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Surface or Depth: A Paradigm Shift in Invasive Epilepsy Monitoring

Stereo Electroencephalography Versus Subdural Strip Electrode Implantations: Feasibility, Complications, and Outcomes in 500 Intracranial Monitoring Cases for Drug-Resistant Epilepsy

Joswig H, Lau JC, Abdallat M, Parrent GP, MacDougall, KW, McLachlan RS, Burneo, JG, Steven, DA. *Neurosurgery*. 2020;87(1):E23-E30. doi: 10.1093/neuros/nyaa112

Background: Both stereoelectroencephalography (SEEG) and subdural strip electrodes (SSE) are used for intracranial electroencephalographic recordings in the invasive investigation of patients with drug-resistant epilepsy. Objective: To compare SEEG and SSE with respect to feasibility, complications, and outcome in this single-center study. Methods: Patient characteristics, periprocedural parameters, complications, and outcome were acquired from a pro- and retrospectively managed data bank to compare SEEG and SSE cases. Results: A total of 500 intracranial electroencephalographic monitoring cases in 450 patients were analyzed (145 SEEG and 355 SSE). Both groups were of similar age, gender distribution, and duration of epilepsy. Implantation of each SEEG electrode took 13.9 $\pm$ 7.6 minutes (20 $\pm$ 12 minutes for each SSE; $P < .01$). Radiation exposure to the patient was 4.3 $\pm$ 7.7 seconds to a dose area product of 14.6 $\pm$ 27.9 rad·cm^2 for SEEG and 9.4 $\pm$ 8.9 seconds with 21 $\pm$ 22.4 rad·cm^2 for SSE ($P < .01$). There was no difference in the length of stay (12.2 $\pm$ 7.2 and 12 $\pm$ 6.3 days). The complication rate was low in both groups. No infections were seen in SEEG cases (2.3% after SSE). The rate of hemorrhage was 2.8% for SEEG and 1.4% for SSE. Surgical outcome was similar. Conclusion: stereoelectroencephalography allows targeting deeply situated foci with a noninferior safety profile to SSE and seizure outcome comparable to SSE.

Commentary

Stereotactic electroencephalography (SEEG) is an invasive method for intracranial monitoring and seizure localization using multiple depth electrodes implanted through small twist drill holes. SEEG was pioneered by Bancaud and Talairach in France in the 1950s and has since remained prevalent in Europe.[1] Over the past 10 years, its use has dramatically increased outside of Europe, including in North America, while the utilization of subdural electrodes (SDE) has decreased.[2] There are likely multiple factors contributing to this paradigm shift, including technological advances to improve ease and accuracy and shorten the time required to perform an SEEG implant. The original Talairach frame allowed only strictly orthogonal electrode trajectories, and planning was guided by 2-dimensional angiography. Presently, planning is facilitated by 3-dimensional (3D) high-resolution magnetic resonance imaging and electrode placement can be aided using 3D printed omnidirectional platforms, robotic assistance, or frameless stereotaxy. Also contributing to increased SEEG utilization may be a growing preference for minimally invasive approaches in surgical fields. Unlike SEEG, SDE placement requires a craniotomy for grid and strip electrode placement, or multiple burr holes for strip electrodes only. It is important to approach this shift away from SDE carefully and not sacrifice safety and efficacy. To date, relatively few studies have compared SEEG and SDE.

In the highlighted study by Joswig and colleagues,[3] investigators retrospectively analyzed complications and outcomes across 500 intracranial EEG implants in 450 patients (approximately 30% SEEG and 70% SDE). The SDE cases included subdural strip electrodes only, as patients who received subdural grids or mixed surface and depth electrodes were excluded. The SEEG implants were performed with frame-based stereotaxy or robotic assistance, while SDE implants were done by placing strip electrodes on the neocortical surface through minicraniotomies, guided by frameless neuronavigation. Bilateral implants were more common with SEEG (46%) than SDE (20%), and while the percentage of electrodes sampling the temporal and frontal lobes was high in both groups ($\sim$70%-80%), only SEEG patients ($\sim$60%) had electrodes sampling the deeper insula. Operative time was lower in the SEEG group. Complications were relatively rare in both groups, including intracranial hemorrhage in less than 3% of individuals, which resulted in permanent neurological deficits in 2 patients in each group. Infection was noted in 2% of SDE patients, but none of the individuals who underwent SEEG. The percentage of individuals who proceeded to resection was not clearly conveyed, but the authors noted that at their center, historically 74% of patients undergo surgery after SDE compared to 54% after SEEG. Finally, the authors report a somewhat higher but statistically insignificant rate of favorable seizure outcome (Engel I or II) after resection following SEEG (∼80% at 2 years) compared to SDE (∼70%). The investigators conclude that SEEG offers noninferior safety and seizure outcomes compared to SDE, using a minimally invasive approach.

Several strengths of this study include a large patient cohort, straightforward comparisons between relatively well-matched patient groups, and the fact that few studies comparing SEEG and SDE at the same surgical center have been reported. By only including patients with subdural strip electrodes versus SEEG depth electrodes, the authors relate apples to apples and simplify their comparison. However, one must also be cautious in extending their findings to grid implantation, which requires a larger craniotomy. This study is a retrospective chart review study where surgical strategy was not assigned or controlled and presumably biased by case nuances and the implant time frame. Also, more information regarding surgical treatment and seizure freedom rates between the 2 groups would be helpful. Nevertheless, this report is another important example of the paradigm shift away from SDE and toward SEEG in invasive epilepsy monitoring, suggesting that SEEG is not associated with worse complication rates or seizure outcomes.

One recent systematic review compared complications and seizure outcomes in patients undergoing SEEG versus SDE, although the individual source studies each evaluated only 1 technique.[4] Compared to SDE, SEEG was associated with a lower rate of resection. In patients who did undergo resection, however, the SEEG cohort experienced reduced morbidity and mortality and a higher seizure freedom rate. A separate single center study comparing 239 patients who underwent SEEG or SDE also found a lower rate of resection after SEEG but decreased risk of complication and higher rate of seizure freedom compared to SDE.[5] One reason for reduced resection rates after SEEG may be that this minimally invasive and flexible technique has "lowers the bar" for epilepsy practitioners to feel comfortable studying challenging patients who require bilateral electrode sampling. A study of 184 patients undergoing bilateral SEEG implants suggested that a strong localization hypothesis prior to implantation is associated with a higher likelihood of resection and seizure freedom.[6] In testing these clinical hypotheses, SEEG allows sampling of deep areas such as insula, sulcal dysplasias, and periventricular nodular heterotopia that are nearly impossible to access with SDE. It is, however, important to remember that intracranial hemorrhage remains a risk when inserting depth electrodes without direct visualization. A large series of 549 SEEG implantations at a single center noted a 19% rate of radiographically perceptible hemorrhage, although rates of symptomatic hemorrhage (2%) and those leading to disability or death (0.6%) were much lower.[7]

Going forward, are there still cases more likely to benefit from SDE implantation in epilepsy surgery? While we do not have strong data to guide us, one may surmise that cases of superficial neocortical epilepsy with a strong localizing hypothesis, but where borders of the epileptogenic zone and nearby eloquent cortex require better delineation and stimulation mapping, may be aided by a grid implantation. Nevertheless, one must remember that approximately two-thirds of cortical gray matter resides in deep sulci or within fissures and is not easily sampled by surface electrodes but can be accessed using depth electrodes. Strategies for electrically stimulating SEEG electrode contacts to map eloquent cortex are also improving with center experience.[8] Finally, it is becoming increasingly apparent that focal epilepsy is more than a disease of a discrete focus, and also a disorder of brain networks. Nodes in these networks may sometimes be anatomically disparate but functionally connected and may be mapped using strategically placed SEEG electrodes.[9,10] The fact remains that no large prospective, controlled study has been performed comparing SEEG to SDE. Evidence from retrospective observations, such as the highlighted study by Joswig and colleagues, does suggest that SEEG is safe with low complication rates and may be effective in accurately identifying seizure onset zones ahead of surgical treatment. The value of further prospective analysis comparing SEEG and SDE will be to better understand whether there are still patient subgroups that benefit from a larger subdural implant.

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