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Intraoperative portable CT-scanner based spinal navigation - a feasibility and safety study

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Abstract

Background Navigation based on an intraoperative CT scan is not a new approach to spinal instrumentation. Innovative intraoperative imaging technology, however, opens new horizons to more precise image acquisition as well as to further workflow. Planning of screw entry-points and trajectories in this study had been based on intraoperative imaging obtained by a portable 32-slice CT scanner. This prospective study evaluates feasibility, accuracy, and safety of this novel approach in an initial series of 85 surgeries.

Method Medical records and radiological materials of 82 patients who underwent the first 85 consecutive stabilisations were analysed. Incorrect screw position, medical and technical complications as well as availability of this procedure in particular spinal levels were the subject of evaluation.

Results Out of 571 implants inserted in all spinal levels, only five screws (0.87 %) did not meet the criteria for correct implant position. These screw misplacements had not been complicated by neural, vascular or visceral injury and the surgeon was not forced to change the position intraoperatively or during the postoperative period. The quality of intraoperative CT imaging sufficient for navigation was obtained at all spinal segments regardless of a patient's habitus or positioning or comorbidity.

Conclusion Intraoperative portable CT scanner-based navigation seems to be an effective way of doing spinal instrumentation guidance. High precision of implant insertion confirms the preconditions of navigation usage during more complex surgeries at any level of the spine.

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Abbreviations

CT	computed tomography
LED	light emitting diode
3D	three-dimensional
CTDI	computed tomography dose index
DLP	dose length product

Introduction

In the field of neurosurgery, new frameless stereotactic navigation systems have been reported since the 1990s [1]. Their function is based on highly precise monitoring of labeled instruments positioned in the registered surgical field. Even if this procedure is associated with a certain degree of inaccuracy, mainly due to the movement of brain structures during retraction and resection of brain tissue (brain shift); this method has been widely clinically adopted and has become a standard in intracranial surgery [2].

Applying the same principle to spinal surgeries was more complicated. The problems are caused by changes in the alignment of individual vertebrae compared to intracranial structures where the anatomical position is relatively constant. Anatomical interpretation of the position in a moving spine, as acquired during preoperative imaging, is virtually impossible to predict over time. With the exception of individual vertebrae and static spinal segments (ankylosis), it is not possible to register anatomic spinal sections in a way corresponding with the preoperative scan. Despite these problems, navigation techniques appeared in spinal surgery in the 1990s. A spinal navigation system based on thke optoelectronic principle was

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designed by Nolte et al., based on laboratory work in 1995 [3]. Its function and safety in clinical practice was described in a comparative study with fluoroscopy guided surgeries five years later by Laine et al. [4]. Recently, the methods of navigated procedures have been developing. A breakthrough was the recent introduction of intraoperative 3D fluoroscopy [5] and much more precise intraoperative CT [6–8] as the initial imaging for the navigated spinal procedures. Intraoperative imaging will capture the spinal segment of interest in the anatomical position the surgeon will instrument. This way, precision and security of individual steps can be ensured [9].

The authors of the presented paper analyzed prospectively collected data in the series of first 85 consecutive surgeries where navigated spinal instrumentation had been based on intraoperative portable CT-scanner imaging. They analyzed technical feasibility of the navigation and CT scan acquisition in all spinal levels. This study further evaluated the accuracy of screw insertion and safety of the procedure for the patient.

Methods

Surgical technique

Not less than 12 h before the surgery, a competent patient was given all the relevant information about the treatment and voluntarily gave the consent not only with the stabilization but also with the intraoperative portable CT scanner-based navigation. The informed consent included discussion of the nature of the procedure, reasonable alternatives to the proposed intervention, and the relevant risks and benefits associated with the procedure, including a possible higher radiation dose from the portable scanner.

The patient position as in in classical fluoroscopy guided surgeries should be simultaneously chosen so that the vertical axis of the instrumented segment corresponds, if possible, with the axis of the portable CT scanner gantry (Body Tom ™®, NeuroLogical, Danvers, USA) (Fig. 1). In the area of the median skin incision, ten fiducial markers provided by the manufacturer of the navigation system (Stealth™, Medtronic, Minneapolis, USA) were placed. They were used for surgical field registration after the skeletization. A further feature in the surgical field registration is the Stealth navigation tracking device attached to a not moving spinous process of one of the instrumented vertebrae (Fig. 2). A portable full body 32-slice CT scanner acquires images of the selected spinal section including the registration markers. It is automatically sent (in the DICOM format) to the navigation system using a direct Ethernet connection. In spinal fixation, we use helical scanning to produce a 1.25 mm slice thickness. The picture is reconstructed into a three-dimensional volume by the Stealth navigation system that will render the skin surface (in the soft tissue display mode) including the fiducial markers. In the 3D

Fig. 1 The portable CT scanner in working position

calcified tissue display mode, we will identify the spinal surface structures and insert virtual implant trajectories in this view. The navigation system also facilitates eventual visualization of the screw trajectory course in sagittal, coronary, and transversal planes. In addition, the navigation system offers "probe view" software, which displays the transition of a virtual implant through a bony structure, similarly to an endosonography examination (Fig. 3). This way, we can define the length and diameter of the intended implant.

All the steps of instrumentation are made by the prepared navigation plan. The exact position of the screw entry-point may be determined using a navigated probe and may be marked with a burr on the surface of the vertebra. The dip should be deep enough to provide support for a technical punch. We will use it to drill the trajectory to the specified depth and orientation. After drilling the passage for the screwwe may predrill the thread to bone or we may insert the implant directly (self-tapping screws). In multiple stage instrumentations a tracking device is attached to a spinous process as close to the middle parts of the instrumented section as possible. Instrumentation in this case starts from the peripheral part (e.g., in L3-L5 stabilization, we attach the frame

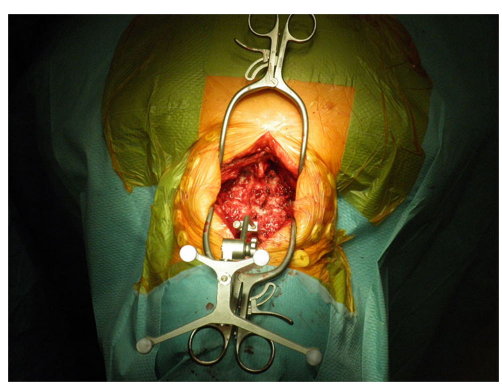


Fig. 2 The navigation tracking device attached to the spinous process of one of the instrumented vertebra at cervical level

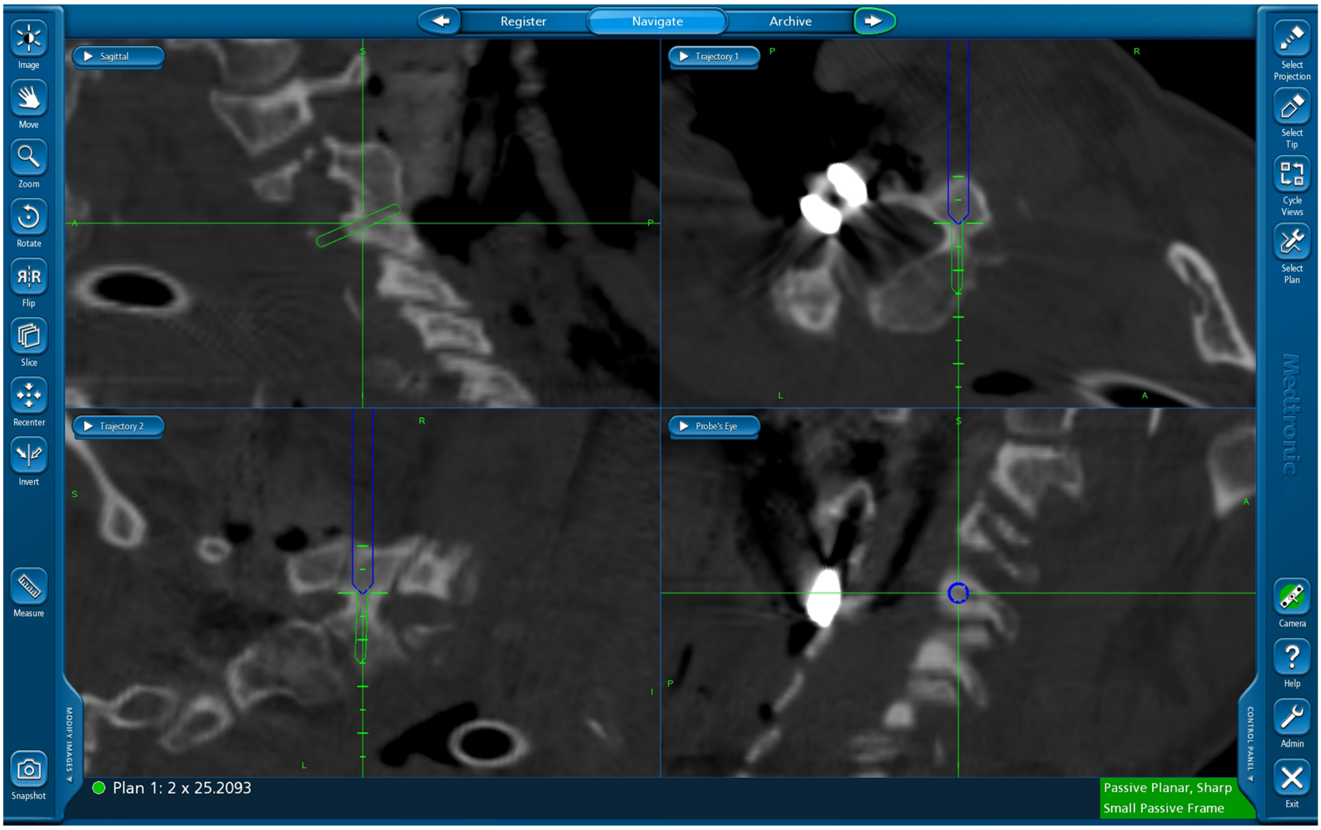


Fig. 3 Plan for pedicular screw insertion in the cervical spine

to L4 and instrumentation starts from L3 and L5). This way navigation inaccuracy due to deflection of the tracking device during the instrumentation may be minimized. After implant insertion, we finish the decompression or reconstruction and secure the individual segments of the internal fixator. The correct implants position is confirmed before the end of procedure with a portable CT scanner (Fig. 4).

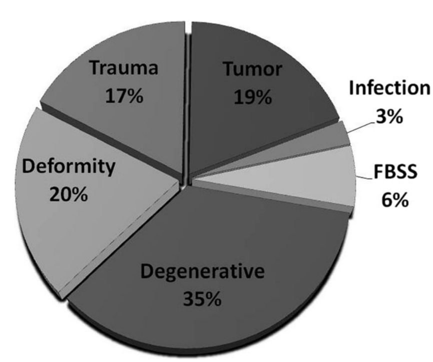
Patients

During the first 18 months of portable CT scanner usage in our department (October 2012–April 2014), the technology of navigated spinal procedures based on intraoperative CT imaging was used in the initial series of 85 consecutive surgeries performed in 82 patients, where we inserted a total of 571 screws. The patient group consisted of 43 men and 39 women of mean age of 54.1 years (range 25–79 years, median 56 years) with the majority of patients being operated for a degenerative condition in the lumbar spine. Exact information about the indication for the surgical procedure is shown in Graph 1; anatomic distribution of the implants is depicted in Graph 2.

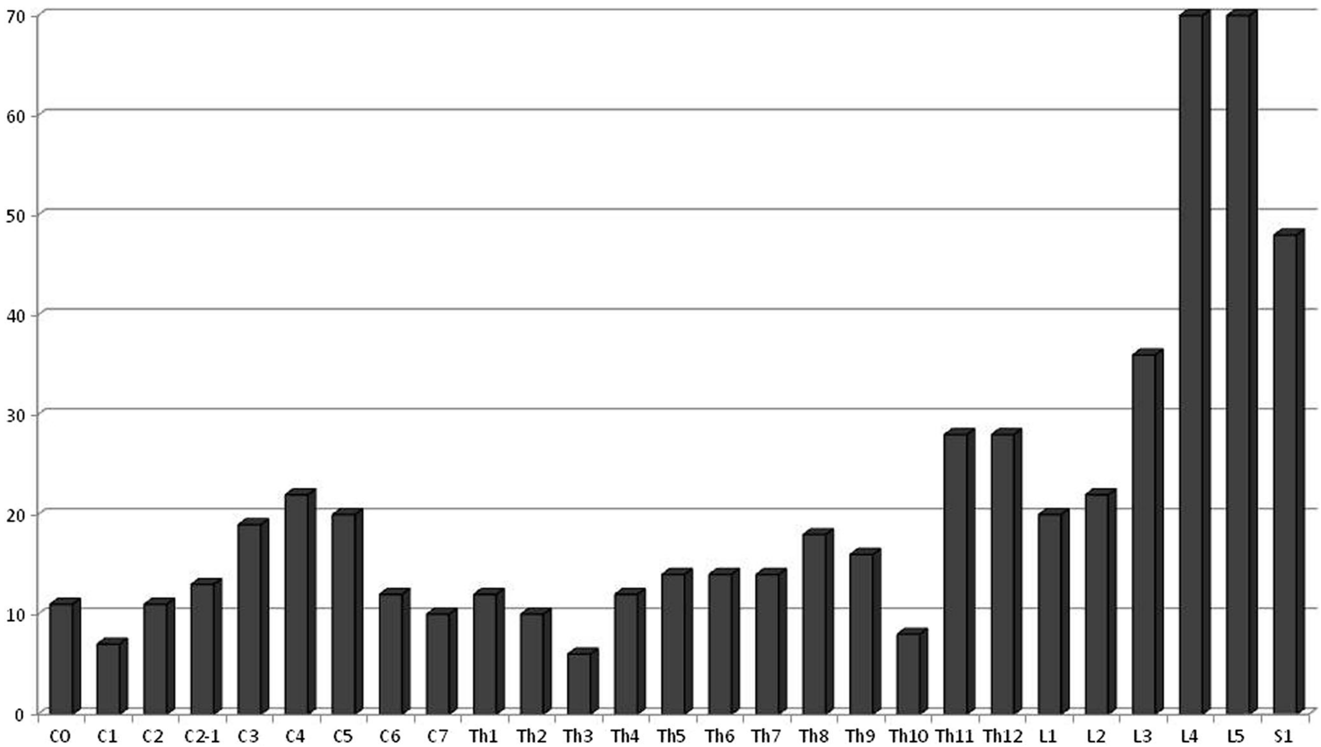
Fig. 4 Correct anatomical position of pedicle screws inserted at the level of C5

Evaluation of accuracy of the screw placement

For the purpose of this study, the correct screw position is defined as the positioning of the screw where no part of the



Graph 1 Indications for spinal stabilizations



Graph 2 The anatomic distribution of implants

screw shaft or tip penetrates the surface of the instrumented bony structure. In this aspect, not only breeching of the pedicle cortex but also perforation of the cortical bone covering the surface of the vertebral body or surface of the vertebral foramen is defined as incorrect screw insertion [10].

Results

Altogether five screws out of 571 inserted spinal implants (0.87 %) did not meet the criteria for correct position: in a single L5 pedicle screw, the threads penetrated through the caudal cortex of the pedicle; one thoracic screw in the T5 and one in the T8 were found to perforate through the ventral vertebral cortex less than 3 mm and a single screw inserted into the T6 vertebra breached the medial pedicle cortex (Fig. 5). The incorrect insertion in ventrally perforating thoracic screws had been adjusted before closing. In instrumented cervical segments, one C3 pedicle screw perforated the cranial end-plate due to rostral orientation of the screw. In our series, there was no neurovascular structure or visceral injury or dural sac laceration observed. Correct screw insertion prevented breaking of the instrumented pedicle, and there were no clinical consequences that would necessitate a reoperation to optimize the implant position or decompression of neural structures.

During the intraoperative CT based surgeries, we did not have a single case of wrong level surgery or a case where the surgical field lucidity was disrupted due to obesity of the patient or anatomical localization with poor radiological visibility or due to radiological artifacts of metal instruments.

After the registration of the surgical field was completed, the navigation system analyzed the precision of the registration process. Average value in our operated patients was 0.44 mm (range of 0.2–1.0 mm), and all calculated values were sufficient to confidently perform instrumentation. In general, higher precision was reached over a larger registered field.

This method of navigated screw insertion based on intraoperative portable CT scanner imaging was applicable in all anatomical levels throughout the spine. In no case we were forced to convert navigated screw insertion into a fluoroscopically guided procedure. The Body Tom ™® gantry diameter (85 cm) allowed us to perform image acquisition even in obese patients. In specific anatomical situations, like in the lumbo-sacral junction, the relatively broad angular scatter requires changing the camera position so that it is able to capture the position of passive reflectors in navigated instruments. The change of camera position assumes the operating theater staff cooperation. There is only a few seconds delay in the overall time to complete the surgical procedure.

Inclusion of the intraoperative CT-based navigation is associated with an increased number of surgical steps. New operation actions include: acquisition of the initial scan, processing of the CT image, trajectory planning, and surgical field registration. In our setting, the completion of these steps

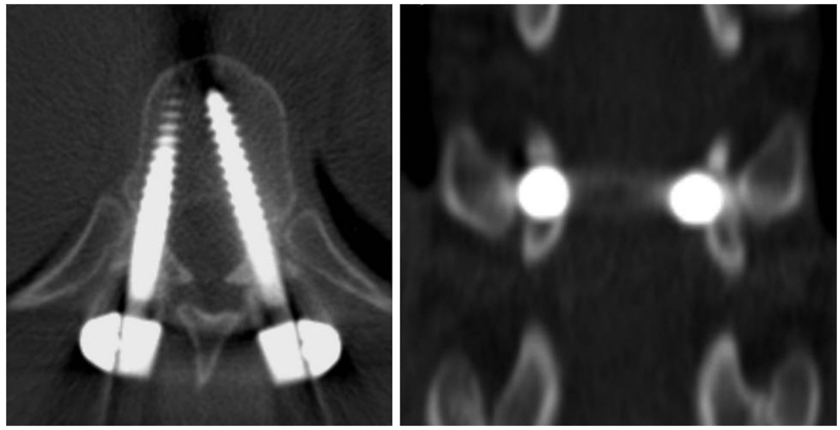


Fig. 5 The CT scan obtained after T6 pedicle screws insertion had identified a medial cortical breach of 2 mm in the left site. This situation was considered to be acceptable without the need for replacement and uncomplicated postoperative course confirmed the consideration

resulted in an 18–40 min increase in the operation time, according to the extent of the instrumented area and complexity of anatomy.

Using the intraoperative CT imaging navigation eliminates the irradiation of the operating theatre staff during the insertion of screws , as the surgical and anesthesia teams are out of the irradiated area during the scanning. CT image acquisition is associated with a higher radiation load for the patient. In our patients, this radiation load is characterized by average values of CTDI at vol 63.8 mGy and DLP 1,660.3 mGy.cm (median 65.6 mGy and 1,619 mGy.cm).

Discussion

Navigated spinal instrumentation in 571 inserted implants series proved its precision and safety with an error rate of 0.87 %. It was a series of 85 instrumented spinal procedures in 82 consecutive patients in whom we decided to test the functionality of the new system to reveal eventual complication. In the group of the very first patients, we used anatomical and even fluoroscopy control during implants insertion for additional verification. After getting used to the system (five to eight surgeries), we completely relied on the virtual reality of the navigation system.

As we concentrated on gaining the maximum experience, the navigation had been used even in the lumbar instrumentation, i.e., in situations, where we would reach comparable results as measured by the insertion precision and clinical safety We even used standard fluoroscopic guidance during the surgery. This step has significantly helped in gaining early clinical experience that allowed us operate with higher confidence even in anatomically more complex areas of the upper cervical spine and the cervico-thoracic junction. Simultaneously, we gained experience with instrument navigation of high angular range during lumbar stabilizations. Intersegmental angles in lumbar lordosis may reach tens of degrees. In this situation, the optoelectronic camera system may not be able to read the position of the registered instrument in the field and requires a change of camera position. It is a situation showing a weak point of the optoelectronic navigation system, and we may presume that an electromagnetic navigation system independent on visibility of the surgical field registration points can solve these problems in the future [11–13].

Other issues to discuss are higher time demands and the patient's radiation exposure. The duration of surgery is prolonged by acquiring the initial scan, processing of the CT image, trajectory planning, and surgical field registration. Increasing the operation time, measured from the skin incision to wound closure, was associated with increasing the anesthesia duration and prolonging the period when the surgical wound was open. About a half an hour delay found during our procedures is significant in short stabilization [14]. With the increasing number of instrumented segments, the time difference decreases when compared to fluoroscopically guided surgeries. We suppose, particularly in large surgeries of spinal deformities, that the time difference will not be significant [15]. Theoretically, the time delay in navigated procedures may be shortened using methods of automatic registration. The CT scan acquisition is associated with higher radiation exposition of the patient compared to standard fluoroscopy; however, it eliminates the operating theatre staff irradiation being out of the irradiated part of the operating theatre [16]. Both of these moments, prolonging the surgery duration and higher irradiation of the patient, should be counterbalanced by the safety of the surgery itself.

Despite the increased number of surgical steps, the learning curve is relatively less steep when both the surgeon and the OT staff become proficient with a minimum amount of effort/time during the series of the first five to eight procedures.

Further technological development in this area may focus on possible automatic registration and on improving the visibility of marked instruments in the surgical field. Both aims may be reached by changing the parameters of the electro-optic system or via the stated replacement for another navigation modality. All the progress in this area may lead to further minimization of the surgical approach and to the utilization of robotic placement for all spinal instrumentation [17]. The clinical experience of the surgeon supported by anatomical and biomechanical knowledge, in combination with the professional approach of the full team, will still be a prerequisite for optimal surgical results.

Conclusion

Navigation based on intraoperative portable CT-scanner imaging is one of the future paths leading to more precise implant insertion into spinal structures. Our initial experience has proven the performance of the system in the spinal surgery field and has confirmed its usability in all the anatomical levels of the spine. High precision of implant insertion confirms the preconditions of navigation usage during surgeries of deformities in congenital or dysplastic or post-traumatic situations as well as in anatomically complex areas of the cervical spine and cervical-thoracic junction. Previous clinical experience with a responsible team approach is a prerequisite of good morphological and clinical results.

Conflicts of interest None.

References

1. Golfinos JG, Fitzpatrick BC, Smith LR, Spetzler RF (1995) Clinical use of a frameless stereotactic arm: results of 325 cases. J Neurosurg 83:197–205
2. Willems PW, van der Sprenkel JW, Tulleken CA, Viergever MA, Taphoorn MJ (2006) Neuronavigation and surgery of intracerebral tumours. J Neurol 253:1123–1136
3. Nolte LP, Zamorano LJ, Jiang Z, Wang Q, Langlotz F, Berlemann U (1995) Image-guided insertion of transpedicular screws. A laboratory set-up Spine 20:497–500
4. Laine T, Lund T, Ylikoski M, Lohikoski J, Schlenzka D (2000) Accuracy of pedicle screw insertion with and without computer assistance: a randomized controlled clinical study in 100 consecutive patients. Eur Spine J 9:235–240
5. Waschke A, Walter J, Duenisch P, Reichart R, Kalff R, Ewald C (2013) CT-navigation versus fluoroscopy-guided placement of pedicle screws at the thoracolumbar spine: single center experience of 4, 500 screws. Eur Spine J 22:654–660
6. Fan Chiang CY, Tsai TT, Chen LH, Lai PL, Fu TS, Niu CC, Chen WJ (2012) Computed tomography-based navigation-assisted pedicle screw insertion for thoracic and lumbar spine fractures. Chang Gung Med J 35:332–338
7. Steudel WI, Nabhan A, Shariat K (2011) Intraoperative CT in spine surgery. Acta Neurochir (Wien) Suppl 109:169–174
8. Tonn JC, Schichor C, Schnell O, Zausinger S, Uhl E, Morhard D, Reiser M (2011) Intraoperative computer tomography. Acta Neurochir (Wien) Suppl 109:163–167
9. Costa F, Cardia A, Ortolina A, Fabio G, Zerbi A, Fornari M (2011) Spinal navigation: standard preoperative versus intraoperative computed tomography data set acquisition for computer-guidance system: radiological and clinical study in 100 consecutive patients. Spine 36:2094–2098
10. Kosmopoulos V, Theumann N, Binaghi S, Schizas C (2007) Observer reliability in evaluating pedicle screw placement using computed tomography. Int Orthop 31:531–536
11. Amiot LP, Lang K, Putzier M, Zippel H, Labelle H (2000) Comparative results between conventional and computer-assisted pedicle screw installation in the thoracic, lumbar and sacral spine. Spine 25:606–614
12. Fraser J, von Jako R, Carrino J, Härtl R (2008) Electromagnetic navigation in minimally invasive spine surgery: results of a cadaveric study to evaluate percutaneous pedicle screw insertion. SAS J 2:43–47
13. von Jako R, Finn MA, Yonemura KS, Araghi A, Khoo LT, Perez-Cruet M (2011) Minimally invasive percutaneous transpedicular screw fixation: increased accuracy and reduced radiation exposure by means of a novel electromagnetic navigation system. Acta Nerochir (Wien) 153:589–596
14. Sasso RC, Garrido BJ (2007) Computer-assisted spinal navigation versus serial radiography and operative time for posterior spinal fusion at L5-S1. J Spinal Disord Tech 20:118–122
15. Papadopoulos EC, Girardi FP, Sama A, Sandhu HS, Cammisa FP Jr (2005) Accuracy of single-time, multilevel registration in image-guided spinal surgery. Spine J 5:263–267
16. Bandela JR, Jacob RP, Arreola M, Griglock TM, Bova F, Yang M (2013) Use of CT-based intraoperative spinal navigation: management of radiation exposure to operator, staff, and patients. World Neurosurg 79:390–394
17. Ringel F, Villard J, Ryang YM, Meyer B (2014) Navigation, robotics and intraoperative imaging in spinal surgery. Adv Tech Stand Neurosurg 41:3–22