The Neurodiagnostic Journal, 00: 1–9, 2019

ISSN: 2164-6821 print / 2375-8627 online
DOI: https://doi.org/10.1080/21646821.2019.1627148

Electrophysiological Mapping and Monitoring during an Awake Craniotomy for Low-Grade Glioma: Case Report

Justin W. Silverstein, DHSc, CNIM, R.EPT, R.NCS.T, CNCT[1,2]; Andrew Rosenthal, B.S., CNIM[1]; Nitesh V. Patel, M.D.[3,4]; John A. Boockvar, M.D.[3,4]

[1]*Neuro Protective Solutions*
New York, New York
[2]*Department of Neurology*
Lenox Hill Hospital Northwell Health
New York, New York
[3]*Department of Neurosurgery*
Lenox Hill Hospital Northwell Health
New York, New York
[4]*Donald and Barbara Zucker School of Medicine at Hofstra/Northwell*
New York, New York

ABSTRACT. *Awake craniotomy is advocated for the resection of supratentorial low-grade gliomas (LGG). The combination of neurophysiological electrical mapping techniques and performing the craniotomy awake has demonstrated increased total and supratotal resection of LGG, as well as increased overall survival rates. We present an illustrative case where the patient's gross motor function deteriorated during the resection of a LGG and mapping techniques using the phase reversal technique and Taniguchi direct cortical stimulation technique while the patient was awake proved to be valuable in determining continuity of the corticospinal tracts.*

KEY WORDS. *Awake craniotomy, brain mapping, direct cortical stimulation, low-grade glioma, phase reversal.*

Awake craniotomy is advocated for the resection of supratentorial low-grade gliomas (LGG) (Duffau 2018). The combination of neurophysiological electrical

Corresponding Author's E-mail: wiredneuro@gmail.com
Received: March 20, 2019. Accepted for publication: May 31, 2019.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/utnj.

mapping techniques and performing the craniotomy awake have demonstrated increased total and supratotal resection of LGG, as well as increased overall survival rates (Berger 1995; Duffau 2018; Saito et al. 2015; Yordanova et al. 2011).

Electrical mapping of eloquent areas can be divided into two categories (sensorimotor localization & direct cortical stimulation). Sensorimotor localization uses the phase reversal technique (PRT) to distinguish between the sensory and motor cortices. A strip or grid electrode is placed subdurally on the brain to record a somatosensory evoked potential (SSEP) from stimulation applied to a contralateral peripheral nerve (usually the median nerve). The SSEP is recorded from the strip or grid. The SSEP is negatively deflected at postcentral locations, whereas at precentral locations the SSEP is positively deflected. As the electrodes cross the central sulcus the SSEP recording would be out of phase (Phase reversal) (Wood et al. 1988).

There are two methods for direct cortical stimulation (DCS); the Penfield method and the Taniguchi method. The Penfield method uses long train (4–5 s), low frequency (60 hz) bipolar stimulation to excite eloquent tissue; whereas, the Taniguchi method uses multi-pulse, short train (5–7 pulses), high frequency (500 Hz) stimulation (Berger 1995; Penfield and Boldrey 1937; Taniguchi et al. 1993; Yingling 2011). The Penfield method is more widely used for electrical mapping in awake craniotomy for language, motor and sensory activation (Berger 1995; Cohen-Gadol 2018; Duffau 2018; Kanno and Mikuni 2015; Kombos and Suss 2009; Ottenhausen et al. 2015; Saito et al. 2015; Skrap et al. 2016). Comparatively, the Taniguchi method offers time-locked motor-evoked potential (MEP) recordings, decreased elicitation of intraoperative seizure, limited-to-no patient movement and the ability to functionally monitor corticospinal pathways throughout tumor resection (Kombos and Suss 2009; Taniguchi et al. 1993; Yingling 2011).

We present an illustrative case where the patient's gross motor function deteriorated during the awake resection of an LGG; PRT and Taniguchi DCS techniques were beneficial for determining the continuity of the corticospinal tracts.

Case Report

A 54-year-old right-handed male was noted to have new onset seizures in July 2018. He was evaluated in Detroit, Michigan and found to have a left frontoparietal lesion adjacent to his left motor cortex (Figure 1). While in Detroit, he was treated with subtotal resection, and the pathology was suggestive of a World Health Organization (WHO) Grade III Glioma. The patient traveled to New York City and sought the expertise of the attending surgeon (JAB) on this manuscript. The patient was neurologically intact, and it was recommended that he undergoes an awake craniotomy for a repeat resection with neuromonitoring.

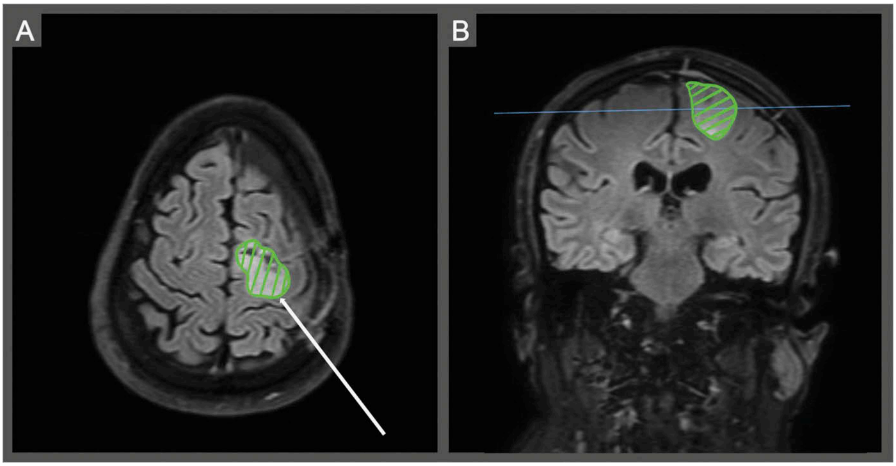

FIG. 1. Pre-operative axial and coronal views. The left and right images are T2-weighted fluid-attenuated inverted recovery (FLAIR) axial and coronal (respectively) MR images from the patient's pre-operative work-up. This sequence is useful for lower grade and poorly enhancing gliomas. The hyperintense region is well demarcated and signifies the span of the patient's lesion. The arrow in image A is pointing to the suspected motor cortex.

METHODS

The electrophysiological neuromonitoring modalities used for this procedure were somatosensory-evoked potentials (SSEP), electromyography (EMG), sensorimotor localization using the phase reversal technique (PRT), direct cortical anodal motor stimulation (DCMEP), and EEG. Gross motor movement was evaluated by qualitative observation during the tumor resection by continuously asking the patient to move their right arm and leg. The qualitative assessment was performed independent of the electrophysiological monitoring and conducted by a neuropsychologist. Upper and lower extremity muscle groups were targeted with standard intraoperative EMG electrodes for EMG and DCMEP recordings. The patient did not feel the placement of the needle electrodes due to adequate sedation. Median and posterior tibial nerve SSEPs were performed bilaterally as a pilot to the PRT. SSEP responses were obtained with a stimulus intensity of 5 mA to minimize patient discomfort. For the PRT, the right median nerve was stimulated at 5 mA, with a 200 μsec pulse-width and recordings were obtained from the 1 × 4 sub-dural electrode. DCMEP was conducted anodally using multi-pulse stimulation with a train of 5, an interstimulus interval of 2 ms (500 Hz), and a constant current stimulation of 2 mA via a handheld monopolar flush-tip probe.

RESULTS

A left-sided awake craniotomy was performed, and gross motor movement was evaluated from the right upper and lower extremities. The patient was alert and had no issues following verbal commands during the resection. The tumor's posterior border encroached upon the patient's left motor cortex. During resection along the posterior border of the tumor, the patient went into right upper extremity motor arrest and was unable to move his right arm. Surgical pause allowed motor function to be restored to the right upper extremity; however, the proximal arm remained weaker than the hand. After a few more minutes of surgical cessation, motor function began returning to the proximal arm as well; however not to baseline function. At this point, resection resumed until another episode of motor arrest occurred, this time in the patient's right lower extremity. Again, there was a surgical pause; however, the gross motor

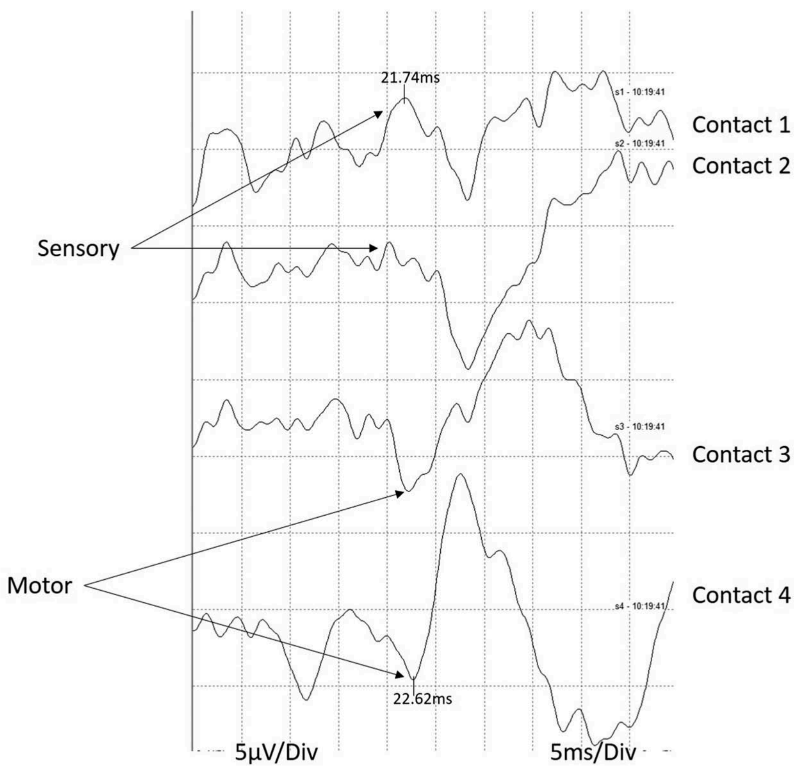

FIG. 2. Phase reversal. The patient is awake which is why the phase reversal has EMG noise artifact. The patient had difficulty tolerating the stimulation even at 5 mA. We were unable to acquire enough trials to eliminate extraneous noise.

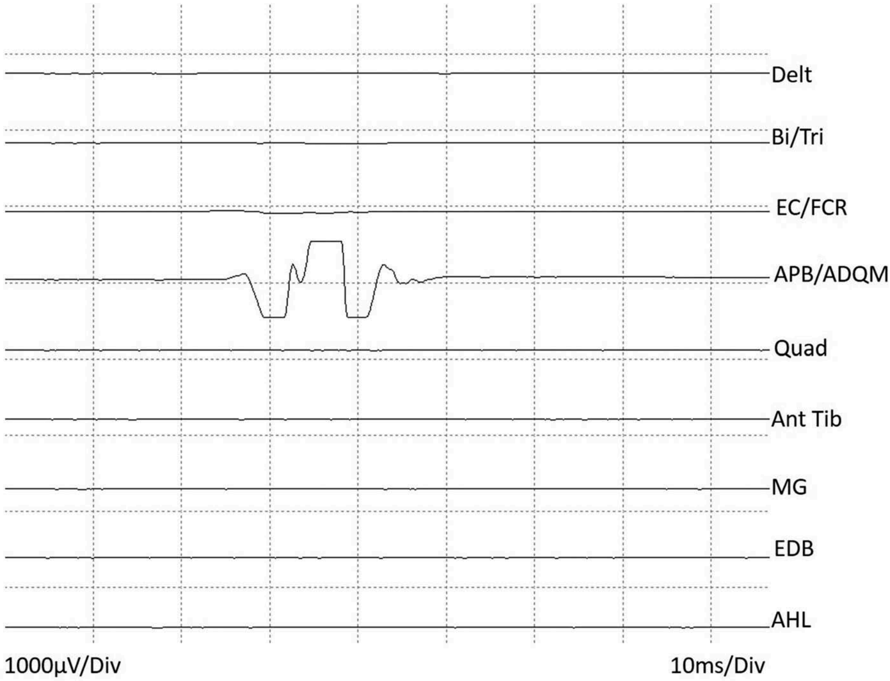

FIG. 3. DCMEP from the right hand. Delt = Deltoid; Bi/Tri = Biceps/Triceps; EC/FCR = Extensor communis/flexor carpi radialis; APB/ADQM = abductor pollicis brevis/abductor digiti quinti minimi; Quad = Quadriceps; Ant Tib = Anterior Tibialis; MG = Medial Gastrocnemius; EDB = Extensor digitorum brevis; AHL = Abductor Hallicis longus.

function of the leg did not return. The surgeon then placed a 1 × 4 strip electrode subdurally, and we performed the PRT to localize the motor cortex and determine its distance from the posterior aspect of the tumor. The PRT revealed a phase reversal between contacts 2 and 3 with contacts 1 and 2 representing the sensory area and contacts 3 and 4 representing motor area (Figure 2).

Once we confirmed the location of the motor cortex, the surgeon used a monopolar probe to stimulate the motor cortex directly to map the motor homunculus and also to evaluate the functional integrity of the pyramidal pathways. Our first stimulation elicited a compound muscle action potential (CMAP) from the Hand (Figure 3), and as we tracked the motor cortex medially with the handheld monopolar probe, we elicited CMAPs from the proximal upper extremities and eventually from the lower extremities (Figures 4 & 5). After confirming continuity of the corticospinal tracts, the surgery was halted, hemostasis was achieved, and closure was commenced. A near complete resection (>95%) of the tumor was accomplished (Figure 6).

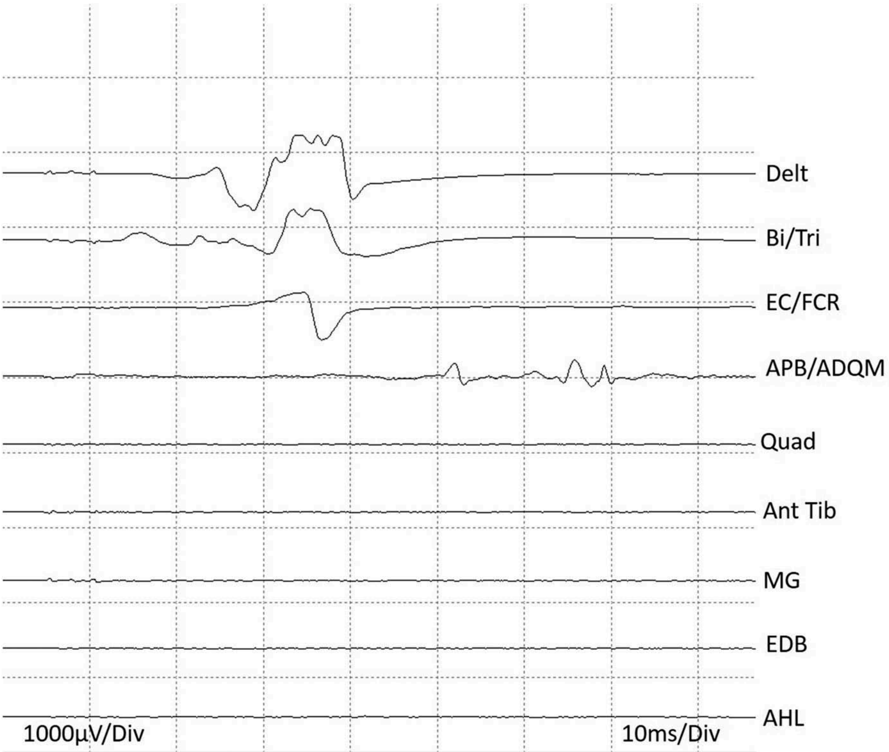

FIG. 4. DCMEP from proximal muscles; please note the late response in the APB/ADQM channel. This is EMG activity noted as the patient was moving his hand. Delt = Deltoid; Bi/Tri = Biceps/Triceps; EC/FCR = Extensor communis/flexor carpi radialis; APB/ADQM = abductor pollicis brevis/abductor digiti quinti minimi; Quad = Quadriceps; Ant Tib = Anterior Tibialis; MG = Medial Gastrocnemius; EDB = Extensor digitorum brevis; AHL = Abductor Hallicis longus.

In the acute post-op phase, the patient was densely hemiparetic on the right side with the lower extremity being weaker than the upper extremity. During the first week following surgery, his strength progressively improved to 4/5 muscle strength in the upper extremities and 3/5 muscle strength in the lower extremities. He was discharged to acute rehab with the ability to ambulate with a walker. At one-month follow-up, he continued to make progress with nearly full strength in his lower extremity and 4/5 strength in his upper. He maintains his antiepileptic regimen consisting of valproic acid, levetiracetam, and lacosamide.

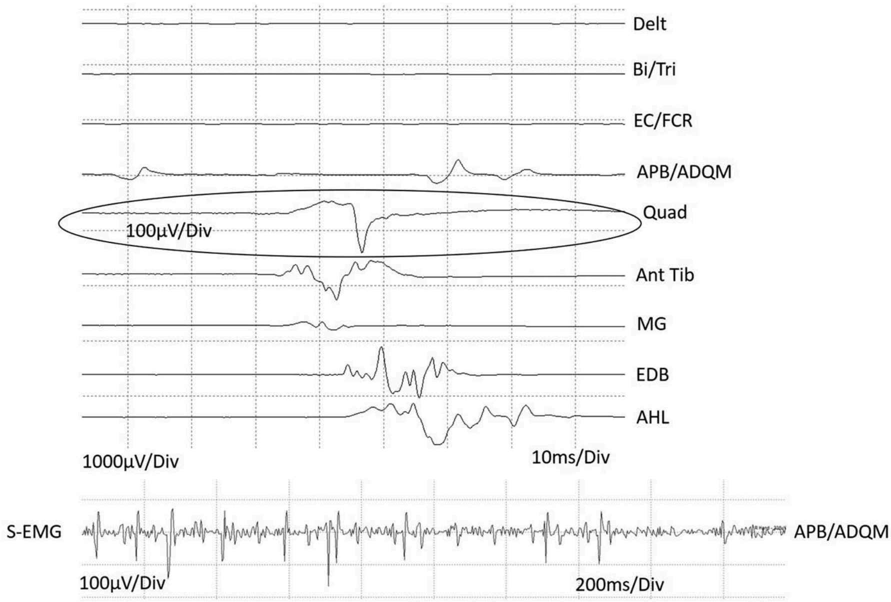

FIG. 5. DCMEP of lower extremity muscles. Note the time-locked EMG in APB/ADQM channel of the DCMEP waveform window. Displayed below is spontaneous EMG activity from the hand muscles during this time. The patient was moving his hands at this time making the EMG from the hand is incidental to the DCMEP. Note that the screen sensitivity for the Running head: Mapping & Monitoring Awake quadriceps is 100 µV compared to the rest of the lower extremities which are robust with a screen sensitivity of 1000 µV. Delt = Deltoid; Bi/Tri = Biceps/Triceps; EC/FCR = Extensor Communis/Flexor Carpi Radialis; APB/ADQM = abductor pollicis brevis/abductor digiti quinti minimi; Quad = Quadriceps; Ant Tib = Anterior Tibialis; MG = Medial Gastrocnemius; EDB = Extensor digitorum brevis; AHL = Abductor Hallicis longus.

DISCUSSION

Maximal tumor removal has shown to increase the survival rate of 14–15 years in patients with LGG (Duffau 2018, 2012). Quality of life is maintained, and permanent post-operative morbidity is avoided when the resection is performed awake with cortical mapping techniques (deWitt Hamer et al. 2012; Duffau 2012, 2017; Hervey-Jumper and Berger 2016). Most mapping techniques described for awake craniotomy during LGG resection include the PRT and the Penfield method of DCS. The Taniguchi method is typically described for functional monitoring of motor pathways after the motor cortex has already been identified (Berger 1995; deWitt Hamer et al. 2012; Duffau 2018, 2012, 2017; Hervey-Jumper and Berger 2016; Kombos and Suss 2009; Ottenhausen et al. 2015; Saito et al. 2015; Skrap et al. 2016; Szelenyi et al. 2010). A newer technique, described by

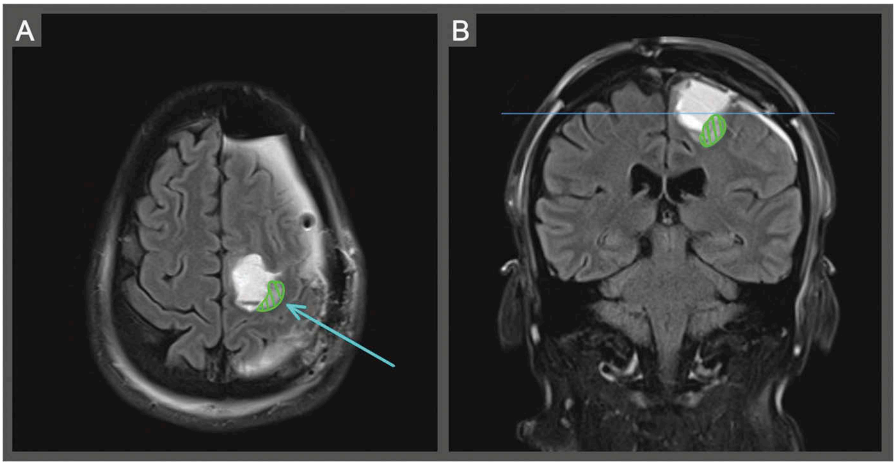

FIG. 6. Post-operative axial and coronal views. The left and right images are T2-weighted fluid-attenuated inverted recovery (FLAIR) axial and coronal (respectively) MR images from the patient's post-operative course. In comparison to his pre-operative imaging, an area of the intentional residual is noted at the inferior lateral margin. The resected volume is marked by a signal more intense (brighter) as compared to the residual, which is in close proximity to the motor cortex (arrow).

Rabbe et al. (2014), describes using an electrified suction device to continuously monitor/identify corticospinal tracts while the surgeon is resecting an infiltrating tumor.

Saito et al. (2015), describes that the MEP recording may provide false-positive information, and voluntary movement should be evaluated to assess intraoperative motor function in the face of an attenuated MEP recording. However, in our case, we saw the inverse to Saito's experience where the electrophysiology was more specific than the qualitative gross motor presentation. Preserved MEPs from direct cortical stimulation coinciding with the patient's motor arrest gave an indication that there was maintained continuity of the pyramidal tracts despite gross paresis or paralysis.

There may be prognostic and diagnostic value with the information provided in this case study; however, this is outside the scope of this manuscript. The authors do believe that the differential diagnosis may have been an onset of supplemental motor area (SMA) syndrome (SMA syndrome presents as temporary weakness in the affected limbs post-operatively) or more likely, direct irritation of the motor cortex itself since the patient did not go into motor arrest until the resection was directly adjacent to the motor cortex (as confirmed electrophysiologically). With evidence of intact DCMEPs and perceived functional integrity of the pyramidal tracts, we posit that the patient's gross motor arrest would remain temporary. To our knowledge, this is the first manuscript to describe intact motor pathways via electrophysiological testing despite gross motor arrest during an awake craniotomy for tumor resection; however, a larger sample size is needed to determine efficacy and statistical significance.

REFERENCES

Berger M. 1995. Functional mapping-guided resection of low-grade gliomas. Clin Neurosurg. 42:437–452.

Cohen-Gadol A. 2018. Language mapping for glioma. Neurosurg Atlas. 4:1–27.

deWitt Hamer PC, Gil Robles S, Zwinderman A, Duffau H, Berger MS. 2012. Impact of intraoperative stimulation brain mapping on glioma surgery outcome: a meta-analysis. J Clin Oncol. 30:2559–2565.

Duffau H. 2012. The challenge to remove diffuse low-grade gliomas while preserving brain functions. Acta Neurochir. 154:569–574.

Duffau H. 2017. Mapping the connectome in awake surgery for gliomas: an update. J Neurosurg Sci. 61:612–630.

Duffau H. 2018. Is non-awake surgery for supratentorial adult low-grade glioma treatment still feasible? Neurosurg Rev. 41(1):133–139.

Hervey-Jumper SL, Berger MS. 2016. Maximizing safe resection of low- and high-grade glioma. J Neuro-Oncol. 130:269–282.

Kanno A, Mikuni N. 2015. Evaluation of language function under awake craniotomy. Neurol Med Chir (Tokyo). 55:367–373.

Kombos T, Suss O. 2009. Neurophysiological basis of direct cortical stimulation and applied neuroanatomy of the motor cortex: a review. Neurosurg Focus. 27(4):E3.

Ottenhausen M, Krieg S, Meyer B, Ringel F 1. 2015. Functional preoperative and intraoperative mapping and monitoring: increasing safety and efficacy in glioma surgery. Neurosurg Focus. 38(1):E3.

Penfield W, Boldrey E. 1937. Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. Brain. 60:389–443.

Rabbe A, Beck J, Schucht P, Seidel K. 2014. Continuous dynamic mapping of corticospinal tract during surgery of the motor eloquent brain tumors: evaluation of a new method. J Neurosurg. 120 (5):1015–1024.

Saito T, Muragaki Y, Maruyama T, Tamura M, Nitta M, Okada Y. 2015. Intraoperative functional mapping and monitoring during glioma surgery. Neurol Med Chir (Tokyo). 55(1):1–13.

Skrap M, Marin D, Ius T, Fabbro F, Tomasino B. 2016. Brain mapping: a novel intraoperative neuropychological approach. J Neurosurg. 125:877–887.

Szelenyi A, Bello L, Duffau H, Fava E, Feigl G, GAlanda M, Neuloh G, Signorelli F, Sala F. 2010. Intraoperative electrical stimulation in awake craniotomy: methodological aspects of current practice. Neurosurg Focus. 28(2):E7.

Taniguchi M, Cedzich C, Schramm J. 1993. Modification of cortical stimulation for motor evoked potentials under general anesthesia: technical description. Neurosurgery. 32:219–226.

Wood C, Spencer D, Allison T, McCarthy G, Williamson P, Goff W. 1988. Localization of human sensorimotor cortex during surgery by cortical surface recording of somatosensory evoked potentials. J Neurosurg. 68:99–111.

Yingling C. 2011. Intraoperative mapping and monitoring of motor cortex - a new paradigm. US Neurol. 7:64–67.

Yordanova Y, Moritz-Gasser S, Duffau H. 2011. Awake surgery for WHO Grade II gliomas within “noneloquent” areas in the left dominant hemisphere: toward a “supratotal” resection. J Neurosurg. 115:232–239.