with symptoms and signs of spinal canal stenosis secondary to L_5-S_1 spondylolisthesis. Decompressive laminectomy, posterolateral fusion, and pedicle screw fixation were performed. Postoperatively, the patient developed weakness of the right extensor hallucis longus muscle as well as subcutaneous fluid collection at the operative site. A postoperative CT scan demonstrates that the right L_5 pedicle screw was placed entirely off the pedicle into the spinal canal. B MRI shows subcutaneous CSF collection. Operative exploration confirmed that the screw partially cut the L5 nerve root and had torn the dura mater

Material and Method

Twelve patients were operated on with the aid of the image-guided technique at the Division of Neurological Surgery, Department of Surgery, King Chulalongkorn Memorial Hospital (KCMH) from June to December 2004 for various types of spinal disorders. Thin section, non-skipped CT scan (Navigator protocol) of the vertebra to be instrumented was obtained prior to surgery in all patients. The image data were then transferred to the computer workstation of the surgical navigating system via a compact disc. Using the spine model regenerated on the computer screen, the proper size and trajectory of the screw tract was carefully planned on the day prior to surgery (Fig. 2).

Intraoperatively, a standard exposure of the spinal level to be instrumented was performed. An active spine frame was attached to the spinous process and point registration of the vertebra (Fig. 3) was established, utilizing passive planar sharp probe under the overlooking camera localizer of the navigating system (Stealthstation Treon Plus, Medtronic). When the computer accepted the accurate registration, the tools for spinal instrumentation mounted with navigating arms were brought into the surgical field. The navigating system was then activated, permitting tracking of the tools in the field. Three planes, real-time images on the computer screen gave feedback information allowing the surgeon to make fine adjustment of the entry point, trajectory, and depth of the track to match the plan (Fig. 4-6). The drill holes were then tapped and screwed. The construct was assembled and the bone graft was laid following the standard procedure. The wound was irrigated and closed.

Postoperatively, thin-cut CT scan was obtained in all instrumented spinal segments in order to assess the screw position and also the degree of pedicle breaching, if presented (Fig. 7). A grading scale was used to designate the position of each pedicle screw into grade I-V[3] (Table 1). The outcome of surgery was assessed by medical record review and telephone interview.

Results

From June to December 2004, twelve patients were operated on at the Division of Neurological Surgery, King Chulalongkorn Memorial Hospital (KCMH) for various types of spinal disorder utilizing image-based technique spinal instrumentation by a single surgeon (PM) (Table 2). There were two female and ten male patients, age 28-73 years (mean 54). Their diagnosis were metastatic tumor (two patients), fracture dislocation (one patient), and spondylolisthesis (nine patients). Their operative time ranged from 150-480 minutes (mean 310 minutes). Their follow-up periods ranged from two weeks to six months.

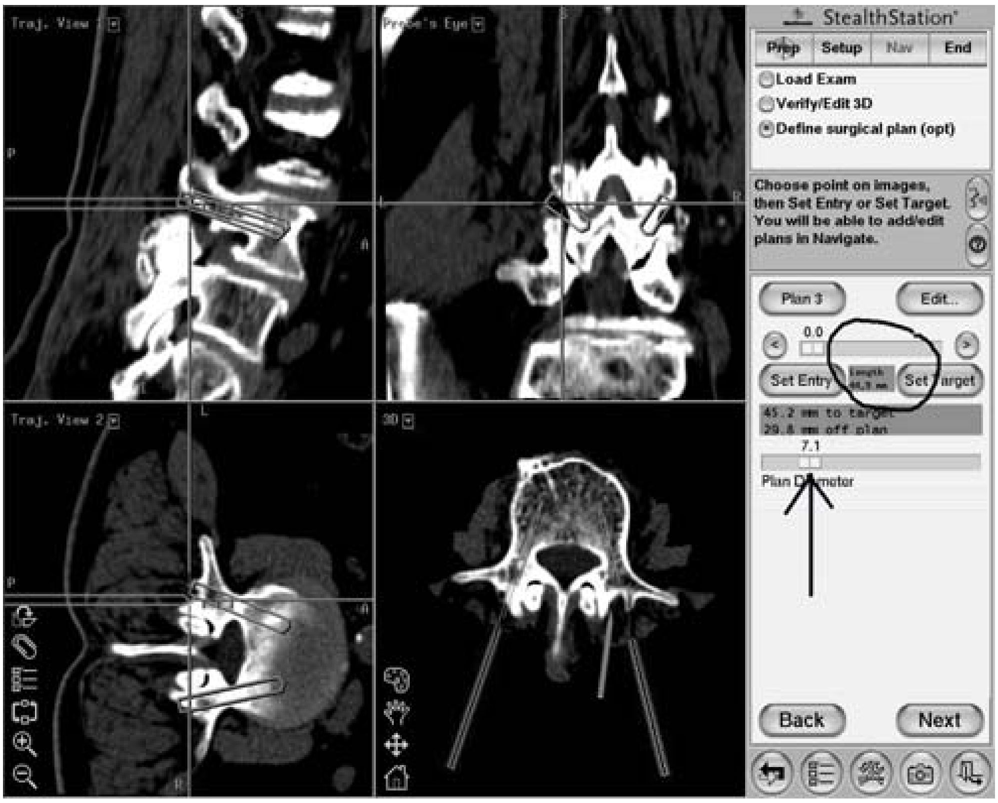


Fig. 2 Computer screen image during preoperative planning, the entry point and trajectory of the pedicle screw can be planned and readjusted in three-dimensional plane. Proper size (diameter and length) of the screw can be obtained by measuring the length (circle) and the diameter (arrow) of the plan

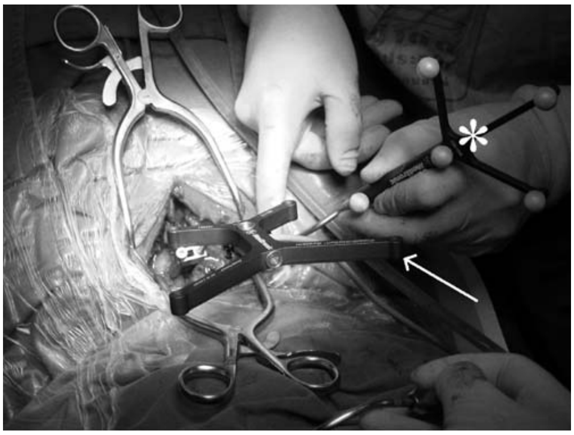


Fig. 3 Point-to-point registration: as the surgeon touches different points (not less than 30 points)on the dorsal surface of the vertebra with the tip of the passive planar sharp probe (asterisk), the computer uses these data to calculate the spatial relationship in space between the vertebra and the active spine frame (arrow)

Fig. 4 The surgeon is probing the pedicle using the navigating pedicle probe (asterisk) that can be tracked by the camera localizer

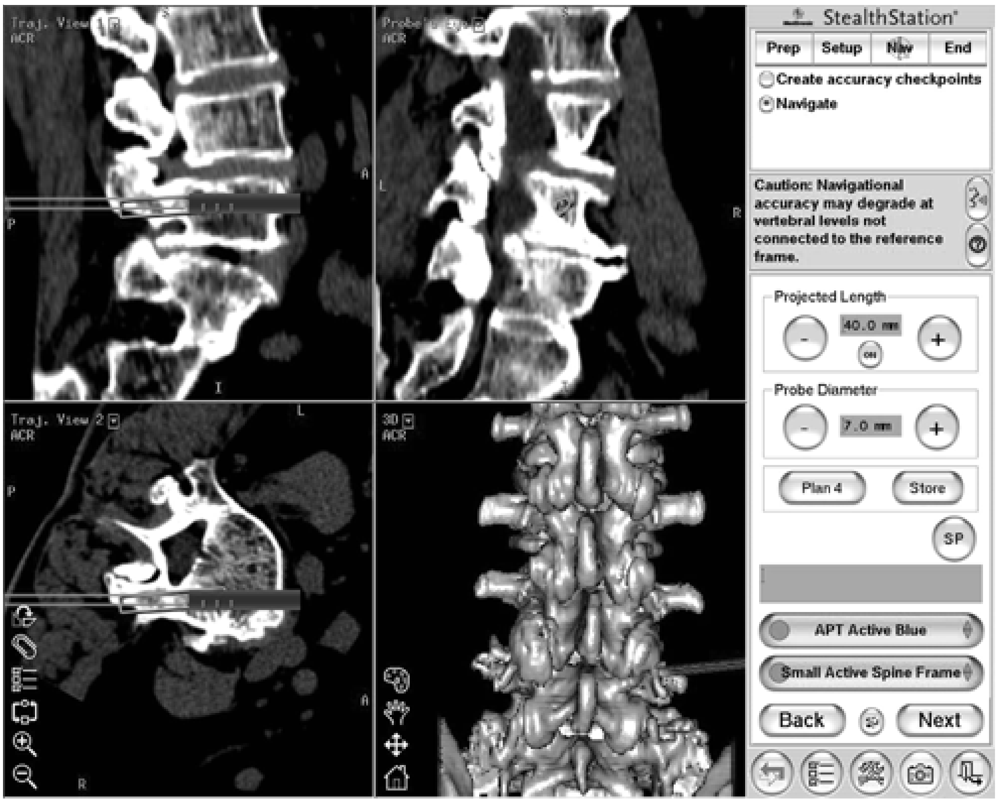


Fig. 5 Computer screen image during navigation: The navigating system tracks the pedicle probe and displays its position and trajectory in three-dimensional real-time images. The surgeon uses this feedback information to readjust the probe trajectory to match the plan before advancing the probe

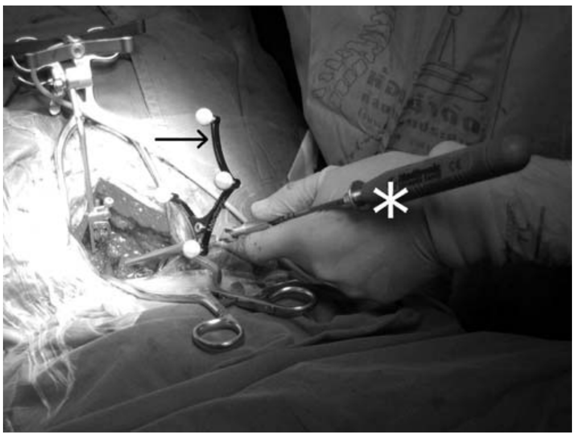


Fig. 6 Alternative method of navigating instrumentation: A detachable tracker (arrow) can be mounted on the drill guide (asterisk) of any spinal system. After a registration process that enables the camera localizer to track a new instrument, a simple drill guide then becomes a navigating drill guide

Fig 7. Postoperative CT scan of a patient in this series demonstrates the ideal screw trajectories (grade I) in C_7 vertebra

Table 1. Pedicle screw position grading

Grade	Descriptions
Grade I	Entirely contained within the pedicle.
Grade II	Violates lateral pedicle but screw tip entirely contained within the vertebral body.
Grade III	Tip penetrates anterior or lateral.
Grade IV	Breaches medial or inferior pedicle.
Grade V	Violates pedicle or vertebral body and endangers spinal cord, nerve root, or great vessels and requires immediate revision.

Fifty-one screws were implanted, two in the cervical spine (C_7), fourteen in the thoracic spine, and thirty-five in the lumbar spine. Postoperative CT scan assessment revealed 50 of grade I screws and 1 grade II screw at T_4 level (1.9%).

During their follow-up periods, one patient died at two months postoperatively due to advanced cancer. There was no direct vascular or neurological complication. All patients responded to telephone interviews that their pain was reduced and their daily life activities increased.

Discussion

Pedicle screw can be used to stabilize the spine for various diagnoses including infection, malignancy, trauma, and deformity(4-6). Contemporary method screw insertion utilizes surface anatomical landmarks combined with lateral fluoroscopic guidance. Although these techniques have been proved useful, they have limitation because they only provide two-dimensional imaging of a complex three-dimensional structure(7). Therefore, 10-20% of screws implanted by these methods have been reported to breach the pedicle cortex(1, 8-9) and be responsible for neurological injury in 4.5% of the patients(8). Placing pedicle screw in thoracic and cervical vertebra is considered more technically challenging than in the lumbar vertebra. The reason being that the pedicles in these regions are smaller and exhibit a high degree of inter- and intra-specimen variability(6,10). Depending on the techniques utilizing in pedicle screw insertion (open laminar, Steffee's, or Roy-Camille's) and the criteria used to grade the screw placement as either "in" or "out", 3-55% breaching rate have been reported(11-13). The high rate of "in" in some series was, in fact, due to inclusion of the pedicle-rib head complex as the acceptable path for the screw(14). In one clinical series, 5% of manually inserted thoracic pedicle screw patients developed

Table 2. Summary of diagnosis, treatment, and result

Patient	Sex	Age	Diagnosis	Operation	Preoperative symptom	Result	Op. time (Min)
1	M	56	Spondylolisthesis L5-S1	PLIF* + Pedicle screw L5-S1	Intermittent claudication	Good, walking, pain free	390
2	M	28	Fracture L4	Pedicle screw L3-L5	Back Pain, no neurodeficit	Good, walking, pain free	240
3	M	59	Spinal stenosis L1-L2	PLIF*, Pedicle screw L1-L2	Back pain, bed ridden	Improve, walking with crane, less pain	360
4	M	54	Metastasis T8-T9	Tumor removal + Pedicle screw T6-T11	Back pain, paraparesis	Walking, back pain due to local recurrent	480
5	M	65	Metastasis L1	Tumor removal + Pedicle screw T12-L2	Back pain, paraparesis	Died 2 months after surgery from advanced cancer	300
6	M	63	Spondylolisthesis L4-L5	PLIF* + Pedicle screw L4-L5	Intermittent claudication	Good, walking, pain free	240
7	M	33	Fracture T6-T7	Pedicle screw T3-T9	Trauma, paraplegia	Ambulation on a wheel chair, paraplegia, pain free	360
8	M	73	Spondylolisthesis L5-S1	PLIF* + Pedicle screw L5-S1	Intermittent claudication	Good, walking, pain free	300
9	M	67	Spondylolisthesis C7-T1	Pedicle screw C7-T1	Paraparesis	Improve, walking with assistance	150
10	M	66	Spondylolisthesis L3-L4	PLIF + Pedicle screw L3-L4	Intermittent claudication	Good, walking, pain free	300
11	F	35	Spondylolisthesis L3-L4	PLIF + Pedicle screw L3-L4	Intermittent claudication	Good, walking, pain free	300
12	F	50	Spondylolisthesis L4-L5	PLIF + Pedicle screw L4-L5	Intermittent claudication	Good, walking, pain free	300

* PLIF= Posterior Lumbar Interbody Fusion

neurological complications as a result of a misplaced screw[8]. 4.7% of Esses and coworkers' series of 617 cases of thoracic pedicle screw suffered nerve root injury[15]. Fluoroscopic guidance in thoracic pedicle screw insertion may also be complicated by the bulky rib cage and intrathoracic structure. Although there is no statistical significance, a group of researchers reported 1% of direct nerve injury and 0.5% of vertebral artery injury in 180 manually inserted cervical pedicle screw patients. There has not been a single neurovascular injury occurred in the image-guided group[16,17].

The only main disadvantage of image-guided pedicle screw insertion is the longer operative time. An *in vitro* study revealed that the average time consumed for insertion of one image-guided screw was 13.5 minutes compared to 4 minutes in lateral fluoroscopic group. However, the benefit of the image-guided technique far outweighs the lengthy time it demands, the rate of medial pedicle violation which may cause catastrophic neurological injury is 0% compared to 5% in lateral fluoroscopic group[18]. The total time of the surgical operation should be decreased as the surgeon gains familiarity with the navigation technique.

Proponents of the lateral fluoroscopic technique sometimes criticized that routine use of image-guided technique may impair the ability to perform conventional pedicle screw insertion when forced to do so[7]. The authors do not agree with that opinion since the image-guided technique gives feedback information to the surgeons whether or not the purposed trajectory in their mind will "match" the ideal trajectory. As a result, the surgeons get the chance to learn more from every navigated screw they put in about the relationship between the surface anatomy and the anatomy of the pedicle. There are also several conditions not suitable for image-guided surgery. For example, laminectomized or spondylolytic patients who do not have spinous process or lack the integrity between the spinous process and the pedicle, are not recommended as the accuracy of the image guidance is decreased. In these circumstances, the authors chose to perform the lateral fluoroscopic method. Therefore, regular utilization of image-guided technique should not impair the skill of the surgeons to perform the conventional technique.

Conclusion

Although conventional lateral fluoroscopic technique of pedicle screws insertion is relatively safe, small but serious complications still occur. Image-guided spinal surgery can fill up this gap by providing additional accuracy and minimizing surgical performance variability. Although the number of patients in the present study is small, the early result is encouraging, and comparable to other series in the literature. Considering this is as the first report of image-guided spinal surgery in Thailand, more favorable outcomes should encourage more spine surgeons to perform image-guided spinal surgery regularly.

Acknowledgement

The authors would like to thank Piyaporn Bonsirikumchai MD, Department of Radiology, King Chulalongkorn Memorial Hospital for her assistance in reviewing the postoperative CT scans.

References

1. Weinstein JN, Spratt KF, Spengler D, Brick C, Reid S. Spinal pedicle fixation: reliability and validity of roentgenogram-based assessment and surgical factors on successful screw placement. Spine 1988; 13: 1012-8.
2. Steinmann JC, Herkowitz HN, el-Kommos H, Wesolowski DP. Spinal pedicle fixation. Confirmation of an image-based technique for screw placement. Spine 1993; 18: 1856-61.
3. Heary RF, Bono CM, Black M. Thoracic pedicle screws: postoperative computerized tomography scanning assessment. J Neurosurg 2004; 100 (4 Suppl Spine): 325-31.
4. Albert TJ, Klein GR, Joffe D, Vaccaro AR. Use of cervicothoracic junction pedicle screws for reconstruction of complex cervical spine pathology. Spine 1998; 23: 1596-9.
5. Chang KW. Oligosegmental correction of post-traumatic thoracolumbar angular kyphosis. Spine 1993; 18: 1909-15.
6. Krag MH, Weaver DL, Beynnon BD, Haugh LD. Morphometry of the thoracic and lumbar spine related to transpedicular screw placement for surgical spinal fixation. Spine 1988; 13: 27-32.
7. Kalfas IH. Image-guided spinal navigation. In: Winn HR, editor. Youmans neurological surgery. 5th ed. Philadelphia: Saunders; 2004: 4743-56.
8. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement in vivo. Spine 1990; 15: 11-4.
9. Roy-Camille R, Saillant G, Mazel C. Internal fixation of the lumbar spine with pedicular plating. Clin Orthop Relat Res 1986; 203: 7-17.
10. Vaccaro AR, Rizzolo SJ, Allardyce TJ, Ramsey M, Salvo J, Balderston RA, et al. Placement of pedicle screws in the thoracic spine. Part I. Morphometric

analysis of the thoracic vertebrae. J Bone Joint Surg Am 1995; 77: 1193-9.
11. Vaccaro AR, Rizzolo SJ, Balderston RA, Allardyce TJ, Garfin SR, Dolinskas C, et al. Placement of pedicle screws in the thoracic spine. Part II: An anatomical and radiographic assessment. J Bone Joint Surg Am 1995; 77: 1200-6.
12. Xu R, Ebraheim NA, Ou Y, Yeasting RA. Anatomic considerations of pedicle screw placement in the thoracic spine. Roy-Camille technique versus open-laminar technique. Spine 1998; 23: 1065-8.
13. Sapkas GS, Papadakis SA, Stathakopoulos DP, Papagelopoulos PJ, Badekas AC, Kaiser JH. Evaluation of pedicle screw position in thoracic and lumbar spine fixation using plain radiographs and computed tomography. A prospective study of 35 patients. Spine 1999; 24: 1926-9.
14. O'Brien MF, Lenke LG, Mardjetko S, Lowe TG, Kong Y, Eck K, et al. Pedicle morphology in thoracic adolescent idiopathic scoliosis: is pedicle fixation an anatomically viable technique? Spine 2000; 25: 2285-93.
15. Esses SI, Sachs BL, Dreyzin V. Complications associated with the technique of pedicle screw fixation. A selected survey of ABS members. Spine 1993; 18: 2231-9.
16. Kotani Y, Abumi K, Ito M, Minami A. Improve accuracy of computer-assisted cervical pedicle screw insertion. J Neurosurg 2003; 99(3 Suppl): 257-63.
17. Abumi K, Shono Y, Ito M, Taneichi H, Kotani Y, Kaneda K. Complications of pedicle screw fixation in reconstructive surgery of the cervical spine. Spine 2000; 25: 962-9.
18. Assakar R, Reyns N, Vinchon M, Demodion X, Louis E. Transpedicular screw placement: image-guided versus lateral view fluoroscopy: in vitro simulation. Spine 2001; 26: 2160-4.

การผ่าตัดดามกระดูกสันหลังด้วยเพดดิเคิลสกรูโดยวิธีการนำวิถีสามมิติแบบไร้กรอบ: ประสบการณ์เริ่มแรกใน โรงพยาบาลจุฬาลงกรณ์

ช่อเพียว เตโชฬาร, พีรพงษ์ มนตรีวิวัฒนชัย, ธนา ทองก้อน, สุรชัย เคารพธรรม

วัตถุประสงค์: *เพื่อศึกษาความแม่นยำและความปลอดภัยของการใส่โลหะดามกระดูกสันหลังโดยวิธีการนำวิถีสามมิติแบบไร้กรอบ*

วัสดุและวิธีการ: *โดยศึกษาย้อนหลังจากเวชระเบียนของผู้ป่วยจำนวน 12 รายซึ่งได้รับการผ่าตัดใส่โลหะดามกระดูกสันหลัง โดยวิธีการนำวิถีสามมิติแบบไร้กรอบ ที่โรงพยาบาลจุฬาลงกรณ์ระหว่าง มิถุนายน-ธันวาคม พ.ศ. 2547 ผู้ป่วยทุกรายได้รับการตรวจหลังผ่าตัด ด้วยเอกซเรย์คอมพิวเตอร์ของกระดูกสันหลังในระดับที่ได้รับการผ่าตัด เพื่อประเมินตำแหน่งของโลหะดามกระดูกสันหลัง ผู้ป่วยจะได้รับการประเมินผลการรักษาและภาวะแทรกซ้อน*

ผลการศึกษา: *ได้ทำผ่าตัดใส่เพดดิเคิลสกรู จำนวน 51 ตัวในผู้ป่วย 12 คน การศึกษาภาพถ่ายเอกซเรย์คอมพิวเตอร์ของกระดูกสันหลังหลังผ่าตัดพบว่าเป็น สกรูอยู่ในตำแหน่งขั้น 1 จำนวน 50 ตัว และอยู่ในตำแหน่งขั้น 2 จำนวน 1 ตัว และไม่พบผลแทรกซ้อนโดยตรงทางระบบประสาทหรือ หลอดเลือดเลย*

สรุป: *การใส่เพดดิเคิลสกรูโดยวิธีการนำวิถีสามมิติแบบไร้กรอบ ช่วยเพิ่มความปลอดภัยให้กับการผ่าตัดใส่โลหะดามกระดูกสันหลัง*
