Navigation-assisted surgery for tumors of the spine

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Abstract

Purpose Computer-assisted navigation systems are largely used for pedicle screws positioning in degenerative and traumatic spine surgery. In oncologic spine surgery its use is still developing and could be extended for tumor identification and excision. Aim of this paper is to present our experience.

Methods Seven selected patients (5 females, 2 males), mean age 44 years (min 17–max 62) affected by primary benign or malignant tumors of the spine or spine metastases were surgically treated with the use of computer-assisted navigation system from March to October 2011.

Results At 18 months mean F.U. (min 15–max 23), no LR were observed. Revision surgery was necessary only in one case for C1 pedicle screw malpositioning.

Conclusions Navigation system can improve surgical accuracy in screws placement and tumor localization and excision. Learning curve and technical aspects must be considered to avoid potential serious mistakes.

Keywords Navigation · Computer-assisted spine surgery · Oncologic surgery · Spine surgery · Tumors

Introduction

Spine surgery is a high-risk surgery carrying the potential of injury to the spinal cord, nerves and important vascular

structures [4]. After many years of practice, experience, development of new surgical instrumentation and variety of surgical procedures requirements for surgical accuracy, safety and good results are also growing. Spine surgery requires knowledge of spinal anatomy and biomechanics and depends on proprioceptive feedback during surgery. Effectiveness and safety depends on accuracy of surgery.

There is general agreement among surgeons that imaging techniques are essential for safe and accurate placement of spinal instrumentation regardless of the complexity of the operation, the anatomical region, and the level of training and comfort level of the individual surgeon. Traditionally imaging techniques involve the use of intraoperative fluoroscopy [14] for active guidance throughout surgery [11]. Unfortunately the use of intraoperative fluoroscopy has significant drawbacks. The entire surgical team (surgeon, assistant surgeon and scrub nurse) has to stay at the surgical field, directly adjacent to the image intensifier. Occupational radiation exposure leads to a high morbidity and mortality risk concerning the development of a thyroid cancer. Radiation-reducing procedures and shielding devices such as a whole-body apron, lead-collar and goggles lead to a significant decrease of mortality and morbidity of radiation-sensitive tissues. This gear is extremely uncomfortable, especially when forces the surgical team to work in awkward positions.

Surgical navigation system is a promising technique that addresses many of these concerns [17, 18]. Computer-guided navigation techniques in spinal instrumentation improve screw placement accuracy [7, 20, 25], potentiate the ability to maximize the screw diameter relative to the pedicle, and reduce potential injury to critical neurovascular structures [1, 21]. Navigation systems are already widely used mainly for pedicle screws placement [10, 23, 24].

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In oncologic spine surgery the navigation system could be very helpful for tumor identification and resection, for specific device placement (electroporation's electrodes) and for the execution of mini-invasive surgical procedure (vertebroplasty). The aim of this study is to evaluate prospectively the results obtained using the navigation system in oncologic spine surgery in a series of seven selected patients.

Materials and methods

From March to October 2011, seven selected patients, five females and two males, mean age 44 years (min 17–max 62) affected by primary or metastatic tumors of the spine have been surgically treated using computer-assisted navigation system.

Pre-and post-operative X-ray and CT scan were performed in all cases.

Indications for surgery were: C2 aggressive angioma; T9 osteoid osteoma; T2 osteoblastoma; C2 pathological fracture due to plasmocytoma; L2 uterus metastasis; T3 pancreas metastasis; L5 melanoma metastasis;

Intralesional excision without instrumentation was performed in case of osteoid osteoma and osteoblastoma; C2 vertebroplasty in case of aggressive angioma; C1–C4 posterior instrumentation in case of C2 plasmocytoma; palliative posterior decompression and instrumentation for L2 metastasis; palliative posterior decompression, instrumentation and T3 vertebroplasty for T3 metastasis; palliative posterior decompression and electroporation in case of L5 melanoma metastasis.

In all cases Medtronic (StealthStation® Navigation System) or Brainlab (VectorVision Spine®) navigation system was used.

The navigation system comprised a computer workstation, reference frame with passive markers, standard probe, and electro-optical camera connected to the computer workstation, which served as a position sensor. The basic data used for navigation included the preoperative computed tomography (CT) imaging data (slice thickness, 2.5 mm; slice range 2 mm) and were matched with intraoperative fluoroscopy images. The data were transferred and recorded on the system computer and reconstructed into 3D images.

After exposing the posterior element, the reference frame of the navigation system was mounted on the exposed spinous process or, in the cervical cases, on the Mayfield support.

Under the navigation system assistance pedicle screws were placed and precise real-time tumor localization was performed.

The accuracy of computer-assisted pedicle screw positioning was evaluated in terms of cortical perforations

graded by 2-mm increments: Grade I (good, no cortical perforation), Grade II (screw outside the pedicle less than 2 mm), and Grade III (screw outside the pedicle larger than 2 mm).

From an oncologic point of view all the patients were classified as NED (no evidence of disease), CDF (continuous disease free) AWD (alive with disease) or DOD (dead of disease).

Results

Mean F.U. is 18 months (min 15–max 23).

No complications were recorded intraoperatively.

A total number of 20 pedicle screws were placed.

With regards to their placement accuracy, 14 screws (70 %) were graded I, 5 screws (25 %) graded II and 1 screw (5 %) graded III (C1 right pedicle screw).

In this last case (graded III), C1 pedicle screw removal was needed and new instrumentation was performed (C0–C4).

From an oncological point of view at the last F.U. no LR were recorded.

The three patients affected by benign primary tumors, after 18 months mean F.U. (min 15–max 23), were classified as NED and CDF.

The patient affected by C2 plasmocytoma after 16 months F.U. is actually classified as NED (Hematologic chemotherapy after surgery was performed).

The three patients affected by spinal metastases after 17 months mean F.U. (min 15–max 20) were classified as locally NED.

Discussion

The state of the art of image-guided spine surgery is heterogeneous in the different spine surgery branches.

The most common application of image-guided spine surgery is nowadays pedicle screws placement [8, 15]; the clinical benefits in terms of increased accuracy and reduced exposure [6, 9] to ionizing radiation are well documented.

The application of this technology for spinal tumor surgery is being developed.

Only few publications report on image-guided spine tumor surgery.

Two papers report on a total of five patients with benign tumors [12]. Rajasekaran et al. [16] report a series of four patients treated for osteoid osteoma in the cervical, thoracic and lumbar spine. Van Royen et al. [22] report on osteoid osteoma in the thoracic and lumbar spine using an image-guided high-speed drill in five patients. Image-guided surgery for dorsal instrumentation in eight patients with

metastatic disease of the thoracic spine was analyzed by Arand et al. [2] and Gebhard et al. [5] who report on 12 patients. Smitherman et al. [19] report on a case of Giant Cell Tumor (GCT) in the thoracic spine, Nagashima et al. [13] described a case of C2 osteoid osteoma curetted using a navigation system.

In March 2011 for the first time this technology was applied to oncologic spine surgery in our unit.

The patient was a 52-year-old female presenting low back pain (VAS = 8/10) resistant to medications due to L2 uterus metastasis (WBB: sec. 6–1; lay. B–C) [3] previously treated with local radiotherapy.

No neurological deficits were present before surgery (Frankel E). Videoendoscopic L2 debulking and percutaneous screws fixation L1–L3 under navigation system control were performed. From the day after surgery the patient was able to stand and walk and a pain reduction was recorded (VAS 3/10). Post-operative CT scan has shown well-positioned screws (2 grade I and 2 grade II) (Fig. 1 a–i).

The second case of this series was a 61-year-old female presenting low back pain and left sciatic pain due to L5 melanoma metastases (WBB: sec. 5–6; lay. B–C) and L4–L5 left herniated disc.

Surgical planning was mini-invasive L4–L5 left hemiectomy after L4 laminectomy and local mini-invasive treatment of the metastasis using electroporation. Using a real-time 3D imaging reconstruction of the anatomy of the vertebral body it was possible to clearly identify the tumor mass and place electroporation (local electrochemotherapy) electrodes around the metastases.

The 6 months F.U. CT scan underlined a small osteolytic area in the same position previously treated. In order to exclude a local recurrence PET-CT and CT scan trocar biopsy were executed. The last PET-CT final result was negative and pathologist's final report referred the presence of necrotic tissue, as the consequence of local chemotherapy (Fig. 2 a–h). After 17 month F.U. the patient is NED.

The first results obtained were considered positive and the application of a navigation system useful. In particular, the possibility to match pre-operative imaging (i.e. CT scan) with real-time 3D anatomy reconstruction during the surgical procedure was considered interesting for the treatment of the tumor of the spine not only to detect neurovascular structures, but also to define in real time the tumor mass margin and check step by step the removal.

Moreover, new technologies developed for spinal navigation system, permit to upload pre-operative patient's MRI and match it with intraoperative images, giving the surgeons the possibility to better define tumor's pseudocapsule or capsule, neurovascular structures and soft-tissue surrounding the lesion.

For these reasons the use of navigation system was extended to primary tumors.

The first case treated was a 17-year-old female presenting scoliosis and thoracic spine pain due to T9 Osteoid Osteoma (WBB: sec. 10–7; lay. B–C).

Right thoracoscopy was performed first. Under fluoroscopic control T9–T10 vertebral bodies were identified. Carbon fiber marker was placed on T9 spinous process, navigation system was set and once the lesion was identified it was completely removed using a high-speed drill connected to the navigation system. In this way it was possible to check moment by moment every drill movement and observe in real time the osteoid osteoma removal.

After surgery the patient was strictly followed up by CT scan and 20 months after surgery she is CDF and NED.

At the beginning of our experience the use of navigation system was limited to lumbar and thoracic spine.

The use was extended for the first time to the cervical spine in case of C2 aggressive angioma (WBB: sec. 11–5; lay. B–C) in a 37-year-old female.

The patient was previously treated using a Halo Vest for 2 months then, under computer-assisted navigation system, C2 vertebroplasty was performed as augmentation. Post-operatively a Philadelphia collar was placed for 2 months.

Vertebroplasty of the cervical spine is normally a high demanding procedure, but with the use of the navigation system it was executed in an easier and safer way.

Immediate post-operative pain relief was obtained and after 18 months F.U. the patient was still pain free with a normal range of motion.

The same system was then used to treat C2 pathological fracture due to plasmocytoma (WBB: sec. 8–5; lay. B–C) in a 62-year-old male.

The patient was neurologically intact (Frankel E).

The patient was placed prone and the use of Mayfield 360° support was necessary. The planned surgery was C1–C4 posterior instrumentation and six pedicle screws were placed under navigation system control. No problems, technical difficulties or complications were recorded during the surgical procedure.

Surprisingly, post-operative CT scan revealed the malpositioning of C1 screws (Grade II the left one, Grade III the right one) that were immediately removed and a new C0–C4 fusion without navigation system was performed. Final Frankel score was E. After surgery specific hematologic chemotherapy was necessary to treat the systemic disease. After 16 month F.U. the patient was locally NED (Fig. 3).

The reason of C1 screws malpositioning is unclear.

Probably there was a mismatch between pre-operative CT scan uploaded in the system and the real-time imaging in the OR due to the different position of the patient during pre-operative CT scan execution (patient supine), and the intraoperative position (prone with a traditional Mayfield 360° support).

Fig. 1 C.C. 52 years, L2 uterus metastases (a, b). Using navigator system, the patient was subjected to minimally invasive L1–L3 instrumentation (c). On the site of the tumor a working camera was positioned (d) whereby, by a navigated high-speed burr, the excision of the tumor was performed through the lamina and the pedicle (e).

In our opinion the use of intraoperative CT scan could help in avoiding these extremely dangerous mistakes in difficult cases.

Following a chronologic order other two cases complete our series.

The first case is a 61-year-old female presenting progressive paraplegia (Frankel C) due to T3 pancreas metastasis (WBB: sec.11–2; lay. B–E). Under navigation system control a complete, precise and rapid T3 debulking and vertebroplasty was performed, ten pedicle screws were placed and T1–T8 instrumentation was achieved. A complete recovery of neurological function was recorded after surgery (Frankel E). Standard post-operative CT scan showed the correct positioning of the cement and screws (8 graded I and 2 graded II). 17 months after surgery the patient is locally NED.

Post-op CT scan shows the good position of the minimally invasive screws and the amount of the decompression (f, g, h). At 6 months from the surgery, CT scan shows a good local control of the disease (i)

The last case is a T2 osteoblastoma (WBB: sec. 11–10; lay. B–C) in a 23-year-old male that was completely identified and removed with the use of navigation system. After surgery the patient was strictly followed up by CT scan and 16 months after surgery he was CDF and NED.

Conclusions

The use of navigation system in oncologic spine surgery could be particularly interesting and helpful.

Clinical benefit in terms of increased accuracy in pedicle screws placement and reduction of the exposure to ionizing radiation are documented.

In oncologic spine surgery the use can be extended to the identification of tumor mass and definition of its

Fig. 2 M.A. 61 years, L5 melanoma metastases (**a**, **b**). A histological slide obtained by a CT-trocar biopsy confirmed the diagnosis (tissue positive to MART 1) (**c**). After an open laminectomy, using navigator system, four needles were positioned around the lesion and

electroporation was performed (**d**, **e**, **f**). A good local control of the disease was confirmed by a CT-trocar biopsy performed 6 months after surgery (necrotic tissue) (**g**, **h**)

margins, giving the surgeon the possibility to control the excisional procedure and protect the neurovascular surrounding structures step by step and in real time, with a 3D point of view.

Considering that image-guided surgery is technically demanding and a learning curve has to be completed, not only “particular” or “demanding” cases should be

navigated to establish a proper routine. Moreover, the presence of carbon fiber devices (i.e. surgical bed and Mayfield support) and intraoperative CT scan could be useful to avoid imaging distortions and increase accuracy of navigation system imaging capture, giving the surgeons the possibility to repair possible mistakes due to mismatch between pre-and intraoperative imaging.

Fig. 3 R.R. 62 years, C2 pathological fracture due to plasmocytoma. Post-operative CT scan shows C1 screws malpositioning

In conclusion, it is relevant that assisted navigation system spine surgery or mini-invasive spine surgery could be applied with good results also in spine tumor field, but these new techniques must be used absolutely according to and respecting the oncological criteria of the treatment.

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Conflict of interest None.

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