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Portable CT scanner-based navigation in lumbar pedicle screw insertion

Pavel Barsa · Petr Suchomel

Keywords Lumbar spine · Pedicle fixation · Operation technique · Intraoperative CT · Navigation

Learning targets

- Intraoperative use of a portable full body 32 slice CT scanner.
- System-assisted insertion of pedicular screws in lumbosacral region using CT-based image guidance.

Introduction

Since the introduction of frameless stereotactic navigation systems for intra-cranial surgery, technology has progressed significantly [1]. Computer-assisted techniques became available for spine surgery in the 1990s and helped improve safety and accuracy, particularly in instrumented procedures. CT-based optoelectronic navigation in spine was originally suggested by Nolte et al. [2]. Amiot et al. [3] later performed successful in vitro testing, using a magnetic-field based navigator, which, however, never gained clinical acceptance. Laine et al. [4] presented evidence for improvement of optoelectronic technique accuracy under clinical conditions, and this became an option to support implant insertion in recent years. Navigation systems in clinical practice are nowadays based on computer tomography imaging (CT-based navigation) or on fluoroscopy imaging (two- or three dimensional fluoroscopy based navigation).

The conventional CT-based navigation technique requires extensive preoperative preparation, including computed tomography with a defined protocol of data acquisition and transfer requirements, as well as a complex patient registration. The development of intraoperative CT scanning also addressed such issues. The conventional CT scanners can soon be expected to be replaced by portable CT scanners. The following paper aims to describe the intraoperative portable CT scanner image acquisition technique, data reconstruction and the planning for a screw trajectory, using a frameless stereotactic image-guidance system as well as demonstrating a safe pedicle screw placement.

Case description

A 61-years-old female with unremarkable past medical, family and social histories presented with 4 years complaints of mechanical low back pain together with slowly progressive one-year history of slight bilateral L5 and S1 weakness. She also described claudication after walking 300 meters, accompanied by pain and paresthesia in the back, buttocks, and lower limbs which she relieved by standing still and through lumbar spine flexion. Lumbar radiographs as well as MR images revealed degenerative changes of the entire lumbar region most prominent at the levels of L4/5 and L5/S1 (Figs. 1, 2). Secondary spinal canal stenosis in both presacral segments consisted of

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P. Barsa (✉) · P. Suchomel
Department of Neurosurgery, Neurocenter, Regional Hospital of Liberec, Liberec, Czech Republic
e-mail: pavel.barsa@nemlib.cz

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enlarged arthritic facet joints, intervertebral disc prolapses and foraminal stenosis due to intervertebral disc collapse (Fig. 3). Degenerative spondylolisthesis L4/5 was also described. The patient had been indicated for instrumented bisegmental decompression and fusion at the levels L4/5, L5/S1.

Surgical procedure

The patient's positioning before the surgery does not differ from that in ordinary instrumented lumbar procedures with midline dorsal approach.

Ten fiduciary markers are placed around the estimated skin incision. The markers, together with spinal structures and Stealth reference frame placed and tightened onto the L4 spinous process are scanned after appropriate skeletization of the segment L4-S1. The 32-slice full-body movable CT scanner produces DICOM compliant images which are automatically sent to the computer assisted surgical navigation system) via Ethernet connection. This allows for an immediate update of the CT image for the purpose of navigation consisting of helical scans of 1.4 mm thickness. The fiduciary markers appear in the 3D reconstruction of the skin surface and support the surgical field registration by the probe rod. The exact position of the probe rod as well as the position of other navigated instruments, including for example the drill guide are confirmed by an electro-optical camera in real time. This camera, connected to the computer, follows the position of passive infrared reflectors or infrared light-emitting diodes (LEDs) attached to the surface of the instruments and serves as a position sensor. Registration is performed in order to accurately match the computer-reconstructed 3-D surgical space with the real surgical space. The calculated accuracy obtained during registration process was 0,6 mm. After the registration process is completed, the surgeon should also check the accuracy of the system against known anatomical landmarks.

Fig. 1 Preoperative AP and lateral plain radiographs of the lumbar spine demonstrating degenerative changes of thorough lumbar region with degenerative spondylolisthesis at the level L4/5 and significant narrowing of the intervertebral space L5/S1. Vertebral body osteophytes together with hypertrophy of zygoapophyzeal joints are also present

Fig. 2 Midsagittal and right parasagittal T2-weighted MR images showing central spinal canal stenosis of the level L4/5 and foraminal stenosis L4/5 and L5/S1. Loss of water content and height of both intervertebral discs together with fatty transformation of vertebral bodies adjacent to L5/S1 intervertebral space can be seen

The obtained images are further used for pre-operative planning such as instrumentation selection inducing estimation of the size and trajectory of implants. With the help of a navigated probe, the surgeon finds the entry points for screws and decorticates dorsal cortex with a burr. A technical drill of 4 mm diameter is used to create a path for the screw through the cancellous bone of the pedicle into the ventral part of vertebral body. The medio-caudal orientation and the angle of approach are dictated by the navigated drill guide. The drilling depth corresponds with the length of the estimated pedicular screws. After checking the path by a navigated probe rod which also serves as a pedicle probe, 50 mm long polyaxial screws of 6 mm diameter were inserted into the L4 and L5 vertebrae and 7 mm diameter screws into the S1 vertebra.

Conventional direct decompression of neural structures was carried out by means of laminectomy and foraminotomy in both spinal segments. After appropriate clearance of intervertebral space and distraction, two PLIF titanium spacers were inserted into both intervertebral spaces and supplemented by bone graft together with graft substitute. A mixture of calcium-phosphate and autologous bone material covered also decorticated bone surface lateral to the entry points in order to achieve 360 degree fusion.

At the end of the surgery a control the final anatomical situation, including the implant position is made. The images can be uploaded to surgical navigation or any image storage system (Fig. 4).

Postoperative information

Postoperative neuroimaging showed correct position of implants and acceptable alignment of the vertebral bodies (Fig. 5). The patient was mobilized 24 h after the surgery. Immediately after the procedure the patient reported disappearance of radicular symptoms and there were also no signs of claudication during the postoperative period. There were no medical complications after the surgery; slowly decreasing intensity of postoperative pain was sufficiently controlled by NSADs.

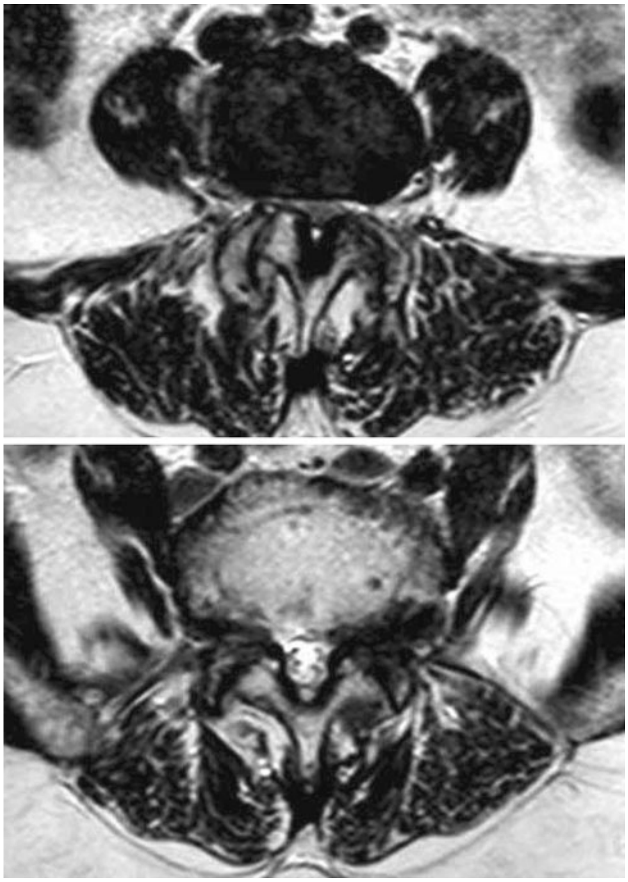

Fig. 3 Axial T2-weighted MR scans of both presacral intervertebral segments demonstrating the degree of central and foraminal stenosis

Discussion and conclusion

Gelalis et al. [5] performed a systematic review of 26 in vivo prospective studies comparing free hand, fluoroscopy guidance and navigation techniques. Studies subjected to metaanalysis included in total 1,105 patients with 6,617 inserted screws. The accuracy of pedicular screw insertion was as follows: in free-hand technique, the percentage of screws fully contained in the pedicle ranged from 69 to 94 %, with the aid of fluoroscopy from 28 to 85 %, using CT navigation from 89 to 100 % and screw insertion accuracy in fluoroscopy-based navigation ranged from 81 to 92 %. The screws positioned by free-hand technique tended to perforate the cortex medially, whereas the screws placed with CT navigation guidance seemed to perforate more often laterally. In conclusion they indeed demonstrated higher accuracy and increased safety in navigated pedicle screw placement in comparison with free-hand technique or with fluoroscopy controlled insertion.

There is also a time concern issue in CT-based navigation of pedicle screws. Most published studies indicated that conventional CT navigated procedures increased surgery time [6, 7]. The situation in portable intraoperative CT-based navigation seems to be similar, despite the fact that anatomical registration in superficial skin landmarks is less demanding. Good handling of the navigation system by the surgeon remains a basic prerequisite for optimal surgical result.

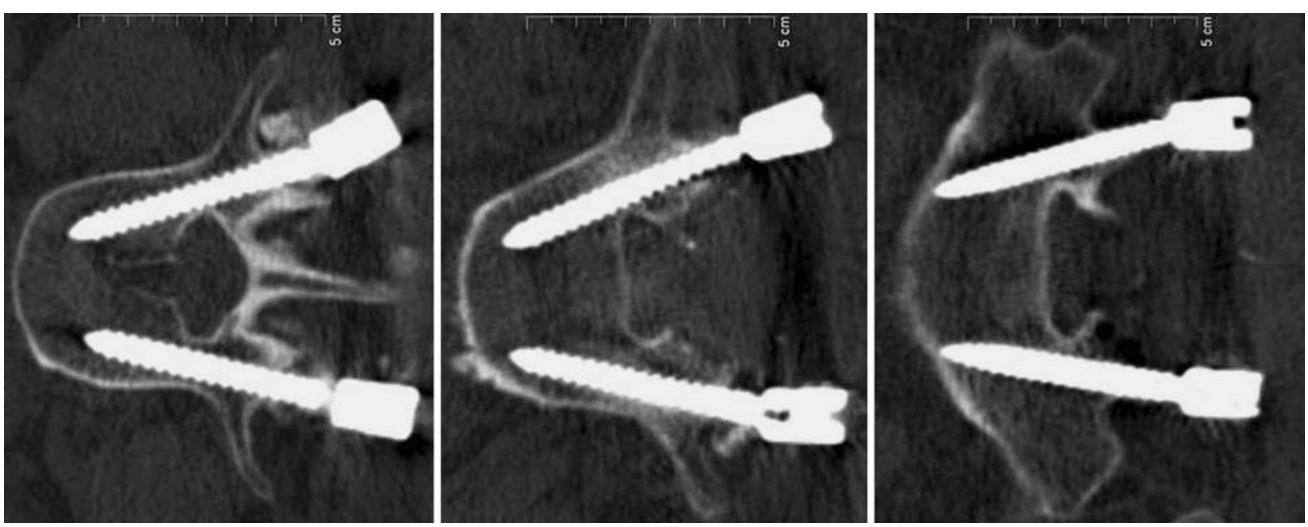

Fig. 4 Axial CT scans showing correct position of transpedicular screws in L4, L5 and S1 vertebra

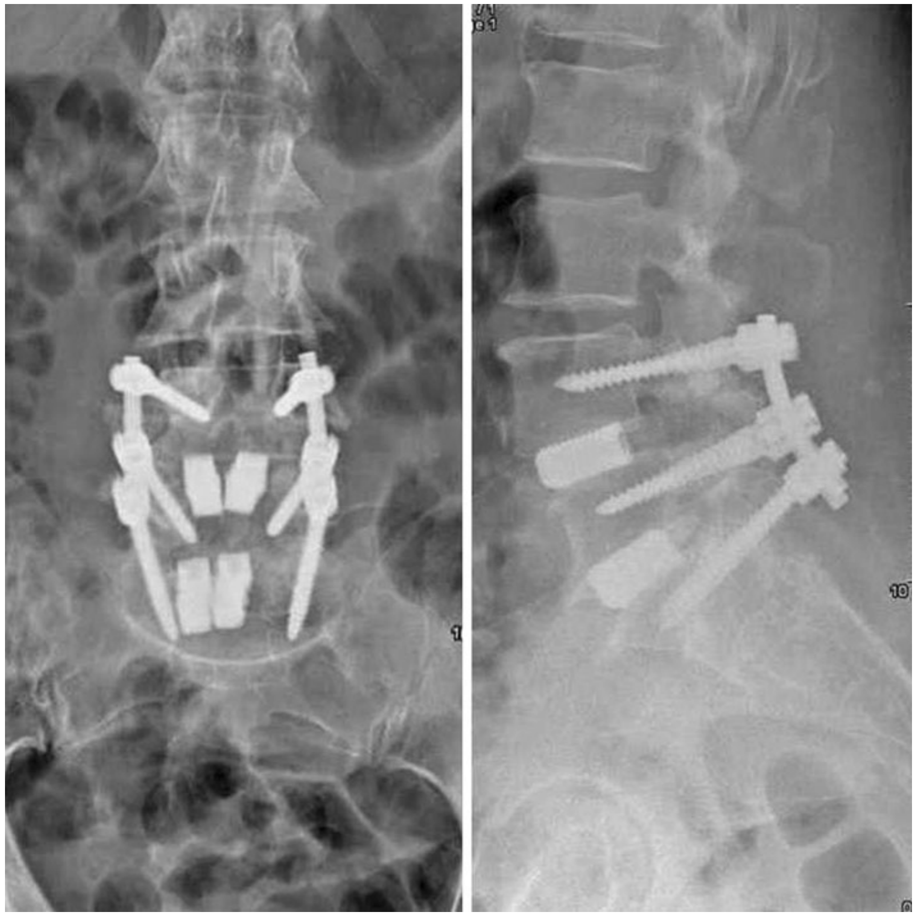

Fig. 5 Postoperative AP and lateral radiographs demonstrating implant position in L4-S1 segment and final anatomical situation of lumbar spine

The portable CT scanner provides affordable high quality intraoperative imaging of bone and soft tissue for use in any spinal procedure, enhancing neuro-navigation and surgical outcomes.

Conflict of interest None.

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