Comparative study of manual versus robot-assisted frameless stereotaxy for intracranial electrode implantation

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INTRODUCTION

SEEG: Stereo Electro Encephalo Graphy: Invasive presurgical investigation in patients with refractory epilepsy:
Transcutaneous implantation of multicontact electrodes into deep cerebral structures suspected of harboring epielptic foci and prolonged EEG recordings from multiple contacts along the electrodes, allowing sampling of superficial and deep structures.
Various methods are used for electrode implantation:

- Stereotaxy: frame-based versus frameless
- Reference imaging: angiography, CT, CT angio, MRI
- Manual versus robot-assisted
- Hardware: a variety of commercially available electrode and fixation peg types

A paucity of literature exists as to the accuracy of these methods. Most authors report 2 to 3 mm deviation from planned trajectory at the target point and a ~95% success rate.

2 methods used at the Montreal Neurological Hospital (MNH):
Before March 2011: manual frameless neuronavigation-based
After March 2011: robot-assisted neuronavigation-based

Purpose: A prospective non-randomized study of electrode implantation from July 2010 to September 2011 to compare the accuracy of electrode implantation between the manual and robot-assisted methods.

Variables:
target error
deviation from planned axis
Error in depth
Entry point error

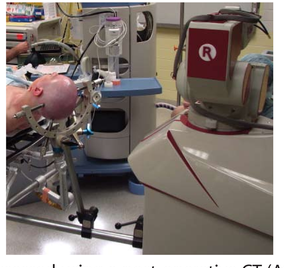
Assessment of:
Intra-operative registration
Learning curve
Variability between surgeons

METHODS

All patients undergoing depth electrode implantation between July 1st 2010 and september 31st 2011 were included.
All planned trajectories were confirmed intra-operatively and saved on the Stealth station.

Before March 2011:
Manual frameless neuronavigation-based method
Neuronavigation: Stealth station (Medtronic)
AO: merged pre-surgical CT, CT angio, plain MRI, proprietary two-channel adaptor, proprietary fixation pegs and 11 channel electrodes
JAH: pre-surgical gadolinium-infused MRI, xxxx adaptor (Medtronic) on articulated arm, Microdeep electrodes (DIXI Medical)

After March 2011:
Robot-assisted neuronavigation-based method
Robot: ROSA (Medtech) with ROSA neuronavigation software using pre-operative CT and MRI
Additional neuronavigation: Stealth Station (Medtronic)
AO: proprietary fixation pegs and electrodes
JAH: Microdeep electrodes (DIXI Medical)



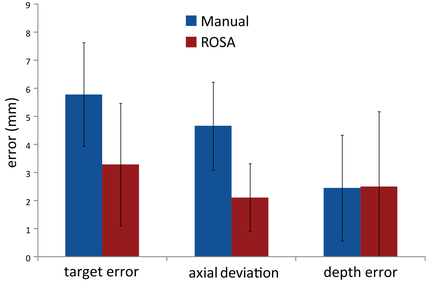
Actual electrode paths were assessed using a post-operative CT (AO) or MRI (JAH) and errors were measured after merging of the pre-operative planning imaging with its trajectories and the post-operative scan.
Co-registration error of the pre- and post-operative scans was assessed by measuring the error on 6 bony and vascular landmarks. A difference between the manual and robot-assisted groups was assessed using a non-parametric Mann-Whitney test.

All statistical analyses were made using non-parametric tests: Kruskall-Wallis tests for multiple comparisons and Mann-Whitney tests for pairwise comparisons..

RESULTS

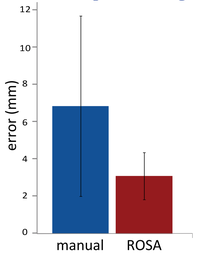
22 patients undewent SEEG investigation. 3 were excluded because of inadequate post-operative imaging.
Manual group: 80 electrodes in 13 patients
Robot group: 37 electrodes in 6 patients
The mean pre- vs post-operative scan coregistration error was 1.0 ± 0.3 mm with no significant differences between groups.
Success rate (ability to hit planned target) was 85% in the manual group and 100% in the robot-assisted group.

Accuracy



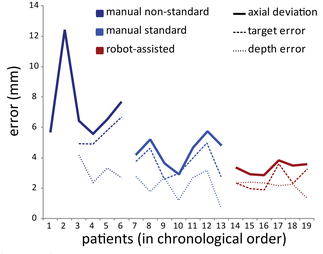
Target error (5.8 vs 3.3 mm) and axial deviation (4.7 vs 2.1 mm) were significanlty different between the manual and robot-assisted groups ($p < 0.05$). Differences in depth error were not significant (2.4 vs 2.5 mm, $p = 0.76$).

Intra-operative registration



Entry point error was significantly higher in the manual group compared to the robot-assisted group (7.0 vs 3.2 mm). This is mostly due to a single patient in the manual group (patient 9, error = 12.7 mm). Without the outlier, entry point errors are not significantly different (4.1 vs 3.2 mm, $p > 0.1$).

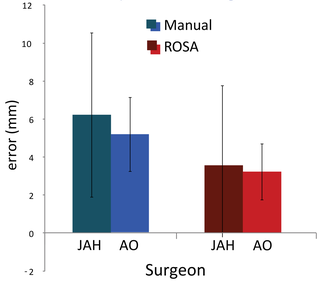
Learning curve



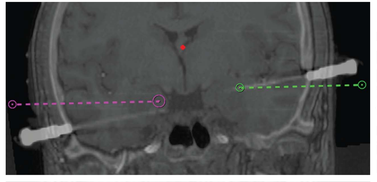
Three phases:
a) Standardization of protocol (data collection, intra-operative correction of final electrode paths)
b) Standardized manual implantation
c) Robot-assisted implantation

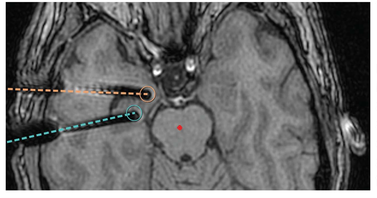
Target error remains significantly different across all groups (7.1 vs 4.6 vs 3.3 mm, $p < 0.05$).

Variability between surgeons



Differences in target error were not significantly different between the two surgeons ($p \geq 0.3$).





Patient 9 (manual method): merged pre-operative MRI with planned trajectories and post-operative CT scan. Significant rotational and translational intraoperative registration errors cause important entry point deviation but relatively small target errors to bilateral amygdala electrodes.

Patient 17 robot-assisted method merged pre-operative MRI with planned trajectories and post-operative MRI. The axial image shows minimal deviation of the right amygdala and hippocampal electrodes from their planned trajectories.

CONCLUSIONS

The robot-assisted method was associated with significant improvement in electrode placement accuracy as assessed by target error, axial deviation and ability to hit the planned target.

Factors

Improved intra-operative patient/image co-registration: although the assessment of intra-operative registration was indirect (using the external tip of fixation pegs as landmarks), additional solidity was probably provided by the fixation system of ROSA to the patient head fixation apparatus.

Learning curve effect: Both surgeons were well experienced in the manual implantation method. The higher error rate can be mostly attributed to failure to correct planned electrode paths intra-operatively.

Intrinsic robot characteristics:
ability to position itself precisely and reliably into planned trajectory
solidity of robotic arm locked in the trajectory

Limitations of the study:
non-randomized
indirect assessment of intra-operative registration
inability to extract planned trajectories directly from ROSA software for comparison (the concomitant use of Stealth station was necessary).

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