Transcript

0:25 Introduction and Surgical Indication. Stereoelectroencephalography (SEEG) is the gold standard to investigate epileptic networks in cases of drug-resistant epilepsy. This technique was introduced for the first time at Sainte-Anne Hospital on May 3, 1957, by Dr. Bancaud and Dr. Talairach and progressively adopted worldwide. Since its introduction in our institution, this procedure has been performed 1536 times. The aim of this surgical procedure is to record cortical activity thanks to deep electrodes implanted under stereotactic conditions, allowing to understand the implications of specific brain cortical zones in seizure onset and/or propagation. The SEEG procedure has numerous advantages that make it the gold standard: 1) the ability to record and monitor simultaneously multiple brain zones, even bilaterally or deep-seated; 2) the low morbidity due to a mini-invasive approach; 3) the potential use of implanted electrodes as a curative treatment via radiofrequency thermocoagulation.

At the beginning, SEEG’s main aim was to circumscribe an epileptogenic zone and to determine if this zone was accessible for surgical treatment via cortectomy. Due to the developments and refinements of the procedure, SEEG is nowadays used to investigate epileptogenic networks, searching to interrupt and/or disrupt epileptogenic aberrant loops.

1:48 Preoperative Planning: Imaging and Trajectory Planning. The software used to plan the trajectories is Brainlab Elements. Brainlab Elements is a surgical software allowing to perform image coregistration, DTI analysis, and trajectory planning. Nonenhanced T1-weighted 3D fast spin echo MRI is used as the reference series: vascular and functional images are coregistered to this reference series. The lead trajectories are defined as a straight line between one entry point (EP) and one target point (TP), in agreement with the surgical epileptologists during a preoperative multidisciplinary board meeting. The definition of the epileptogenic zone is based on preoperative noninvasive investigations: at first, results of video-EEG recordings; clinical examination with a complete neuropsychological assessment; then the imaging data with 3T, 7T, and functional MRI; and finally the metabolic imaging with a
PET-MRI. This workup must lead to a first delimitation of a quite restricted possible seizure onset zone and spatio-temporal seizure propagation patterns: the electrodes’ trajectories are then placed into the corresponding anatomical structures keeping in mind its low spatial resolution. The trajectories are also planned with a 2-mm margin distance from at-risk zones (vessels and sulci) by two neurosurgeons, blind to each other. Vascular images, in particular 3D angiography sequences, are acquired for each patient and used to adjust the trajectories. The idea is to avoid, and lower as much as possible, any risk of hematoma or bleeding during or after the procedure. The trajectories are validated during a dual consensus. In our experience, a dozen electrodes per SEEG is sufficient to investigate a delimited epileptic area: if the epileptogenic zone hypothesis is not supported by the SEEG analysis, a second SEEG procedure could be performed to investigate a second zone. The increase in number of implanted electrodes does not necessarily increase the identification of an epileptogenic zone and could complicate the understanding of the procedure by the patient: delimitate a well-defined area to perform a cortectomy. Once the definitive trajectories are validated, the planning process is firmly started. The neuramate robot control station, the Digital Imaging and Communications in Medicine (DICOM) coordinates of each trajectory are transferred to the neuramate (Renishaw) robot control station.

**Surgical Workflow**

**4:06 Patient Positioning and Registration.** Surgical setup consists in positioning the patient’s head in a Talairach head clamp (DIXI). The Talairach head clamp is still in use in Sainte-Anne Hospital, but the neuramate robot can be used with other head fixation systems such as the Leksell frame G. During this step, it is important to maintain the head in a neutral position and to include as much as possible the skull base in the O-arm field (Medtronic) of view: the aim is to ease the coregistration between 3D O-arm series acquired intraoperatively and those of the preoperative MRI. Positioning and intraoperative planning procedure is similar to the robot-assisted stereotactic biopsy performed in our institution. Artifacts due to the Talairach head clamp (or any other head fixation system) should be taken into consideration during intraoperative imaging acquisition. As for a classical CT scan, one profile and one anteroposterior x-ray (XR) images are acquired, to position the head at the center of the O-arm field of view. The final O-arm position is then registered.

**5:05 Robot Calibration.** Before starting the surgical procedure, the robot is to be checked. On the robot control station, the NMControl program is switched on and a test procedure is started. During this phase, the accuracy of the robot, the system communication, the different reference positions, the anticollision system, and the remote control are verified. If the test is passed, the robot can be used.

**5:33 Imaging Coregistration.** The laser tool holder is installed on the robotic arm, and it has to be firmly attached thanks to two fixation screws. The neurlocate (Remishaw) registration module is positioned on the laser tool holder: this is the frameless system consisting of 5 ruby spheres, enabling intraoperative registration without the need for bone or skin anchored fiducials. It is of utmost importance to have it correctly aligned because it will position the robot into the operative room space. The neurlocate registration tool must be positioned as close to the patient’s head as possible and aligned with the calvaria on the vertex, reducing the space between the skin and the neurlocate ruby spheres. A 3D O-arm acquisition is made and verified: all the 5 ruby spheres must be identified. The 3D acquisition is performed at a low-dose level to minimize patient irradiation. The image is coregistered to the preoperative MRI. The imaging coregistration is roughly made manually and then refined by automatic algorithm. The quality of the coregistration process is verified by two neurosurgeons and the planned trajectories are controlled again.

**6:36 Second O-Arm Acquisition and Accuracy Control on Skin Surface.** An additional safety check is realized. The robot is positioned into one trajectory axis: a wire metallic pin inserted into the standard tool holder is put in contact with the patient’s skin. A 3D O-arm series is acquired, then coregistered with preoperative MRI: the O-arm metallic pin has to be precisely aligned with the planned trajectory. This allows a final evaluation of the robot accuracy.

**7:01 Guiding Screw Installation.** The O-arm can be moved away from the surgical field, thanks to the registration of its position during the first step of the procedure. For each trajectory, the robotic arm is aligned on the trajectory axis. A minimal hair shaving is performed around the EP located on the skin. The robotic arm is then moved as close as possible to the patient’s head to minimize mechanical deviation during the drilling process. The drill hole is performed with a 2.5-mm-diameter drill bit: the drilling movement must be as smooth as possible and the bit as sharp as possible. The length of the drill bit is defined to perforate exclusively the bone without damaging the dura mater: a locking device is secured on the drill to execute this procedure with a minimal risk.

Once the bone hole is made, the durotomy is realized thanks to a thin monopolar coagulation. The guiding screw dimension is chosen according to a homemade software, SEEGapp, and then secured into the skull. A 3D O-arm series is acquired, then coregistered with preoperative MRI: the O-arm metallic pin has to be precisely aligned with the planned trajectory. This allows a final evaluation of the robot accuracy.
9:05 Park Position and End of the Procedure. The robot is moved in park position. The electrodes’ cables are fastened to the scalp by surgical stitches. Lastly, the Talairach head clamp is removed starting from the anterior pins moving subsequently to the posterior ones.

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References

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Author Contributions
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Supplemental Information
Patient Informed Consent
The necessary patient informed consent was obtained in this study.

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