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Original article

Direct electrical bipolar electrostimulation for functional cortical and subcortical cerebral mapping in awake craniotomy. Practical considerations

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ABSTRACT

Introduction. – The aim of brain glioma surgery is to maximize the quality of resection, while minimizing the risk of sequelae. Due to the frequent location of gliomas near or within eloquent areas, owing to their infiltrative feature, and because of major interindividual variability, the anatomofunctional organization and connectivity must be studied individually. Therefore, to optimize the benefit-to-risk ratio of surgery, intraoperative functional mapping is extensively used.
Material and methods. – This article aims at describing the rationale, indications and practical aspects of intraoperative direct electrical bipolar electrostimulation for cortical and subcortical mapping under awake conditions using the asleep-awake asleep anaesthetic protocol in the setting of cerebral gliomas. We will address the operative approach, including patient positioning, functional mapping resection strategy, anaesthetic conditions, as well as tips and pitfalls.
Results. – The intraoperative direct electrical bipolar electrostimulation enables: (i) to study the real-time individual cortical functional organization; (ii) to study the anatomofunctional subcortical connectivity along the resection; (iii) to tailor the resection according to individual corticosubcortical functional boundaries. This is an easy, accurate, reliable, well-tolerated and safe detection technique of both cortical and subcortical functionally essential structures during resection. It should be performed in the context of a standardized protocol involving members of both anaesthesiology and neurosurgery teams at neurosurgical centers specialized in surgical neuro-oncology.
Conclusion. – Intraoperative direct electrical bipolar electrostimulation for cortical and subcortical mapping under awake conditions is currently considered the "gold standard" clinical tool for brain mapping during cerebral resection in neuro-oncology.

1. Introduction

The role of surgery in the treatment of brain tumours is to achieve maximal safe tumour removal, histopathological diagnosis, and alleviate focal neurological deficits secondary to mass effect and increased intracranial pressure, whilst minimizing the operative risks. Tumours located within eloquent cortex pose a particular surgical challenge due to the high risk of postoperative neurological deficit. To minimize the risk of damage to such areas, intraoperative functional mapping is often used. This article aims to describe the rationale, indications and practical aspects of intraoperative direct electrical bipolar electrostimulation for cortical and subcortical mapping under awake conditions using the asleep-awake-asleep anaesthesia protocol in the setting of cerebral gliomas. We will address the operative approach, including patient positioning, functional mapping and resection strategy, anaesthetic considerations, as well as tips and pitfalls.

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2. Effectiveness of intraoperative functional mapping for glioma resection

Whatever the grade of malignancy, it is well established that glioma survival is linked to the extent of tumour resection and to the functional status of the patient. Furthermore, the extent of safe resection and the postoperative functional status of the patient are linked. Furthermore, intraoperative direct electrostimulation mapping for glioma resection will help us to achieve this. On this basis, we propose that intraoperative electrostimulation functional mapping should be universally implemented as a standard of care for glioma surgery. Previous studies have demonstrated the functional and survival benefits of intraoperative electrostimulation functional mapping for glioma resection [1]. A recent, large meta-analysis incorporating more than 8000 patients undergoing resection of a supratentorial glioma with or without use of intraoperative electrostimulation functional mapping clearly demonstrated that resections with the use of intraoperative electrostimulation functional mapping were associated with fewer late severe neurological deficits (3.4% vs. 8.2%) and more extensive resection (75% vs. 58%) although the tumours were more frequently in eloquent locations (100% vs. 96%) [2]. Similarly, a cohort study of supratentorial infiltrative glioma who had resective surgery with or without use of intraoperative electrostimulation functional in the same institution previously demonstrated that resections with the use of intraoperative electrostimulation functional mapping were associated with fewer late severe neurological deficits (6.5% vs. 17%) and more extensive resection (76% vs. 44%) although they more frequently involve eloquent locations (62% vs. 35%) [3]. In addition, the use of awake craniotomy can result in a considerable reduction of resource utilization, without compromising patient care, by minimizing the intensive care time and total hospital stay by the avoidance of deficits [4–7].

3. Indications of awake intraoperative functional mapping during glioma resection

We would argue that the use of intraoperative cortical and subcortical electrostimulation mapping is now mandatory during the resection of infiltrative lesions located within or adjacent to language areas and their connecting pathways [1,2,8–11]. The indications of awake craniotomies and intraoperative cortical and subcortical electrostimulation mapping can be extended to map and preserve other brain networks not directly involved in language, crucially for motor pathways, but also for somatosensory, visual, vestibular functions, spatial awareness, and cognitive function (calculation, memory, understanding, judgement) [12]. In addition, awake craniotomies for intraoperative cortical and subcortical electrostimulation mapping can be used to map and preserve brain networks overlying a well delineated lesion in order to remove the perilesional brain tissue that may contain isolated glioma cells in the context of infiltrative gliomas [13], that may contain isolated neoplastic cells in the context of metastases, or that may contain epileptogenic hemosiderin infiltration in the context of cavernous angiomas [14]. Awake craniotomies and intraoperative cortical and subcortical electrostimulation mapping can be used to map and preserve brain networks to functionally tailor a transcortical approach as an alternative to the classical transulcal approach to reach a deep-seated lesion [15,16]. In addition, reoperation using awake craniotomy and intraoperative cortical and subcortical electrostimulation mapping can be easily performed to achieve a more complete resection following an initial incomplete tumour removal thanks to brain plasticity [17,18]. Finally, cortical and subcortical electrostimulation mapping can also contribute to a better understanding of the functional organization of the brain [19]. As a practical consequence, invasive electrophysiological investigation is the current gold standard method for mapping brain functions [19,20]. Examples of indications of intraoperative direct cortical and subcortical electrostimulation mapping under awake conditions are presented in Fig. 1.

4. Limitations of intraoperative functional mapping for cerebral resection under awake conditions

Preoperative anaesthetic work-up is essential, the main contra-indications to surgery being acute or unstable coronary disease, severe asthma, severe reduction in mouth opening (< 30 mm), obesity (body mass index > 35 kg/m^2), clinically disabling gastroesophageal reflux, partial airway obstruction of any cause, or poor functional status unrelated to the neuro-oncological disease [21]. Although age is not a strict contra-indication, older patients are rarely offered such treatment. However, in a study comparing elderly patients (> 65 years old) to younger patients, it appears that intraoperative functional mapping for cerebral resection under awake conditions in the elderly population with good preoperative functional status was both feasible and not associated with increased perioperative morbidity or mortality [22].

The patient's functional status should be assessed preoperatively to determine the extent of neurological and neuropsychological functional impairment, if any. If the patient has a dense hemiparesis (0–3/5), intraoperative motor mapping will often not be effective. If antigravity movements are present preoperatively, however, it is usually possible to stimulate both cortical and subcortical motor pathways intraoperatively, although the robustness of the response will be dependent on the degree of functional integrity [4].

Patients who undergo intraoperative language mapping should be preoperatively tested for language mistakes. Patients must be able to name common objects with a baseline error rate lower than 25%, with each slide presented at least three times. In patients who have moderate to severe dysphasia in either comprehension or expression, successful language mapping will not be possible. Therefore, these patients may either be asleep during surgery, without any attempt to do more than an intralesional decompression, or be challenged with steroids and diuretics for one to two weeks and then re-evaluated regarding their baseline error rate in naming [4].

Patients with symptomatic increased intracranial pressure due to significant vasogenic oedema and mass effect from their tumour may not be candidates for an intraoperative functional mapping for cerebral resection under awake condition because of the potential for cerebral herniation out of the dural opening. Alterations in arterial CO_2, in the setting of a patient not well ventilated, despite the use of osmotic diuretics, may compromise the safety of the planned craniotomy and tumour resection. Swelling, herniation and contusion may occur, resulting in an abandonment of the procedure [4]. Therefore, these patients may first receive an intralesional decompression to alleviate mass effect and increased intracranial pressure under asleep conditions either during a first surgery, or during the first step of an asleep-awake-asleep procedure. Examples of the management of increased intracranial pressure in cases of intraoperative direct cortical and subcortical electrostimulation mapping under awake conditions are presented in Fig. 2.

5. Preoperative preparation

Preoperative evaluation and preparation are a key to successful intraoperative functional mapping under awake conditions. Preoperative preparation should ideally comprise of at least three