Brain hodotopy: new insights provided by intrasurgical mapping

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Introduction

The dilemma of cerebral surgery is to optimize the extent of resection while preserving brain function [18]. This is particularly challenging when the lesion is located within eloquent areas, which is quite frequently the case, for example, for low-grade gliomas [19]. Since anatomical landmarks are crucial but definitely not sufficient to understand the individual anatomo-functional organization, brain mapping methods should now be used in a systematic manner in both the perioperative and the intraoperative period. Functional cortical mapping is the first step, as regularly reported in the recent literature. However, although detection and preservation of the axonal connectivity are also essential, the subcortical structures have yet received little attention.

The study of both cortical and subcortical organization is mandatory to avoid postsurgical permanent deficit. Indeed, lessons from stoke studies have taught that a damage of the white-matter pathways generated a more severe neurological worsening than lesions of the cortex. By combining cortical function and axonal connectivity, an updated model of cerebral processing has recently been proposed, moving from a classical “localizationist” view to a “hodotopical” framework [4]. In pathology, according to this new concept, a topological mechanism (from Greek topos, place) refers to a dysfunction of the cortex (deficit, hyperfunction of a combination of the two), whereas a hodological mechanism (from Greek hodos, road or path) refers to a dysfunction related to connecting pathways (disconnection, hyperconnection, or a combination of the two) [5]. In other words, it is mandatory to take into account the complex functioning of a large-scale distributed cortico-subcortical network to understand both the physiology and the functional consequences of a lesion of this circuit, with possibly different deficits depending on the location and the extent of the damage (e.g., purely cortical or purely subcortical or both).

In contrast to extraoperative electrical mapping, intraoperative direct brain stimulation enables to map not only the cortex before any surgical resection but also the white-matter bundles. Such data are very important to tailor the resection according to functional boundaries and thus to optimize the benefit-to-risk ratio of the surgery. In addition, they provide new insights into brain’s processing, with fundamental implications in the field of cognitive neurosciences. The aim is to review the new findings brought by intrasurgical cortical and subcortical electrical mapping, which, in combination with functional neuro-imaging, open the door to a “connectionist” view of cerebral functioning [13, 15].
Intraoperative electrostimulation: new insights into the anatomo-functional cortical organization (topos)

Anatomo-functional organization of the supplementary motor area

The supplementary motor area (SMA) – the frontomesial area located in front of the primary motor area of the inferior limb – is involved in the planning of movement. Its resection induces the classical SMA syndrome. This syndrome is characterized by a complete akinesia and even mutism in cases of lesions of the left dominant SMA and occurs approximately thirty minutes after the end of the resection as observed in awake patients [22]. It suddenly and spontaneously resolves around the tenth day after surgery, even if some rehabilitation for 1 to 3 months is often needed in order to allow a better recovery. By preoperative fMRI, it has been shown that the occurrence of this syndrome was not related to the volume of the frontal resection but was directly related to the removal of a specific structure called the SMA proper, detectable on the preoperative imaging. Thus, on the basis of the presurgical fMRI, it is now possible to predict before surgery if an SMA syndrome will or will not occur postoperatively and to inform the patient and his family [41, 42]. Moreover, by coupling preoperative fMRI, the pattern of clinical deficit after surgery, and the extent of resection on the postoperative MRI, the existence of a somatotopy within the SMA proper has been demonstrated, namely (from anterior to posterior), the representation of language (at least in the dominant hemisphere), of the face, then the superior limb, and then the inferior limb (immediately in front of the paracentral lobule) [37]. As a consequence, it is also possible to predict before SMA resection the severity and the pattern of the postoperative transient deficit (e.g., only mutism, mutism and akinesia of the superior limb, or akinesia of the entire hemibody). This has an important impact on the planning of a specific rehabilitation.

Role of the insular lobe in language and swallowing

Although tumors, particularly low-grade gliomas, frequently involve the insular lobe, this structure has long been poorly studied for technical reasons. The insula is an anatomical, cytoarchitectonic, and functional interface between the allocortex and neocortex. Recent studies have enabled to better understand the implication of this multimodal lobe in many functions (for a recent review, see [7]), particularly for language. Indeed, preoperative fMRI has regularly showed an activation of the anterior insular cortex in the dominant hemisphere during language tasks as reported for healthy volunteers. Moreover, these results were confirmed by intraoperative electrical mapping (IEM), which induced language disorders and, more specifically, articulatory disturbances when applied on the insular cortex, supporting a role of this structure in the complex planning of speech [16, 20, 21, 36] as previously suggested in stroke studies [9]. These data have important implications for the neurosurgeon, since for a left dominant (fronto-temporo-)insular lesion, resection carries a high risk to be incomplete. Moreover, following resection of gliomas involving the right nondominant insulo-opercular structures, the induction of a transient Foix-Chavany-Marie syndrome can be observed, that is, a bilateral facio-linguo-pharyngo-laryngeal palsy with a reversible inability of the patient to speak and swallow [25].

Anatomo-functional organization of the left inferior frontal gyrus

IEM showed that the classical “Broca area” was not basically involved in speech production, but in high-level language processing (such as language switching [51, 52]), with its posterior part (pars opercularis) being more involved in phonological processing, its superior part (pars triangularis) implied in syntactic processing [60], and its anterior part (pars orbitaris) more involved in a large semantic network un-