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HOW I DO IT - NEUROSURGICAL TECHNIQUES

Minimally invasive transforaminal lumbar interbody fusion with the ROSA™ Spine robot and intraoperative flat-panel CT guidance

Louis Chenin[1] · **Johann Peltier**[1] · **Michel Lefranc**[1]

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Abstract
Background Circumferential arthrodesis is commonly used to treat degenerative lumbar diseases. Minimally invasive techniques may enable faster recovery and reduce the incidence of postoperative infections.
Methods We report on the surgical technique of a transforaminal lumbar interbody fusion (TLIF) procedure performed with the assistance of a new robotic device (ROSA™ Spine) and intraoperative flat-panel CT guidance.
Conclusions The combined use of this new robotic device and intraoperative CT enables accurate and safe arthrodesis in the treatment of degenerative lumbar disc diseases.

Keywords Transforaminal · Fusion · Minimally invasive · Robot · Intraoperative CT

Relevant surgical anatomy

The transforaminal lumbar interbody fusion (TLIF) procedure was first described in 1998 by Harms and Jeszenszky [1] and has since been used widely in the treatment of spondylolisthesis or recurrent herniated discs because of the low incidence of perioperative complications [2–4].

A transforaminal approach to the lumbar spine requires a good knowledge of all surrounding structures (inferior and superior articular facets, pars interarticularis, insertion and position of the ligamentum flavum, position of the traversing and exiting nerve roots), particularly during a minimally invasive procedure. For such a procedure, the "Wiltse" approach is used, and consists of a "pass" between the multifidus and longissimus muscle [5].

Description of the technique

We performed circumferential lumbar arthrodesis using a robot-assisted, minimally invasive, transforaminal approach (MiTLIF) with the ROSA™ Spine (from Medtech®, France) with intraoperative flat-panel CT(fpCT) guidance (using the O-arm®).

The patient is placed in the prone position on a radiotransparent spinal operating table. The O-arm® device and the ROSA™ Spine robot is put in place (Fig. 1). As with all minimally invasive neuronavigation procedures, a percutaneous reference pin is placed in the iliac wing (Fig. 2). Three-dimensional (3D) images from the O-arm® CT scanner are transferred to the ROSA™ Spine adjunct surgical workstation. Recording is performed by automatic recognition of a "fiducial box" held by the robotic arm (Fig. 3).

First, the 3D trajectory for bilateral transpedicular screw placement is planned (Fig. 4). Secondly, a hole is drilled through each pedicle using real-time, roboticized navigation guidance (i.e., the robot is able to track the movements of the patient's body in real time) (Fig. 5). A guide-tube needle is passed through the skin, then

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✉ Louis Chenin
raflouis@gmail.com

[1] Neurosurgery Unit, Amiens University Medical Center, Avenue René Laënnec, Salouël, 80054 Amiens cedex 1, France

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Fig. 1 A view of the operating theater after draping under sterile conditions. The O-arm® flat-panel CT device is placed to the left of the surgeon and the ROSA™ SPINE robot is placed facing the surgeon and slightly to his left. The robot's specific fiducial marker and stereoscopic camera are located slightly to the right of the surgeon

through the pedicle into the posterior part of the vertebral body. After a guide wire has been placed through the guide-tube needle, the latter is removed. The guide-tube needle, guide wire, and all instruments are monitored by the robot (via real-time, computer-aided navigation). This tracks the instruments' exact spatial positions throughout the surgery. The Sextant® percutaneous system (Medtronic®, USA) is used for this procedure. Dilators are placed via the guide wire, pedicles are threaded, and screws inserted via the guide wire under real-time robotic guidance. The size of each screw is based on pedicle size measurements in the initial 3D planning. Thirdly, the two

Fig. 2 A close-up view of the robot's fiducial marker. This enables the robot to monitor its own movements in real time. This further improves safety by merging these data with information from the iliac crest fiducial marker

Fig. 3 The special "fiducial box" is held by the robotic arm, which moves along the lumbar spine region of interest. 3D acquisition of the O-ARM is then performed during a period of 30 s while the patient's breath is held, with the box in front of the spine

percutaneous incisions are combined in order to position the retractor. Exposure of the articular facet enables initiation of the foraminotomy. The surgeon is free to use a navigated pointer to recognize anatomic features more easily. Adequate discectomy then enables placement of the TLIF cage.

Lastly, arthrodesis is completed by introducing and clamping the rods. Another fpCT scan acquisition is then performed to check the final position of the mounting (Fig. 6).

Fig. 4 The surgeon chooses the entry and end points, the trajectories, and the screw diameter using the robot's software. The robot's display screen shows the entire trajectory in three dimensions

Fig. 5 After planning, a hole is drilled in the pedicle with guidance from the robotic arm. A tubular muscle retractor is then applied and the pedicle is threaded

Indications

MiTLIF is commonly used to treat degenerative lumbar diseases such as spondylolisthesis and recurrent herniated discs. The use of intraoperative fpCT guidance such as OARM coupled with neuronavigation, and now robotics, can reduce the frequency of poor arthrodesis screw positioning [6].

Limitations

MiTLIF is now a safe, effective, and widely used spine surgery technique [2, 7]. However, the learning curve is long [8] and this technique is reserved for experienced surgeons. Furthermore, this cannot be employed in a high-grade spondylolisthesis because of the lack of good decompression.

The time taken to position the patient is currently lengthy. The ability to create screw trajectories before surgery could accelerate the workflow and reduce operating time.

The ROSA^{TM} Spine system is an advanced spine navigator with a roboticized arm. If there is a displacement of the reference spine, the robot will interpret it as a movement of the body and will induce error in the placement of the screw accordingly. Utmost care not to touch the reference spine is required.

If the surgery introduces significant change in the spine anatomy, it appears necessary to perform another acquisition in order for the robot to take into account the modifications.

Avoiding complications

Complications of TLIF (such as durotomy, in 5.1 % of cases and infection in 0.2 %) are infrequent, but well known [4]. When performed in a location above L2, an angiogram must be done of the lower part of the medulla to take into account the radiculomedullary artery (Adamkiewiecz) [9] and to avoid severe ischemic complications.

It is necessary to put the screws in place before foraminotomy to avoid significant movements of the spine. We advise navigating all instruments when performing the foraminotomy, particularly at the beginning of the procedure.

Specific perioperative considerations

A multidisciplinary approach including pain physicians, physiotherapists, and spine surgeons is recommended.

On the day after surgery, the patient is allowed to stand upright. A physiotherapist advises the patient regarding good positions and movements. A lumbar X-ray is performed 2 days after surgery. Discharge from hospital takes place about 4 days.

A follow-up lumbar spine X-ray is required at 3 months and a lumbar CT scan at 1 year in order to confirm bone fusion.

Specific information for patients regarding surgery and potential risks

First, the miTLIF approach may reduce blood loss, infection rate, and speed recovery compared to open techniques. The

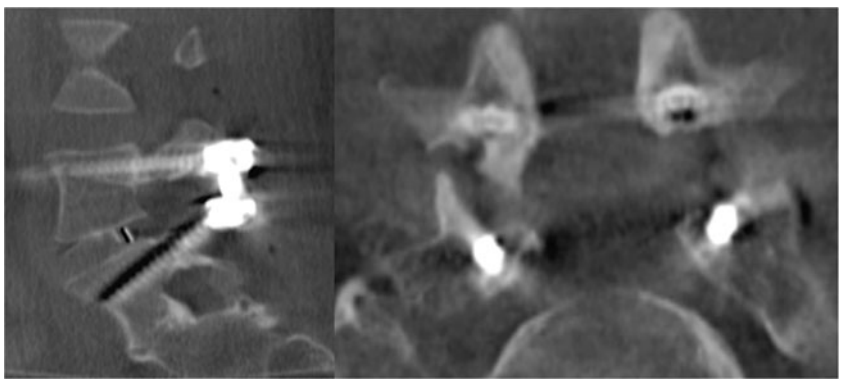

Fig. 6 3D lumbar flat-panel CT scan. Sagittal view showing the L4-L5 foraminotomy, confirming that the mounting is well positioned. Coronal view showing the absence of cortical breach in all pedicles

robot is an advanced spine navigator; therefore the overall risk appears to be similar to navigated TLIF.

Second, the O-arm® device performs a 3D acquisition during a period of 30 s breath-hold. Subsequently, the robotic arm tracks all patient movement. This is of significant value because the spine is a dynamic structure that can move slightly during surgery (e.g., due to respiratory motion) [10]. The robot also monitors movements of the body induced by the surgeon.

Third, the use of a fpCT scan leads to a decrease in overall patient radiation exposure (dose 2.5 times less than a multibarret CT scan). There is also no need to do a lumbar CT scan directly after surgery.

Finally, we have never had to convert the MiTLIF with the robot to the traditional open technique, but it appears reasonable that the surgeon should know how to perform the operation without the robot.

Key points:

1. The patient is placed in the prone position on a radiotransparent spinal operating table with the O-arm® device and the ROSA™ SPINE robot in place.
2. A percutaneous reference pin is placed in the iliac wing and acquisition of a lumbar fpCT scan is done during a period of 30 s with patient's breath held.
3. Images are then transferred to the ROSA™ Spine adjunct surgical workstation.
4. Trajectories for bilateral transpedicular screw placement are planned by the surgeon.
5. The robot determines exact positions along the planned trajectory, with real-time navigation guidance.
6. Pedicles are threaded percutaneously, and screws are inserted.
7. The two incisions are combined in order to carry out a transforaminal approach using a specific minimally invasive muscle retractor.
8. Exposure of the left (or right) articular facet enables initiation of the foraminotomy. Adequate discectomy then allows placement of the cage.
9. Arthrodesis is then completed by introducing and clamping the rods.
10. Another fpCT scan is then performed in order to check the final position of the mounting.

Compliance with ethical standards

Conflict of interest Lefranc has provided consultancy services to Medtech®. The other authors (Chenin, Peltier) report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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