

Review

Current value of intraoperative electrocorticography (iopECoG)

Karl Roessler^{a,*}, Elisabeth Heynold^{a,1}, Michael Buchfelder^a, Hermann Stefan^b, Hajo M. Hamer^b^a Neurosurgical Clinic, University Hospital Erlangen, Germany^b Epilepsy Center, Neurological Clinic, University Hospital Erlangen, Germany

ARTICLE INFO

Article history:

Received 8 May 2018

Revised 28 June 2018

Accepted 29 June 2018

Available online 9 November 2018

Keywords:

Intraoperative ECoG
Focal cortical dysplasia
Temporal lobe epilepsy
Extratemporal epilepsy

ABSTRACT

Objective: Intraoperative electrocorticography (iopECoG) can contribute to delineate the resection borders of the anticipated epileptogenic zone in epilepsy surgery. However, it has several caveats that should be considered to avoid incorrect interpretation during intraoperative monitoring.

Methods: The literature on iopECoG application was reviewed, and pros and cons as well as obstacles to this technique were analyzed.

Results: The literature of the first half of the nineties was very enthusiastic in using iopECoG for tailoring the resection in temporal as well as extratemporal epilepsy surgery. Mostly, this resulted in a good correlation of postresection ECoG and excellent seizure outcome. In the second half of the nineties, many authors demonstrated lack of correlation between iopECoG and postoperative seizure outcome, especially in surgery for temporal lobe epilepsy with hippocampal sclerosis. In the noughties, investigators found that ECoG was significantly useful in neocortical lesional temporal lobe epilepsy as well as in extratemporal lesional epilepsies. Extratemporal epilepsy without lesions proved to be more a domain of chronic extraoperative ECoG, especially using depth electrode recordings. In recent years, iopECoG detecting high-frequency oscillations (ripples, 80–250 Hz, fast ripples, 250–500 Hz) for tailored resection was found to allow intraoperative prediction of postoperative seizure outcome.

Conclusion: After a period of scepticism, iopECoG seems back in the focus of interest for intraoperative guidance of resecting epileptogenic tissue to raise postoperative favorable seizure outcome. In temporal and extratemporal lesional epilepsies, especially in cases of focal cortical dysplasia, tuberous sclerosis, or cavernous malformations, an excellent correlation between iopECoG-guided resection and postoperative seizure relief was found.

© 2018 Elsevier Inc. All rights reserved.

1. Introduction

Intraoperative electrocorticography (iopECoG) was introduced by Penfield and Jasper in the late 1930s at the Montreal Neurological Institute for the intraoperative identification of epileptic brain tissue [1]. Because of the short duration of iopECoG monitoring (mostly a maximum period of 15 to 30 min is used), normally only interictal electric discharges (interictal spikes) are detected. Unique electrocorticography (ECoG) signatures are only detected in specific lesions, like cortical dysplasias [2]. Furthermore, iopECoG is highly vulnerable to anesthesiological agents. Sufentanil, fentanyl, alfentanil, propofol, and methohexital have been reported to produce epileptiform changes on ECoG whereas halothane, barbiturates, and benzodiazepines may suppress epileptic activity. In addition, pharmacological activation is

possible [3]. Thus, interobserver disagreement about the different spike types makes an objective result of the iopECoG monitoring difficult [4]. These obstacles have to be considered when using iopECoG for intraoperative decision-making in resective epilepsy surgery (Figs. 1–5).

2. Results

In temporal lobe epilepsy with mesial temporal sclerosis, investigators agree that iopECoG is not necessary for delineation of resection of the mesial structures because there was no correlation found between residual spikes and poor seizure outcome [5–7]. In temporal lobe epilepsy without hippocampal sclerosis and lesions in the neocortex like epilepsy-associated tumors, iopECoG-tailored resection of the perilesional zone led to favorable seizure outcome [8]. In hippocampal sclerosis, iopECoG is useful if there is dual pathology [9]. Patients with nonlesional (magnetic resonance tomography (MRI)-negative) temporal lobe epilepsy benefit most from chronic implantation of electrodes to identify seizure-onset zones during seizure monitoring at the epilepsy monitoring unit (EMU) [10]. One of the main domains of iopECoG seems to be temporal and extratemporal focal epilepsies

* Corresponding author at: Department of Neurosurgery, University Hospital Erlangen, Schwabachanlage 6, 91054 Erlangen, Germany.

E-mail address: karl.roessler@uk-erlangen.de (K. Roessler).

¹ K.R. and E.H. contributed equally to this work.



Fig. 1. OR equipped with neuronavigation, intraoperative MR tomography, and iopECoG.

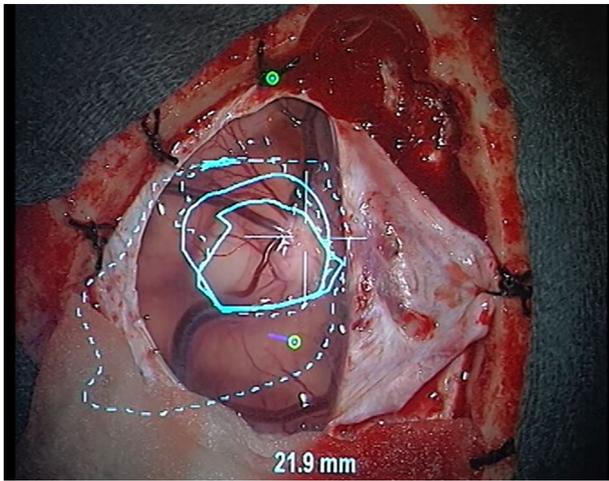


Fig. 2. Case O.M. Long-term epilepsy-associated tumor in the left frontal supplementary motor area, intraoperative view. The tumor is delineated by neuronavigation-blue lining.

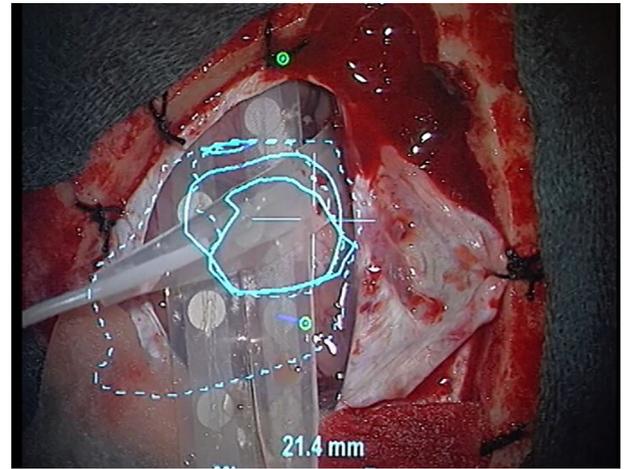


Fig. 3. Case O.M. iopECoG using four 4 contact stripes.

with structural lesions (e.g., focal cortical dysplasia (FCD), tuberous sclerosis (TS), and cavernous malformations (CM)) [2,8,11–13]. The majority of patients with nonlesional extratemporal lobe epilepsy will also require chronic extraoperative ECoG monitoring at the EMU [10]. Intraoperative detection of high-frequency oscillations (HFOs, ripples, fast ripples) has been proved to have a high prognostic value for postresection seizure outcome [14]. An ongoing prospective trial will address the value of intraoperative HFO monitoring in the future [15]. The variable significance of ECoG during the last decades is best demonstrated in Table 1.

3. Conclusion

Intraoperative electrocorticography has a significant value during resective epilepsy surgery [10]. Especially in lesional temporal and extratemporal focal epilepsies (FCD, TS, CM, and low-grade gliomas), iopECoG facilitates the definition of the borders of the perilesional epileptogenic brain tissue in adult as well as pediatric epilepsy surgery [4,16]. During the last few years, intraoperative-tailored resection based on HFOs was found to provide the best correlation to postoperative seizure outcome [14].

Conflict of interest

The authors declare no conflicts of interest.

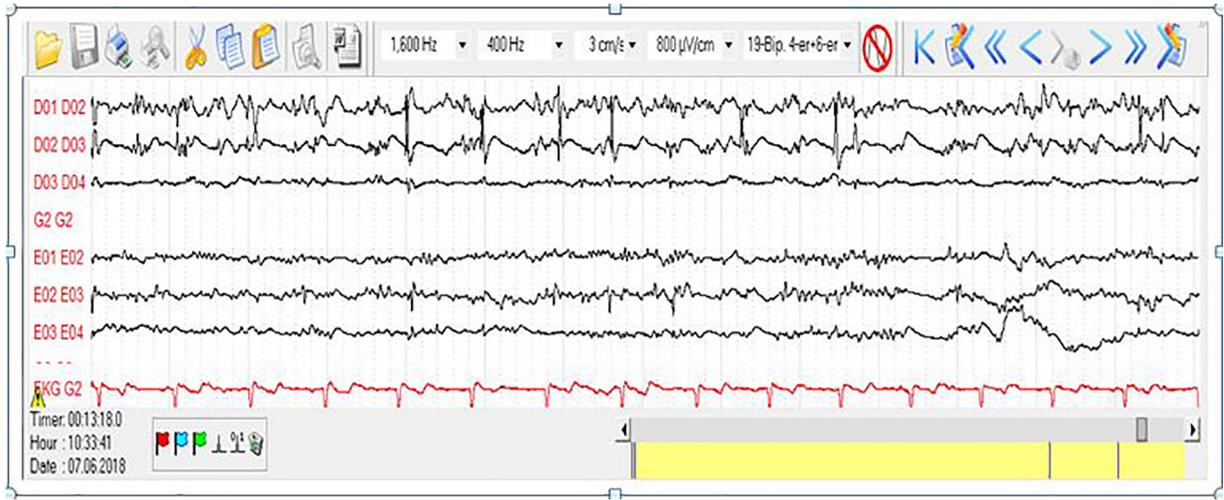


Fig. 4. Case O.M. iopECoG, demonstration spikes within and around the lesion, sampling rate: 2024 Hz, filter: 120–400 Hz.

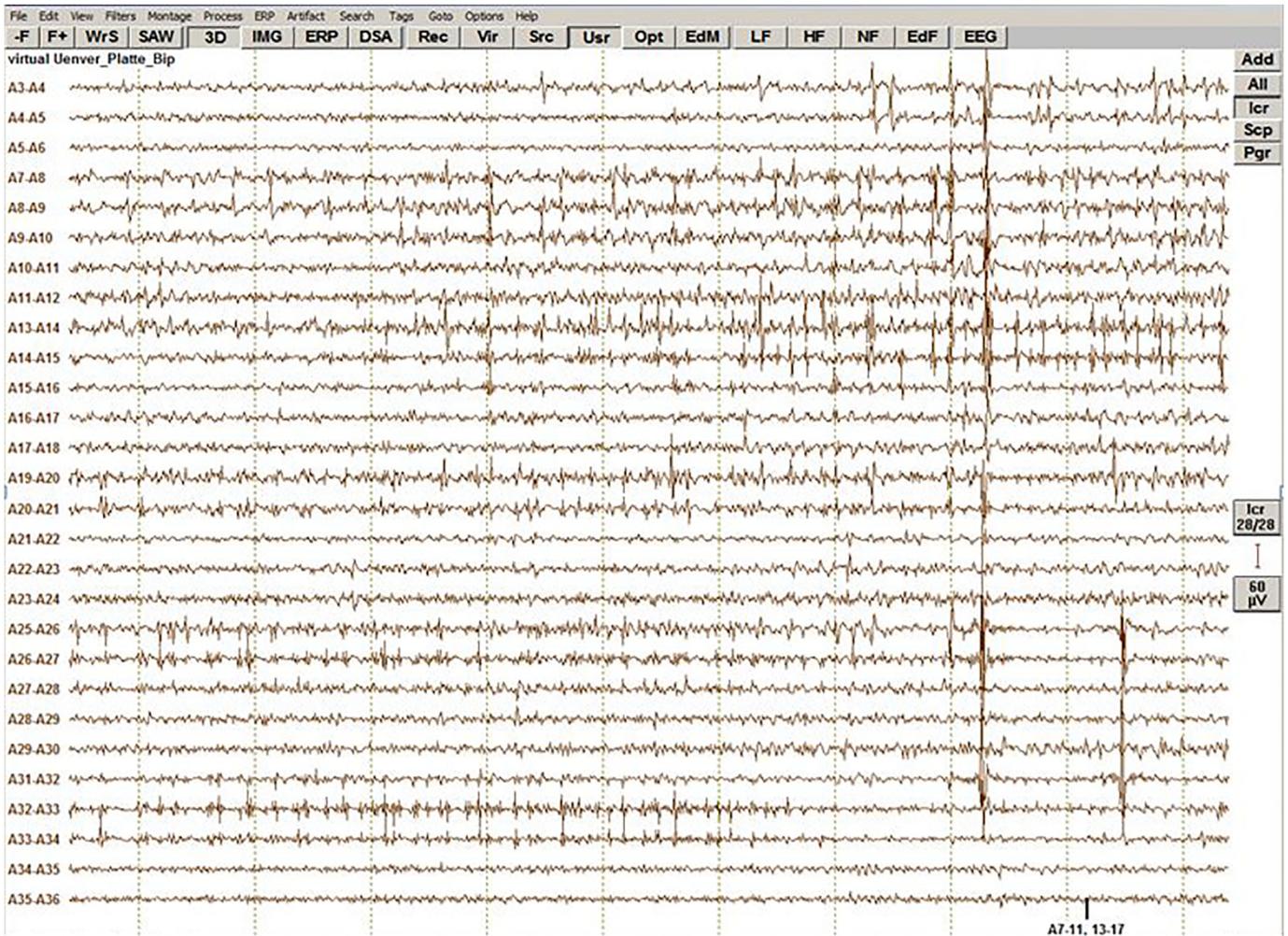


Fig. 5. Case Ü.F. HFO in a patient with FCD and extraoperative monitoring using a 64-contact plate, sampling rate: 2024 Hz, filter: 120–900 Hz.

Table 1

Studies in green: positive correlation between ECoG and seizure outcome, studies in orange: partly positive/partly negative correlation, studies in red: no correlation between ECoG and seizure outcome; LA: local anesthesia; FCD: focal cortical dysplasia; FLE: frontal lobe epilepsy; SAHE: selective amygdalohippocampectomy; LEAT: long-term epilepsy-associated tumors; AMR: anterior mesial temporal lobe resection; PPV: positive predictive value, NPV: negative predictive value.

Author	Age group	Resection site	ECoG type	Guidance resection	Postresection ECoG predicts outcome
McBride et al. [17]		Temporal	Spikes	+	±
Fiol et al. [18]		Temporal	Spikes	+	+
Stefan et al. [19]		Temporal	Spikes	–	+
Jennum et al. [20]		Mixed	Spikes	+	+
Berger et al. [16]	Children, tumors	Mixed	Spikes	+	+
Palmini et al. [2]	Mixed	Mixed	Polyspikes	+	+
Tsai et al. [21]		Temporal	Spikes	–	–
Cascino et al. [22]		Temporal	Spikes	–	–
Tran et al. [5]		Temporal	Spikes	–	No correlation at all
Kanazawa et al. [23]		Temporal, LA surgery	Spikes	–	–
Alarcon et al. [24]		Temporal	Spikes	+	Leading spikes, +
Schwartz et al. [6]		Temporal	Spikes	+	No correlation at all
Ferrier et al. [25]		Frontal, FCDs	Spikes	+	±
Wennberg et al. [12]		Lesional FLE	Spikes	+	+
McKhann et al. [26]		Temporal, Hippocampus	Spikes	+	±
Chen et al. [27]		Temporal, SAHE	Spikes	+	Positive correlation
Oliveira et al. [28]		Temporal	Spikes	–	±
Sugano et al. [29]		Temporal, LEATs	Spikes	+	±
Yajakar et al. [29]	Children	Mixed	Spikes	+	More extraoperative ECoG, ±
Morales Chacon et al. [30]	Adults	Temporal, dual pathology	Spikes	+	Less spikes, but no correlation
Tripathi et al. [8]	Adults	Temporal	Spikes	+	+
San-Juan et al. [7]	Adults	Temporal, AMR	Spikes	–	No correlation
Burkholder et al. [31]	Adults	Temporal	Spikes	+	+
Zweiphenning et al. [32]		Temporal	Fast ripples	+	Identification of epileptic zone?
Greiner et al. [4]	Children	Mixed	Spikes	+	Trend to positive correlation
Tahry et al. [33]		Not specified	Spikes	–	–
Fedele et al. [34]	6 yrs mean	Not specified	Fast ripples	+	PPV 100%, NPV 38%
Van't Klooster et al. [15]	15 yrs mean	Temporal, extratemp	HFOs	+	Positive correlation
Hussain et al. [35]	Children	Mixed	Fast ripples	+	Positive correlation
Bansal et al. [36]	Children	Mixed	Spikes	+	No correlation to ECoG findings
Herlopian et al. [37]	Mixed	Temporal, SAHE	Spikes	–	–

Palmini et al. [2]; Greiner et al. [4]; Tran et al. [5]; Schwartz et al. [6]; San-Juan et al. [7]; Tripathi et al. [8]; Wennberg et al. [12]; Van't Klooster et al. [15]; Berger et al. [16]; McBride et al. [17]; Fiol et al. [18]; Stefan et al. [19]; Jennum et al. [20]; Tsai et al. [21]; Cascino et al. [22]; Kanazawa et al. [23]; Alarcon et al. [24]; Ferrier et al. [25]; McKhann et al. [26]; Chen et al. [27]; Oliveira et al. [28]; Sugano et al. [29]; Morales Chacon et al. [30]; Burkholder et al. [31]; Zweiphenning et al. [32]; Tahry et al. [33]; Fedele et al. [34]; Hussain et al. [35]; Bansal et al. [36]; Herlopian et al. [37].

References

- Almeida AN, Martinez V, Feindel W. The first case of invasive EEG monitoring for the surgical treatment of epilepsy: historical significance and context. *Epilepsia* 2005; 46:1082–5. <https://doi.org/10.1111/j.1528-1167.2005.66404.x>.
- Palmini A, et al. Intrinsic epileptogenicity of human dysplastic cortex as suggested by corticography and surgical results. *Ann Neurol* 1995;37:476–87. <https://doi.org/10.1002/ana.410370410>.
- Keene DL, Whiting S, Ventureyra EC. *Electrocorticography. Epileptic Disord* 2000;2: 57–63.
- Greiner HM, et al. Pre-resection intraoperative electrocorticography (ECoG) abnormalities predict seizure-onset zone and outcome in pediatric epilepsy surgery. *Epilepsia* 2016;57:582–9. <https://doi.org/10.1111/epi.13341>.
- Tran TA, et al. Significance of spikes recorded on electrocorticography in nonlesional medial temporal lobe epilepsy. *Ann Neurol* 1995;38:763–70. <https://doi.org/10.1002/ana.410380511>.
- Schwartz TH, et al. The predictive value of intraoperative electrocorticography in resections for limbic epilepsy associated with mesial temporal sclerosis. *Neurosurgery* 1997;40:302–9 (discussion 309–311).
- San-Juan D, et al. The prognostic role of electrocorticography in tailored temporal lobe surgery. *Seizure* 2011;20:564–9. <https://doi.org/10.1016/j.seizure.2011.04.006>.
- Tripathi M, et al. Intra-operative electrocorticography in lesional epilepsy. *Epilepsy Res* 2010;89:133–41. <https://doi.org/10.1016/j.eplepsyres.2009.12.007>.
- Yang T, Hakimian S, Schwartz TH. Intraoperative electrocorticography (ECoG): indications, techniques, and utility in epilepsy surgery. *Epileptic Disord* 2014;16:271–9. <https://doi.org/10.1684/epd.2014.0675>.
- Jayakar P, et al. Diagnostic utility of invasive EEG for epilepsy surgery: indications, modalities, and techniques. *Epilepsia* 2016;57:1735–47. <https://doi.org/10.1111/epi.13515>.
- Salanova V, Andermann F, Olivier A, Rasmussen T, Quesney LF. Occipital lobe epilepsy: electroclinical manifestations, electrocorticography, cortical stimulation and outcome in 42 patients treated between 1930 and 1991. *Surgery of occipital lobe epilepsy. Brain* 1992;115(Pt 6):1655–80.
- Wennberg R, Quesney LF, Lozano A, Olivier A, Rasmussen T. Role of electrocorticography at surgery for lesion-related frontal lobe epilepsy. *Can J Neurol Sci* 1999;26: 33–9.
- Wang DD, et al. Transmantle sign in focal cortical dysplasia: a unique radiological entity with excellent prognosis for seizure control. *J Neurosurg* 2013;118:337–44. <https://doi.org/10.3171/2012.10.JNS12119>.
- van't Klooster MA, et al. Tailoring epilepsy surgery with fast ripples in the intraoperative electrocorticogram. *Ann Neurol* 2017;81:664–76. <https://doi.org/10.1002/ana.24928>.
- van't Klooster MA, et al. High frequency oscillations in the intra-operative ECoG to guide epilepsy surgery ("The HFO Trial"): study protocol for a randomized controlled trial. *Trials* 2015;16:422. <https://doi.org/10.1186/s13063-015-0932-6>.
- Berger MS, Ghatan S, Haglund MM, Dobbins J, Ojemann GA. Low-grade gliomas associated with intractable epilepsy: seizure outcome utilizing electrocorticography during tumor resection. *J Neurosurg* 1993;79:62–9. <https://doi.org/10.3171/jns.1993.79.1.0062>.
- McBride MC, Binnie CD, Janota I, Polkey CE. Predictive value of intraoperative electrocorticograms in resective epilepsy surgery. *Ann Neurol* 1991;30:526–32. <https://doi.org/10.1002/ana.410300404>.
- Fiol ME, Gates JR, Torres F, Maxwell RE. The prognostic value of residual spikes in the postexcision electrocorticogram after temporal lobectomy. *Neurology* 1991;41:512–6.

- [19] Stefan H, Quesney LF, Abou-Khalil B, Olivier A. Electroconvulsive therapy in temporal lobe epilepsy surgery. *Acta Neurol Scand* 1991;83:65–72.
- [20] Jennum P, Dam M, Fuglsang-Frederiksen A. Effect of barbiturate on epileptiform activity: comparison between intravenous and oral administration. Sphenoidal, zygomatic and temporal recordings. *Acta Neurol Scand* 1993;88:284–8.
- [21] Tsai ML, et al. Electroconvulsive therapy in patients with medically intractable temporal lobe seizures. I. Quantification of epileptiform discharges prior to resective surgery. *Electroencephalogr Clin Neurophysiol* 1993;87:10–24.
- [22] Cascino GD, et al. Electroconvulsive therapy and temporal lobe epilepsy: relationship to quantitative MRI and operative outcome. *Epilepsia* 1995;36:692–6.
- [23] Kanazawa O, Blume WT, Girvin JP. Significance of spikes at temporal lobe electroconvulsive therapy. *Epilepsia* 1996;37:50–5.
- [24] Alarcon G, et al. Origin and propagation of interictal discharges in the acute electroconvulsive therapy. Implications for pathophysiology and surgical treatment of temporal lobe epilepsy. *Brain* 1997;120(Pt 12):2259–82.
- [25] Ferrier CH, et al. Relevance of residual histologic and electroconvulsive therapy abnormalities for surgical outcome in frontal lobe epilepsy. *Epilepsia* 2001;42:363–71.
- [26] McKhann II GM, Schoenfeld-McNeill J, Born DE, Haglund MM, Ojemann GA. Intraoperative hippocampal electroconvulsive therapy to predict the extent of hippocampal resection in temporal lobe epilepsy surgery. *J Neurosurg* 2000;93:44–52. <https://doi.org/10.3171/jns.2000.93.1.0044>.
- [27] Chen X, et al. Predictive value of electroconvulsive therapy in epilepsy patients with unilateral hippocampal sclerosis undergoing selective amygdalohippocampectomy. *Neurosurg Rev* 2006;29:108–13. <https://doi.org/10.1007/s10143-005-0002-8>.
- [28] Oliveira PA, et al. Can intraoperative electroconvulsive therapy patterns predict surgical outcome in patients with temporal lobe epilepsy secondary to unilateral mesial temporal sclerosis? *Seizure* 2006;15:541–51. <https://doi.org/10.1016/j.seizure.2006.06.009>.
- [29] Sugano H, Shimizu H, Sunaga S. Efficacy of intraoperative electroconvulsive therapy for assessing seizure outcomes in intractable epilepsy patients with temporal-lobe-mass lesions. *Seizure* 2007;16:120–7. <https://doi.org/10.1016/j.seizure.2006.10.010>.
- [30] Morales Chacon L, et al. Microscopic mild focal cortical dysplasia in temporal lobe dual pathology: an electroconvulsive therapy study. *Seizure* 2009;18:593–600. <https://doi.org/10.1016/j.seizure.2009.06.008>.
- [31] Burkholder DB, et al. Interictal scalp electroencephalography and intraoperative electroconvulsive therapy in magnetic resonance imaging-negative temporal lobe epilepsy surgery. *JAMA Neurol* 2014;71:702–9. <https://doi.org/10.1001/jamaneurol.2014.585>.
- [32] Zweiphenning WJ, et al. High frequency oscillations and high frequency functional network characteristics in the intraoperative electroconvulsive therapy in epilepsy. *NeuroImage* 2016;12:928–39. <https://doi.org/10.1016/j.neuroimage.2016.09.014>.
- [33] El Tahry R, et al. Post-resection electroconvulsive therapy has no added value in epilepsy surgery. *Acta Neurol Belg* 2016;116:279–85. <https://doi.org/10.1007/s13760-016-0641-2>.
- [34] Fedele T, et al. Prediction of seizure outcome improved by fast ripples detected in low-noise intraoperative corticogram. *Clin Neurophysiol* 2017;128:1220–6. <https://doi.org/10.1016/j.clinph.2017.03.038>.
- [35] Hussain SA, et al. Intraoperative fast ripples independently predict postsurgical epilepsy outcome: comparison with other electroconvulsive therapy phenomena. *Epilepsy Res* 2017;135:79–86. <https://doi.org/10.1016/j.eplepsyres.2017.06.010>.
- [36] Bansal S, et al. Seizure outcomes in children following electroconvulsive therapy-guided single-stage surgical resection. *Pediatr Neurol* 2017;71:35–42. <https://doi.org/10.1016/j.pediatrneurol.2017.01.024>.
- [37] Herlopian A, Shihabuddin B. Predictive value of electroconvulsive therapy in patients with mesial temporal lobe epilepsy undergoing selective amygdalohippocampectomy. *J Clin Neurophysiol* 2017;34:370–4. <https://doi.org/10.1097/WNP.0000000000000376>.