Int J CARS (2012) 7 (Suppl 1):S19–S22
DOI 10.1007/s11548-012-0700-y

MINIMALLY INVASIVE SPINAL SURGERY

Evaluation of new approaches for lumbar intraforaminal disc prolapse removal using 3D surgical planning

D. Foti[1], V. Ferrari[2], D.L. Lauretti[3], M. Ferrari[2], F. Mosca[2], R. Vannozzi[1]
[1]AOUP, Neurosurgery, Pisa, Italy
[2]University of Pisa, EndoCAS, Pisa, Italy
[3]University of Pisa, Radiology, Pisa, Italy

Keywords Neurosurgery · Lumbar disc prolapse · Surgical planning · Medical imaging

Introduction

Radiculopathy due to lumbar disc prolapse is the most common diagnosis in spinal surgery. Most patients heal after a 6–8 weeks medical treatment; 10–15 % still complaining pain, undergo microsurgery. Intraforaminal disc prolapse is a particular kind of hernia as for intensity of pain and for anatomical features. The conventional (ipsilateral) approaches for its removal require a partial or complete resection of facet joint, intertransverse ligament cutting or disruption of the pars interarticularis, risking chronic low back pain and long-term instability.

Recently we described a new minimally-invasive technique [1], simple to perform and carried out by contralateral side (CL), which allows a wide exposure of intervertebral foramen space and nerve root, even through a minimal spinous-laminar reduction, and to successfully remove the disc herniation.

More recently we performed a new contralateral approach in 5 patients, carried out by contralateral side and upper lumbar level (CL-up). All patients were post-operatively pain free.

Even if this two new approaches seem to be very useful for the patient, in terms of pain removal and spine stability, the choosing of the best surgical approach is today heuristic and it is difficult to describe the new accesses created, even using intra-operative live images (Fig. 1). A clear description of the surgical access is fundamental to train residents and to diffuse the technique in other centres.

Purpose

The purpose of this work is:

- to present and describe the two new surgical approaches above mentioned with short video clips and imaging
- to detail a specific 3D pathoanatomy of patients suffering from radiculopathy due to intraforaminal disc prolapse, through processing of preoperative CT images
- to compare the CL approach with the new variant CL-up

Methods

Using diagnostic CT images we segment bone, disc prolapse and nervous structures to obtain a patient specific 3D model of the anatomy on which the surgeon simulates different drilling approaches, to expose the prolapse, in order to chose the best one.

The spine was segmented using a semiautomatic tool that the authors integrated into the open source software ITK-SNAP 1.5 [2, 3]. The segmentation procedure is simply based on the neighbourhood connected region growing algorithm appropriately parameterized for the specific anatomy.

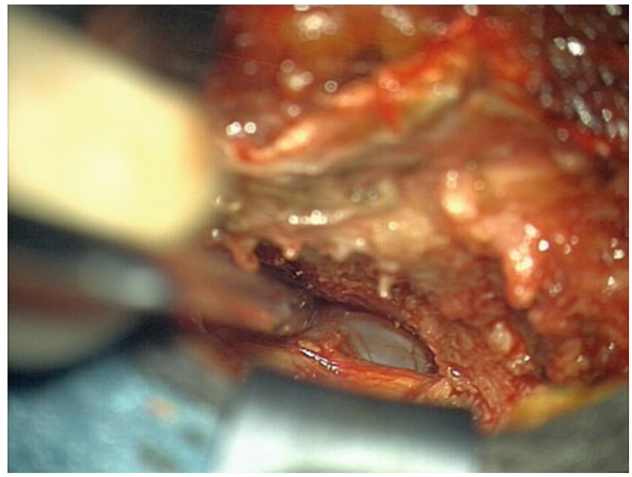

Fig. 1 Microscope image acquired during an intraforaminal prolapsed disc removal

Disc prolapse and nervous structures, which are sometimes difficult to distinguish on CT image also for experts human eyes of radiologists and neurosurgeons, are manually segmented using tools that allow the user to colour and to label the images using pen like instruments or contours.

After that the software creates the corresponding 3D meshes applying the marching cubes algorithm on the segmented voxels (Fig. 2a).

Finally the neurosurgeon, simulates different drilling approaches using a tool, integrated in the same software, that allows to insert cylinders (with selected axis, length and diameter) on the segmented images, and the software clears the voxels associated to the bone contained in the cylinder.

The efficacy of this technique was evaluated on a case by two expert surgeons and two residents.

The patient was affected by L4-L5 right intraforaminal disc prolapse. After complete visualization of hernia-nerve conflict, we simulated the CL and CL-up approaches, virtually removing caudal-basal portion of spinous process and inner part of contralateral lamina on the first approach, cranial ridge of contralateral lamina and cranial-basal portion of spinous process on the second one.

Results

Through this procedure was possible to render a 3D detailed interactive model of spinal functional unit L4-L5, the whole neuroforamen region, the right L4 spinal nerve in its entire course, the conflict hernia-nerve and to simulate the two mentioned approaches. In the first (CL), a surgical canal was created from left side, through the L4-L5 interlaminar space, toward contralateral pedicle of L4: the right L4 nerve was clearly visualized, squeezed against the L4 right pedicle, by a cranially and laterally directed disc prolapse (Fig. 2b). In the second (CL-up) a surgical canal was created from left side, through L3-L4 interlaminar space, toward contralateral pedicle of L4 (Fig. 2c). The

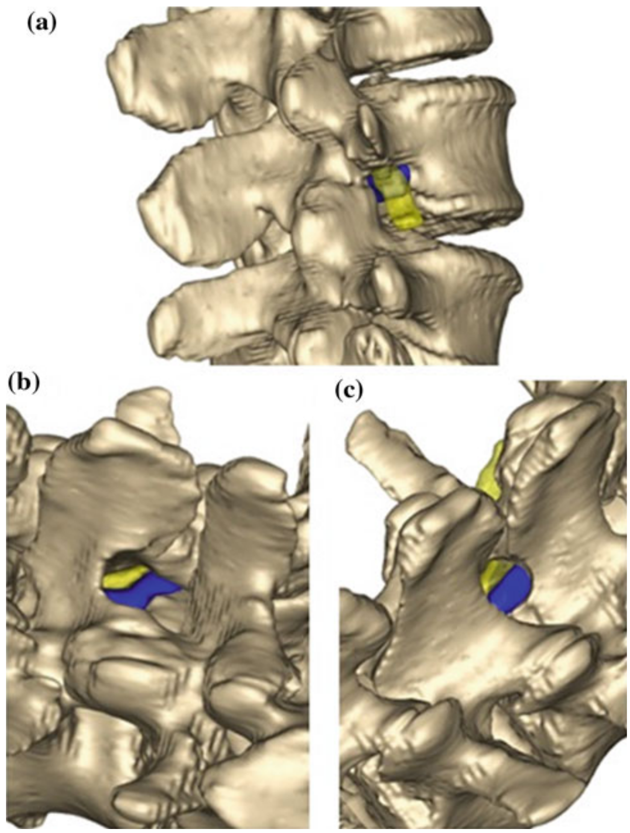

Fig. 2 **a** 3D rendering of the lumbar spine, disc prolapse (*blue*) and right L4 nerve (*yellow*); **b** 3D rendering after CL approach simulation; **c** 3D rendering after CL-up approach simulation

same scenery was seen (pedicle-nerve-prolapse), but from a cranial point of view.

Conclusions

The view and the working space were satisfying in both surgical canals. In the CL approach the disc prolapse was visualized first, then right L4 nerve, finally the L4 pedicle. Conversely, in the CL-up approach (L3-L4 interlaminar space), the right L4 pedicle was seen first, then the squeezed nerve, its axilla and finally the disc prolapse.

This study confirmed that L4-L5 CL-up approach for L5-S1 intraforaminal disc prolapse involves a shorter operative distance, a safer manipulation of neural structures and a lower bone reduction of L5 lamina-spinous complex.

Pre-operative planning is of a paramount importance to obtain a detailed and custom pathoanatomy. This 3D technique allows to study individual features of surgical anatomy, realizing a perspective very familiar to the surgeon who can assess the best surgical choice for the patient.

Developing software to speed labelling and segmentation procedures of the preoperative planning can be next step in future studies.

In a didactical scope, this 3D platform could be very useful for residents and young surgeons that want to approach a detailed spinal anatomy and understand the indications and the vantages of a contralateral approach.

Acknowledgments

The research leading to these results has received funding from Regione Toscana.

References

[1] Berra LV, Foti D, Ampollini A, Faraca G, Zullo N, Musso C. Contralateral Approach for Far Lateral Lumbar Disc Herniations: A Modified Technique and Outcome Analysis of Nine Patients. Spine 2010;35(6):709–713

[2] Ferrari V, Carbone M, Cappelli C, Boni L, Melfi F, Ferrari M, Mosca F, Pietrabissa A. Value of MDCT images segmentation for pre-operative planning in general surgery. In. Mar;26(3): 616–26 Surgical Endoscopy

[3] Ferrari V, Cappelli C, Megali G, Pietrabissa A. An anatomy driven approach for generation of 3D models from multi-phase CT images. In International Journal of Computer Assisted Radiology and Surgery, Supplement 1/June CARS 2008

Intraoperative navigation system for spine surgery

A. De Mauro[1], J. Mazars[1], L. Manco[1,2], T. Mataj[1,2], A. Hernández Fernández[3], L.T. De Paolis[2]

[1]Vicomtech-IK4, eHealth and Biomedical Applications, San Sebastian, Spain

[2]University of Salento, Department of Engineering for Innovation, Lecce, Italy

[3]San Sebastian Hospital, Department of Spine Surgery, San Sebastian, Spain

Keywords Image guided surgery · Computer aided surgery · Augmented reality · Spine surgery

Purpose

In the recent years, surgery has been strongly influenced by new technologies.

Computer Aided Surgery (CAS) offers several benefits for patient's safety, but fine techniques targeted at obtaining minimally invasive and less traumatic treatments are required since intra-operative false movements can be devastating and result in patient's death.

The precision of the surgical gesture is directly related to the surgeon's experience.

Nowadays, spine surgeons use X-ray devices (C-arm) as the unique imaging guidance during the intra-operative phase (for example in order to check if the pedicle screws are positioned correctly inside the patient anatomy and if the planned trajectories are respected).

In this paper we present the development of a navigation system based on conventional medical devices (optical tracking systems and endoscopes) suitable to be used in minimally invasive surgical procedures.

Main objectives of this project are:

- to reduce the radiation exposure to the patient and medical staff (minimizing the use of the C-arm);
- to reduce the operation time;
- to increase precision of surgery.

In many operating room settings an image intensifier system shows the position of anatomical structures in one plane, but a sight in several planes to get a proper three-dimensional impression is missing.

Additionally, patients may have had several previous operations, resulting in scar tissue formation or complex morphology.

A particular problem occurring in spinal surgery is the screw fixation during which even very experienced surgeons perforate the cortex up to 40 % of cases, and that always bears the risk of a lesion of the nerve roots, particularly when only lateral X-ray images are available.

The idea behind our research is to explore the use of open-source software in combination with conventional medical devices in order to enhance the accuracy in the surgical area (or in a specific surgical procedure phase) in which none or only expensive commercial systems are available.

Methods

We are currently developing software architecture for intra-operative purposes based on standard Image Guided Therapy (IGT) interventions setup (i.e. monitors and navigated surgical instruments for the pedicle screw implantation).

A segmentation of the real patient images is done by a medical expert (radiologist) to provide the volumetric description of the internal organs. The 3D patient reconstruction can be displayed in any desired plane for preoperative analysis and planning or for intra-operative purposes (matching the position and orientation of the instruments to the patient's morphology).

Anatomical landmarks are accurately defined at this step. These points are used in the patient registration phase to match the preoperative data with the patient real position during the whole operation (of course the patient position of the area of interest has to be fixed before the registration phase).

An optical system is used to track patient and tools position.

A tool composed of reflecting spheres (markers) is placed on each surgical tool and on the plastic phantom of the patient and is characterized by a different geometrical configuration. A module developed upon the open source software 3D Slicer [1] is used to visualize in real-time the scene (Fig. 1).

An algorithm based on the standard ICP method performs the patient registration using a minimum of four points. Additionally, this module provides the possibility to prepare fiducial points lists (based on the preoperative images) which can be used in different phases of surgery depending on the surgeon's needs. Textures are applied at the objects of the scene in order to improve the realism.

Before surgery, an area of interest in which the screw will be implanted can be defined. This information together with the shape of the screw is used to give a continuous video feedback to the surgeon (Fig. 2 left side). Red or green colors are associated with bad or good real-time tool positioning. Information on distance from a particular region of interest can be easily visualized in axial, sagittal and coronal views.

The current frequent use of the C-arm will be minimized because after an initial registration phase, a stereotactic system will be used to offer a real-time optical guidance to surgical movements in relation with the preoperative (CT/MRI) images. Currently we are extending this work to provide an augmented reality endoscopic view of the previously described objects, regions or organs.

The motivation to this extension is that endoscopic techniques have now been advanced to the treatment of spinal disorders (degenerative disc disease, scoliosis, kyphosis, spinal column tumors, infection, fractures and herniated discs). With these endoscopic techniques muscles are dilated apart, rather than cut, and the operation is performed with minimal injury to any surrounding tissues. The surgeon can insert the tracked endoscope through a small cut guiding it to the problem area while the navigation system visualizes structures of interest and distances directly in the endoscopic view (Fig. 2 right side). The calibration of the endoscope is performed using Zhang [2] standard technique.

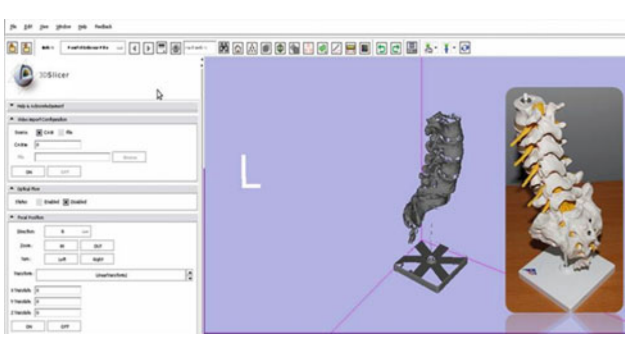

Fig. 1 3D reconstruction and visualization of the phantom

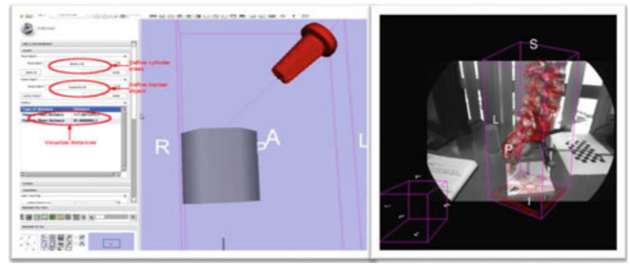

Fig. 2 Path analysis during the screw positioning (*left*) and endoscopic augmented reality (*right*). The real scene is merged with 3D virtual objects of interest directly in the endoscopic view

As future work we consider that the use of the AR endoscopic view can bring benefits to other disciplines like abdominal laparoscopy or neurosurgery. Additionally, the use of a robot for a precise endoscope positioning and navigation will be evaluated.

Results

Visual feedback runs at a reasonable frame rate of 16–30 fps depending by the complexity of the rendered scene. Trajectories can be planned with a user friendly and easy to use interface which we are developing considering a user centric design around the surgeon/radiologist. A similar user interface guides the intra-operative phase of screw implantation.

Conclusion

We presented the development of an IGS solution for spine surgery based on conventional medical devices and open-source software.

The objective of this work is to enhance the surgeon's ability for a better intra-operative orientation by giving him a three-dimensional view and other information necessary for a safe navigation inside the patient. In addition, it will reduce the radiation exposure to the patient and medical staff as well as the operation duration and, possibly, also the cost of such operations.

References

[1] Pieper S, Halle M, Kikinis R. (2004) 3D SLICER. Proceedings of the 1st IEEE International Symposium on Biomedical Imaging: From Nano to Macro 2004; 1:632–635 Lastname A, Lastname B (2012) Title. Journal 6(1):1–20

[2] Zhang Z. (2000) A flexible new technique for camera calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence, 22(11):1330–1334

The use of a combined navigation and CT-scanner for posterior thoracolumbar instrumentation: implications on the intra-operative rate of positioning corrections for screws

T.R. Blattert[1], R.L. Jilavu[1], W. Leinich[1], V.A. Rusu[1], H. Balling[1]
[1]Orthopaedic Clinic Schwarzach, Spine Surgery and Traumatology, Schwarzach, Germany

Keywords Spinal instrumentation · Thoracolumbar · CT scanner · Computed navigation

Purpose

Computer-assisted navigation enables positioning of pedicle screws with high precision. However, malpositioning cannot be ruled out entirely, even while using navigational techniques. CT-scans will help in assessing correct screw positioning and can be performed either post- or intraoperatively. To assess the immediate usefulness of a device combining both navigational and CT-scan features in a single technical system, we analysed our series of posterior thoracolumbar instrumentations in terms of intraoperative correction rate for screw positioning.

Methods

We included all posterior thoracolumbar instrumentations within the time period of February to December 2011 that were performed with the use of O-Arm® Surgical Imaging System (Medtronic). All surgeries were done in a navigated and CT-controlled manner. All immediate intraoperative corrections of screw positions were assessed, after having been identified as malpositions by intraoperative CT-scanning. If screw correction was performed, another CT-scan was conducted.

Results

51 patients (average age 62 years, range: 28–87 years) with 305 navigated pedicle screws were included in this prospective study. For 33 patients, the surgery performed was elective, for 18 the indication was revision surgery. In the order of incidence, the following indications were found: degenerative disease, deformity, fractures, spondylodiscitis, and metastases. For 57 % of all surgeries performed, the number of intraoperative CT-scans was one, whereas for the other 43 % more than one scan was necessary. The rate for immediate intraoperative correction of screw positioning was 13/305 pedicle screws (4.2 %). The most frequent reason for screw corrections was an unsatisfying depth of screw insertion or screw length in 8 of 13 cases.

Conclusion

Computer navigation does not entirely rule out screw malpositioning. The possibility of immediate detection of malpositioned pedicle screws by means of an intraoperative CT-scan may help in decreasing the number of revision surgery. The use of the O-Arms seems to be justified for two reasons: apart from allowing intraoperative navigation, it enables the intraoperative detection of malpositioned pedicle screws and thus helps to avoid the need for revision surgery.