The Accuracy of Computer-Assisted Pedicle Screw Placement in Degenerative Lumbrosacral Spine Using Single-Time, Paired Point Registration Alone Technique Combined with the Surgeon's Experience

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Objective: *Evaluate the accuracy of computer-assisted pedicle screw placement in patients with degenerative lumbrosacral spine using single-time, paired point registration alone technique in combination with the surgeon's experience.*
Material and Method: *A computer-assisted pedicle screw insertion in lumbrosacral spine were performed in 62 consecutive patients (363 screws) using single-time, paired point registration without surface matching. After finding the entry point and trajectory of the pedicle under image guidance, the surgeon then inserted pedicle screws by his experience. Postoperative DynaCT scans were obtained and interpreted by two neuroradiologists. The Kappa statistic was used to measure the degree of interobserver agreement. The screw position was graded as follows: Grade A = entirely within the pedicle; B = medial or lateral pedicle wall breach less than 2 mm; C = medial or lateral pedicle wall breach equal to 2-4 mm; D = medial or lateral wall breach more than 4 mm. Clinical outcomes including a numeric pain score, neurologic symptoms, and complications were reviewed from all charts of patients. Additionally, the registration error, registration time, screwing time, and estimated blood loss were analyzed.*
Results: *A total of the 363 pedicle screws, the first neuroradiologist interpreted grade A in 95.6%, grade B in 4.1% and grade C in 0.3%, while the second neuroradiologist interpreted grade A in 95.3%, grade B in 3.6%, and grade C in 1.1%. There was no incidence of grade D in this present study. No neurologic or vascular injuries occurred from pedicle screw placement. The mean registration error was 1.54 $\pm$ 1.28 (range, 0.9-2.5) mm with the mean time required for the registration process for each patient was 3.64 $\pm$ 1.92 (range, 2-8) minutes. The mean screwing time for each patient was 20.29 $\pm$ 9.44 (range, 13-40) minutes. The mean pain score improved from 6.45 $\pm$ 1.74 points preoperatively to 3.04 $\pm$ 0.82 points postoperatively. In the radiculopathy group, motor power gradually improved in all patients.*
Conclusion: *The use of single-time, paired point registration without surface mapping combined with surgeon's perception for computer-assisted pedicle screw insertion has proven to be a safe and effective technique in degenerative lumbrosacral spine. The author's technique did not rely solely on the image guidance. However, the navigation system would be very beneficial to improve decision-making, especially in surgery of patients with distorted spinal anatomy. Besides, this technique may decrease the overall operative time without compromise the accuracy of pedicle screw placement.*

Keywords: *Pedicle screw, Computer-assisted surgery, Navigation, Single-time registration, Lumbrosacral spine*

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Pedicle screw placement in lumbar and sacral spine has widely been accepted by worldwide spine surgeons to achieve solid fusion. Even though pedicle screws were implanted by experienced surgeons with anatomical landmarks and intraoperative fluoroscopy, there still was a problem of pedicle screw misplacement, causing neurologic complication[1-5]. *In vitro* study to access accuracy of spinal pedicle fixation under fluoroscopy control in two planes, Weinstein et al[6] reported 21% of misplacement rate with 92% of cortical perforations within spinal canal. Also Castro et al[4], *in vivo* and *vitro* study using CT scan for assessment of accuracy of pedicle screw placement, showed a misplacement rate of 25% in cadavers and up to 40% in the patient group.

After introducing anatomical landmarks on the posterior aspect of the spine as fiducial points,

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which are easily distinguishable in both image space and physical space, combined with a dynamic reference frame (DRF) attached to the spinous process[7], spinal image guidance has been developed and used to improve the accuracy and safety of pedicle screw placement. Although many studies published better results of image-guided spinal surgery compared with conventional technique[1,8-11], many spine surgeons have not accepted this technology into their practice. The major reason is time-consuming due to the registration process, matching between the image-based anatomy and the exposed operative anatomy. There are two basic techniques used for the registration process in computer-assisted spinal surgery including paired point matching alone and paired point matching supplemented with surface matching[12]. Paired point registration begins with selection of a minimum of three fiducial points on the workstation 3D image and mapping them with precisely identify points in operative field, whereas surface registration is accomplished by touching multiple random anatomic points on the posterior vertebral segment. Surface matching technique certainly adds time for the registration and eventually lengthens the entire operative time[12,13]. Furthermore, registration can be divided into single-level vertebral registration for the whole spinal navigation[14,15], single-time registration for whole interested vertebrae[1,16,17] and separate registration for each vertebra[14,15,17-20]. Separate registration technique is performed for each instrumented vertebral level to minimize the problem of discrepancies in patient position between preoperative CT scans (supine) and intraoperative position (prone). Nevertheless, this technique can lengthen the registration and total operative time. Although image-guided spinal surgery is useful for pedicle screw placement, it is not a substitute for anatomical knowledge and surgical experience but rather serves as an adjunct to the surgeon's judgment and technical skill[10,16,21-23]. In the present study, the authors modified the technique as simple as possible by avoiding surface and separate registration. The purpose of the present study was to define the accuracy of computer-assisted pedicle screw placement using single-time, paired point registration alone technique in combination with the surgeon's experience.

Material and Method

Between December 2006 and October 2008, the authors studied 62 consecutive patients who underwent lumbar or lumbrosacral fusion with pedicle screws for degenerative conditions of the spine at Prasat Neurological Institute. This present study protocol was approved by the ethics committee of Prasat Neurological Institute. All of the patients were operated on by the single surgeon (PI). The StealthStation Navigation System (Medtronic SNT, Louisville CO, USA), which is the optical tracking system, has been used in Prasat Neurological Institute since August 2004. CT scans (Asteion, Toshiba, Tokyo, Japan) of the vertebra to be instrumented were obtained prior to surgery in all patients with the protocol consisting of contiguous, non-skipped axial slices with constant slice thickness of 2.0 mm. The image data were transferred to the computer workstation of the surgical navigating system via a compact disc. At least six to ten fiducial points at the tip of spinous processes and the tip of transverse processes were selected by covering the whole instrumented surgical area on the workstation monitor displaying in axial, coronal, Sagittal and 3D reconstruction images (Fig. 1A). All patients were positioned prone on a Wilson frame adjusted to maintain lumbar lordosis (Fig. 1B). After a

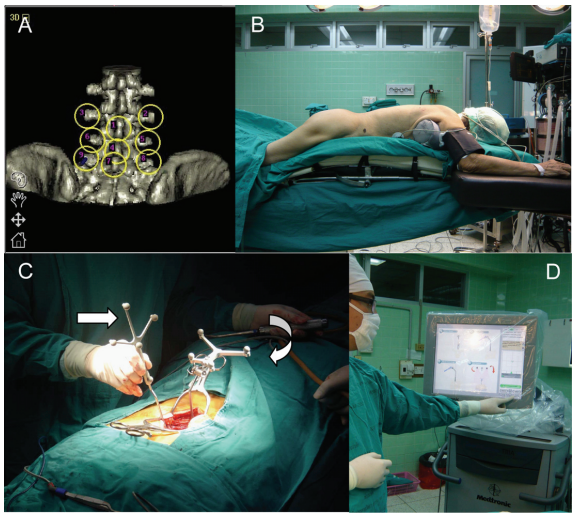

Fig. 1 (A) 3D reconstructed image on workstation monitor showed nine fiducial points at the tip of spinous processes and the tip of transverse processes were selected by covering the whole instrumented surgical area. (B) Prone position of the patient on Wilson frame. (C) The surgeon was using registration probe (straight arrow) on the spine of patient, attached with dynamic reference frame (curved arrow). (D) The surgical assistant was working via the touch screen monitor

standard exposure of the spinal level to be instrumented was performed, a DRF equipped with light-emitting diodes (LEDs) was attached to the spinous process of a rostral vertebra (Fig. 1C). A camera array was moved for proper distance to locate the spatial position of LEDs on the reference frame and the registration probe. The surgical assistant controlled the workstation monitor, covered by a clear, sterile drape, via touch screen monitor without any technician (Fig. 1D). Paired point matching was completed by introducing a registration probe equipped with five LEDs to touch the anatomical landmarks on the exposed spine that corresponded to the chosen registration points. A registration error in millimeters was calculated on the workstation monitor by accepting this error of less than 3 mm. After successful registration process, spinal navigation was verified by touching several identifiable points on the patient vertebra, ensuring that these points correspond to the points on the computer workstation. Combining with anatomical technique by the surgeon's experience, multiplanar image guidance was used to assist to find the proper entry point and trajectory of the pedicle by the registration probe (Fig. 2). The posterior cortex of the entry point was then removed by a rougeur and made a pilot hole with an awl. The entry point and trajectory of the pedicle were checked again by the registration probe. The pedicle probe was advanced to create a path through intrapedicular cancellous bone following with a tap device without using image guidance anymore. Screw diameter and length were estimated by the surgeon's perception. Before insertion of the pedicle screw, a ball-tipped feeler was always used to confirm the integrity of the pedicle wall. All of the pedicle screws of each patient were placed under the same registration. CD Horizon M8 (Medtronic Sofamor Danek USA), screws diameter 5.5-7.5 mm, length 35-45 mm and rod diameter 5.5 mm were used in all cases. Screw positions were verified with fluoroscopy postoperatively with only one or two shot exposure.

DynaCT scans (AXIOM Artis FD Biplane Angiosuite; Siemens Medical Solutions, Erlangen, Germany), obtained on all patients for revealing the screw position postoperatively, were analyzed by two independent neuroradiologists, interpreting multiplanar and 3D reconstructed image on 3D workstation (Leonardo workstation; Siemens Medical Solutions, Malvern, Pa) using InSpace software (Siemens Medical Solutions) equipped with a measuring device accurate to 1 mm (Fig. 3). The screw position was graded as follows, Grade A = entirely within the pedicle, B = medial or lateral pedicle wall breach less than 2 mm, C = medial or lateral pedicle wall breach equal to 2-4 mm and D = medial or lateral wall breach more than 4 mm. The degree of interobserver agreement was measured using the kappa statistic. All charts of patients were reviewed for preoperative and postoperative numeric pain score (0= no pain, 10= worst pain), neurologic symptoms, estimated blood loss, and complications. Additionally, registration error, registration time, and screwing time were analyzed. The data was analyzed using SPSS-version 16. Descriptive statistics in term of frequency, mean $\pm$ standard deviation, and range were used to report all results.

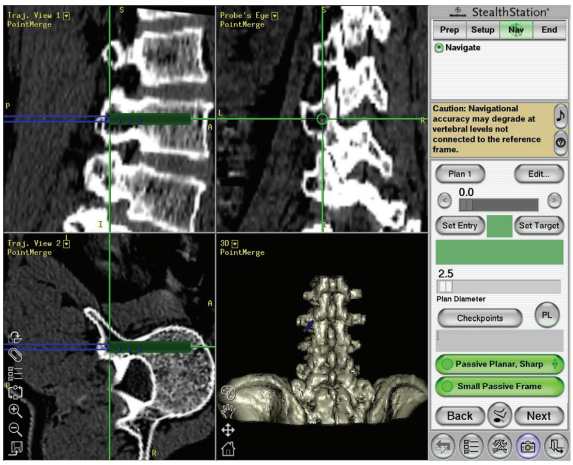

Fig. 2 Workstation screen demonstrated navigation for left L3 under multiplanar plane

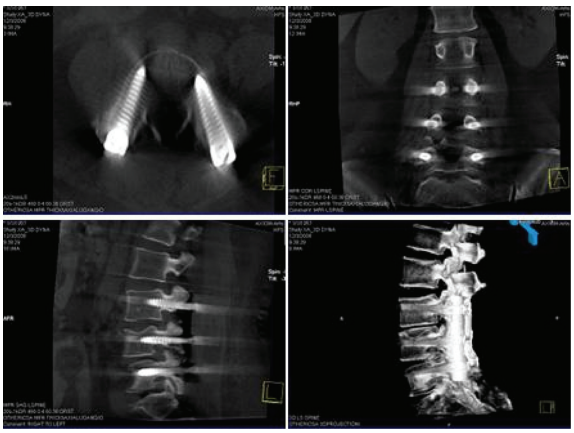

Fig. 3 Multiplanar and 3D reconstructed image of DynaCT scans showed satisfactory position of pedicle screws

Results

There were 18 men and 44 women with a mean age of 58 ± 9 (range, 39-76) years. Their diagnoses included spondylolisthesis in 43 patients, degenerative scoliosis in nine, spinal stenosis in four and spondylolisthesis post lumbar surgery in six. For previous surgery cases, the diagnoses included spondylolisthesis post laminectomy in three and adjacent segment disease post pedicle screw placement in three. The mean follow-up period was 17.63 ± 4.67 (range, 10-24) months. Three hundred sixty three pedicle screws were placed including four in the right L1 level, five in the left L1, 12 in the right L2, 12 in the left L2, 39 in the right L3, 39 in the left L3, 59 in the right L4, 59 in the left L4, 59 in the right L5, 59 in the left L5, eight in the right S1 and eight in the left S1. Single-level pedicle screw insertion was performed in 19 patients, two-levels in 27, three-levels in nine, four-levels in five and five-levels in two.

Postoperative DynaCT scans revealing screw position were reviewed by two neuroradiologists (Table 1, 2). For the three hundred sixty three pedicle screws, the first neuroradiologist interpreted grade A in 95.6%, grade B in 4.1%, and grade C in 0.3%, while the second neuroradiologist interpreted grade A in 95.3%, grade B in 3.6%, and grade C in 1.1%. There was no incidence of grade D in the present study. The rate of pedicle violation (combined Grade B, C, and D) evaluated by the first and second neuroradiologist were 4.4 and 4.7%, respectively. There were three medial pedicle breaches in grade B and one in grade C reported by the first neuroradiologist, whereas there were two medial pedicle breaches in grade C reported by the second one. Twelve lateral pedicle breaches were assessed in grade B by both neuroradiologist and two in grade C by the second one. Kappa value was 0.69, which represented good agreement between both neuroradiologists.

Clinical presentation of the patients could be divided into 3 groups; first, thirty-five patients presented with pain (back and/or radicular pain); second, nine patients with radiculopathy; third, the remaining eighteen patients with pain and radiculopathy. The mean pain score preoperatively was 6.45 ± 1.74 (range, 2-8) points, while the mean score postoperatively was 3.04 ± 0.82 (range, 2-5) points. In the radiculopathy group, motor power gradually improved in all patients within six months to

Table 1. Evaluation of pedicle screw position, assessment by the first neuroradiologist

Spinal level	No. of screws	Grade A	Grade B (M/L*)	Grade C (M/L*)	Grade D (M/L*)
L1	9	9	0/0	0/0	0/0
L2	24	24	0/0	0/0	0/0
L3	78	78	0/0	0/0	0/0
L4	118	113	0/5	0/0	0/0
L5	118	112	1/5	0/0	0/0
S1	16	11	2/2	1/0	0/0
Total (%)	363 (100)	347 (95.6)	15 (4.1)	1 (0.3)	0

* M = medial violation of the pedicle wall; L = lateral violation of the pedicle wall

Table 2. Evaluation of pedicle screw position, assessment by the second neuroradiologist

Spinal level	No. of screws	Grade A	Grade B (M/L*)	Grade C (M/L*)	Grade D (M/L*)
L1	9	8	0/1	0/0	0/0
L2	24	24	0/0	0/0	0/0
L3	78	78	0/0	0/0	0/0
L4	118	111	0/6	0/1	0/0
L5	118	112	0/5	0/1	0/0
S1	16	13	0/1	2/0	0/0
Total (%)	363 (100)	346 (95.3)	13 (3.6)	4 (1.1)	0

* M = medial violation of the pedicle wall; L = lateral violation of the pedicle wall

one year. No neurologic or vascular injuries occurred from pedicle screw placement. No screws required repositioning.

The mean registration error was 1.54 ± 1.28 (range, 0.9-2.5) mm with the mean time required for the registration process for each patient was 3.64 ± 1.92 (range, 2-8) minutes. The mean screwing time for each patient was 20.29 ± 9.44 (range, 13-40) minutes. Estimated blood loss averaged 455 ± 17 (range, 150-1,600) ml.

Discussion

The most important plane for pedicle screw insertion is the axial plane, which is the only plane that can demonstrate violation of spinal canal by misplaced screw placement. Standard fluoroscopy and fluoroscopy-based navigation provide only anteroposterior and lateral view, whereas computer-assisted image guidance also provides the axial view[22].

The registration process of CT-based image guidance is an important step in achieving successful navigation[9,12,22]. Because of concern about discrepancies in anatomical orientation due to change in patient position between preoperative data (supine position) and intraoperative field (prone position), separate registration was then advocated in many studies[7,14,15,17,19,22]. However, registration at each spinal level separately especially in multilevel disorders adds significant time to the operative procedure and makes surgeons cumbersome.

Kalfas et al[15] proposed two options for registration; first method was to select new registration points at the new level; second method was to verify on a bone landmark of the new level by using the registration data of the previous level. Later, Lee et al[14] compared single-level vertebral registration for whole instrumented vertebrae and separate registration to assess the accuracy of pedicle screw placement in 47 patients. They found that separate registration at each instrumented level enhanced the accuracy of the pedicle screw placement. All five poorly placed screws in a group of single-level registration occurred at levels that were not registered.

A prospective study by Laine et al[1], single-time, paired point matching alone for whole instrumented vertebrae, used six fiducial points and specific instruments (pedicle probe and awl) equipped with light emitting diodes. The malplacement rate of computer-assisted surgery was 4.3%, while conventional technique 14.3%. One malpositioned screw in conventional method caused nerve root injury. Afterwards, Laine et al[11] published another randomized controlled study to assess the accuracy of pedicle screw insertion with and without computer assistance by the same previous technique. The malplacement rate of the computer-assisted group and the conventional group were 4.6% and 13.4%, respectively. Complications in the conventional group included two nerve root lesions, one endplate fracture, one major intraoperative bleeding, and one postoperative death.

Papadopoulos et al[16], in a prospective study of accuracy of single-time multilevel registration with point merge and surface merge for multilevel pedicle screw placement, concluded that this technique may decrease operative time without compromising the increased accuracy of pedicle screw placement in the setting of degenerative lumbar spine.

Holly et al[12] compared the navigational accuracy of paired point matching alone and paired point in conjunction with surface- matching registration separately of seventy-five pedicle screws placing in three embalmed human cervicothoracic spinal specimens. They concluded that paired point matching alone offered equivalent navigational accuracy to paired point matching supplemented with surface matching and was likely to result in decreased operating room time.

In point-based registration of rigid body, West et al[24] suggested four guidelines for the placement of fiducial points to minimize the target registration error: 1) avoid near-collinear configurations, 2) use as many points as possible, 3) arrange the markers as far from each other as possible and 4) ensure that the target is in the center of the registered fiducial points. In the present study corresponding to West et al, the fiducial points were selected at least six to ten points in noncollinear configuration surrounding the whole instrumented vertebrae. Only tips of transverse and spinous process were chosen as fiducial points in order to easily identify intraoperatively, whereas some studies[8,14] included other parts such as superior and inferior articular process that are not easy to find out the exact points.

In the present study, the authors modified the technique to comfortably use computer-assisted spinal surgery using single-time paired point matching without surface registration for whole instrumented level combined with the anatomical knowledge of the surgeon. After complete registration and verification, interactive image guidance then was used to assist the surgeon to orientate unexposed spinal anatomy for

finding the entry point and trajectory of the pedicle. Another factor of frustration during the screwing process is staring at the monitor by the eyes deviating from the surgical field to view the image-guided information. Therefore, screwing process in this present study was performed by the surgeon without using image-guided awl, probe, tap and screwdriver instrument.

Pedicle screw placement by computer-assisted surgery requires surgeons who have an experience in conventional surgical techniques and image guidance system[11,20,23]. This present study was started beyond learning curve of the surgeon who was familiar with the use of computer-assisted spinal guidance and had experience in conventional techniques using anatomic landmarks. Therefore, the mean time for registration and screwing were decreased because of confidence of the surgeon and no need to use intraoperative fluoroscopy frequently. Furthermore, the surgeon used the navigation system just for guidance of the entry point and trajectory without utilization of other image-guided accessories, which spend more time. For these reasons, this technique may indirectly lead to decreasing the overall operative time. Nevertheless, the surgeon must be aware about some accuracy degradation by any cause for example unintended movement of the reference frame. Verification step to identify anatomy in the next level can be repeated throughout the screwing procedure when the surgeon has some doubt of accuracy.

Of the 363 screws placed, both neuroradiologists reported the screw position similarly in grade A of 95.6% and 95.3%. The first neuroradiologist reported overall pedicle breaches in 4.4%, whereas the other neuroradiologist reported in 4.7%. Gertzbein et al[2], in a study of the accuracy of pedicle screw placement, found that the distance of 0-4 mm beyond the medial border of the pedicle could be considered within the safe zone. In addition, Schulze et al[25] found that the neurologic symptoms rarely occurred unless the violation of the pedicle wall was more than 6 mm. In the present study, all medial pedicle breaches (grade B and C) were less than 4 mm that were considered in the safe zone.

Actually, CT-based navigation does not provide real-time image guidance due to differentiation in position before and during the procedure. However, degenerative lumbar spine diseases are usually associated with decreasing of intersegmental movements. Thus, positional error should be reduced in this present study because all patients had degenerative changes. There was no study comparing the alteration between supine and prone position on the Wilson frame that was used in the present study. Benfanti et al[26], in evaluation of the effect of hip position on total and segmental lumbar lordosis in patients and volunteers in standing and prone on the Wilson frame, concluded that hip flexion was associated with a significant decrease in lumbar lordosis that should be preserved during instrumented lumbar fusion for maintenance of normal sagittal alignment.

In vitro study to determine occupational radiation exposure during lumbar fluoroscopy of Rampersaud et al[27] concluded that fluoroscopically assisted thoracolumbar pedicle screw placement exposed the spine surgeon to significantly greater radiation levels than surgeons performing non-spinal musculoskeletal procedures. In the present study, fluoroscopy was used only postoperatively to confirm pedicle screw position, therefore radiation exposure to surgeons and operating room staff was reduced by this modified technique.

In situations when normal spinal anatomic landmarks have been altered or obscured such as revision surgery in case of previous posterolateral fusion and degenerative scoliosis. Image-guided spinal surgery may be useful to improve the accuracy in pedicle screw placement. Austin et al[10] compared three techniques to insert pedicle screw in a scenario that all posterior landmarks had been obliterated and found that CT-based surgery was superior to either fluoroscopy-based or open laminoforaminotomy technique. The registration process used a point-based mapping with four fiducial points for each of the specimens because the specimens were fused together, and then any of the segments were less likely to move. In addition, Lim et al[28] determined the accuracy rate of CT-based image-guided pedicle screw insertion in previously fused lumbar spines using paired point combined with surface matching. They reported pedicle wall violation in 4.1% of all pedicle screws without neurologic deficit and revision of malpositioned screws. For scoliosis, the rotation of pedicle makes anatomic relationships distorted, so it is difficult to place the pedicle screw by conventional techniques[29]. Besides, fluoroscopy and fluoroscopy-based image guidance have a limitation owing to producing only two-dimensional images. Then, image-guided spinal navigation has become a useful tool for this situation[23,30].

Currently, spinal image guidance by 3D fluoroscopy or intraoperative CT scanner can obviate the need for the registration process[23,31]. Nevertheless, these innovative technologies are still not widely used in routine practice owing to high equipment cost.

Conclusion

In the present study, the use of single-time, paired point registration without surface mapping combined with surgeon's perception for computer-assisted pedicle screw insertion has proven to be a safe and effective technique in degenerative lumbrosacral spine. The authors' technique did not rely solely on the image guidance. However, the navigation system would be very beneficial to improve decision-making, especially in surgery of patients with distorted spinal anatomy. Besides, this technique may decrease operative time without compromising the accuracy of pedicle screw placement.

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Potential conflicts of interest

None.

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การศึกษาความแม่นยำของการผ่าตัดใส่ pedicle screw โดยใช้คอมพิวเตอร์ช่วยผ่าตัดในบริเวณกระดูกสันหลังส่วน lumbrosacrum ที่เกิดจากความเสื่อมด้วยเทคนิค single-time, paired point registration โดยลำพังผสมผสานกับประสบการณ์ของศัลยแพทย์

ประเสริฐ เอี่ยมปรีชากุล, ชนะ จงโชคดี, วุฒิพงษ์ ฐิรโคไท

วัตถุประสงค์: เพื่อประเมินความแม่นยำของการผ่าตัดใส่ pedicle screw โดยใช้คอมพิวเตอร์ช่วยผ่าตัดในผู้ป่วยที่มีกระดูกสันหลังเสื่อมบริเวณ lumbrosacrum โดยใช้เทคนิค single-time, paired point registration โดยลำพังผสมผสานกับประสบการณ์ของศัลยแพทย์

วัสดุและวิธีการ: การผ่าตัดใส่ pedicle screw โดยใช้คอมพิวเตอร์ช่วยผ่าตัดบริเวณกระดูกสันหลังส่วน lumbrosacrum กระทำในผู้ป่วยทั้งหมด 62 ราย (363 screws) โดยการใช้ single-time, paired point registration โดยปราศจากการใช้ surface matching หลังจากการหาทางเข้าและแนวของ pedicle ภายใต้การใช้ image guidance แล้วศัลยแพทย์จะใส่ pedicle screw ต่อโดยใช้ประสบการณ์ของเขา หลังผ่าตัดผู้ป่วยจะได้รับการทำ DynaCT และจะถูกแปลผลโดยรังสีแพทย์ทางระบบประสาท 2 ท่าน สถิติแบบ Kappa ถูกนำมาใช้วัดระดับการเห็นพ้องระหว่างผู้สังเกตการณ์ ตำแหน่งของ screw ถูกจัดเกรดดังนี้: A = ทั้งหมดอยู่ภายใน pedicle; B = มีการทะลุผนังของ pedicle ทาง medial หรือ lateral น้อยกว่า 2 มม.; C = มีการทะลุผนังของ pedicle ทาง medial หรือ lateral ระหว่าง 2-4 มม.; D = มีการทะลุผนังของ pedicle ทาง medial หรือ lateral มากกว่า 4 มม. ผลลัพธ์ทางคลินิกอันได้แก่ a numeric pain score, อาการแสดงทางระบบประสาทและภาวะแทรกซ้อน ได้รับการตรวจสอบจากแฟ้มของผู้ป่วยทุกราย รวมทั้งค่าความผิดพลาดของการ registration, ระยะเวลาในการ registration, ระยะเวลาในการใส่ screw และปริมาณเลือดที่สูญเสียก็ถูกนำมาวิเคราะห์ด้วย

ผลการศึกษา: จากการศึกษา screw ทั้งหมด 363 ตัว รังสีแพทย์ท่านแรกแปลผลเป็นเกรด A 95.6%, B 4.1% และ C 0.3% ขณะที่รังสีแพทย์ท่านที่สองแปลผลเป็นเกรด A 95.3%, B 3.6% และ C 1.1% โดยที่ไม่มีเกรด D เลยในการศึกษานี้และไม่พบการบาดเจ็บต่อระบบประสาทและหลอดเลือดจากการใส่ pedicle screw เลยค่าเฉลี่ยของความผิดพลาดของการ registration คือ 1.54 $\pm$ 1.28 มม. (ระหว่าง 0.9-2.5) และค่าเฉลี่ยของเวลาที่ใช้ในการ registration คือ 3.64 $\pm$ 1.92 นาที (ระหว่าง 2-8) ส่วนเวลาเฉลี่ยในการใส่ screw ของผู้ป่วยแต่ละคนอยู่ที่ 20.29 $\pm$ 9.44 นาที (ระหว่าง 13-40) ค่าเฉลี่ยของความเจ็บปวดดีขึ้นจาก 6.45 $\pm$ 1.74 แต้มก่อนผ่าตัดเป็น 3.04 $\pm$ 0.82 แต้มหลังผ่าตัดในกลุ่มที่มี radiculopathy กำลังของกล้ามเนื้อดีขึ้นในผู้ป่วยทุกราย

สรุป: การใช้ single-time, paired point registration โดยปราศจากการใช้ surface mapping ผสมผสานกับการรับรู้ของศัลยแพทย์ในการใส่ pedicle screw โดยใช้คอมพิวเตอร์ช่วยผ่าตัด ได้รับการพิสูจน์ล้วว่าเป็นเทคนิคที่มีความปลอดภัยและมีประสิทธิภาพในกระดูกสันหลังที่มีความเสื่อมบริเวณ lumbrosacrum โดยเทคนิคของผู้นิพนธ์ไม่ได้ขึ้นอยู่กับเพียงแค่ image guidance เท่านั้นอย่างไรก็ตาม ระบบนำวิถีมีประโยชน์มากในการเพิ่มการตัดสินใจโดยเฉพาะอย่างยิ่งในการผ่าตัดผู้ป่วยที่ มีการเปลี่ยนแปลงทางกายวิภาคของกระดูกสันหลังนอกจากนี้เทคนิคนี้อาจจะช่วยลดระยะเวลาการผ่าตัดโดยรวมทั้งหมดโดยไม่ทำให้ความแม่นยำของการใส่ screw ลดลง