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Alexandra J. Golby and Peter McLaren Black

Special Surgical Considerations for Functional Brain Mapping 111

Hussein Kekhia, Laura Rigolo, Isaiah Norton, and Alexandra J. Golby

The development of functional mapping techniques gives neurosurgeons many options for preoperative planning. Integrating functional and anatomic data can inform patient selection and surgical planning and makes functional mapping more accessible than when only invasive studies were available. However, the applications of functional mapping to neurosurgical patients are still evolving. Functional imaging remains complex and requires an understanding of the underlying physiologic and imaging characteristics. Neurosurgeons must be accustomed to interpreting highly processed data. Successful implementation of functional image-guided procedures requires efficient interactions between neurosurgeon, neurologist, radiologist, neuropsychologist, and others, but promises to enhance the care of patients.

Part I: Techniques

Overview of Functional Magnetic Resonance Imaging 133

Gary H. Glover

Blood Oxygen Level Dependent (BOLD) functional magnetic resonance imaging (fMRI) depicts changes in deoxyhemoglobin concentration consequent to task-induced or spontaneous modulation of neural metabolism. Since its inception in 1990, this method has been widely employed in thousands of studies of cognition for clinical applications such as surgical planning, for monitoring treatment outcomes, and as a biomarker in pharmacologic and training programs. More recently, attention is turning to the use of pattern classification and other statistical methods to draw increasingly complex inferences about cognitive brain states from fMRI data. This article reviews the methods, challenges, and future of fMRI.

Brain Mapping Using Transcranial Magnetic Stimulation 141

José Rafael Romero, Deisy Marcela Ramirez, Linda S. Aglio, and Laverne D. Gugino

Transcranial magnetic stimulation (TMS) is a novel brain stimulation technique that has advanced the understanding of brain physiology, and has diagnostic value as well as therapeutic potential for several neuropsychiatric disorders. The stimulation involves restricted cortical and subcortical regions, and, when used in combination with a visually guided technique, results in improved accuracy to target specific areas, which may also influence the outcome desired. This article reviews the principles underlying the mechanism of action of TMS, and discusses its use to obtain functional maps of the motor and visual cortex, including technical considerations for accuracy and reproducibility of mapping procedures.

Clinical Magnetoencephalography for Neurosurgery 153

Steven M. Stufflebeam

Noninvasive neuroimaging aids in surgical planning and in counseling patients about possible risks of surgery. Magnetoencephalography (MEG) performs the most

common types of surgical planning that the neurosurgeon faces, including localization of epileptic discharges, determination of the hemispheric dominance of verbal processing, and the ability to locate eloquent cortex. MEG is most useful when it is combined with structural imaging, most commonly with structural magnetic resonance (MR) imaging and MR diffusion imaging. This article reviews the history of clinical MEG, introduces the basic concepts about the biophysics of MEG, and outlines the basic neurosurgical applications of MEG.

PET and SPECT in Brain Tumors and Epilepsy 169

Laura L. Horky and S. Ted Treves

Molecular imaging with positron emission tomography (PET) plays an important role in the diagnosis and management of patients with brain tumors and epilepsy. The clinical uses of FDG are discussed, as well as the research applications of novel PET tracers. Where applicable, single-photon emission computed tomography (SPECT) is also discussed.

An Introduction to Diffusion Tensor Image Analysis 185

Lauren J. O'Donnell and Carl-Fredrik Westin

Diffusion tensor magnetic resonance imaging (DTI) is a relatively new technology that is popular for imaging the white matter of the brain. This article provides a basic and broad overview of DTI to enable the reader to develop an intuitive understanding of these types of data, and an awareness of their strengths and weaknesses.

Multimodal Image Registration for Preoperative Planning and Image-Guided Neurosurgical Procedures 197

Petter Risholm, Alexandra J. Golby, and William Wells III

Image registration is the process of transforming images acquired at different time points, or with different imaging modalities, into the same coordinate system. It is an essential part of any neurosurgical planning and navigation system because it facilitates combining images with important complementary, structural, and functional information to improve the information based on which a surgeon makes critical decisions. Brigham and Women's Hospital (BWH) has been one of the pioneers in developing intraoperative registration methods for aligning preoperative and intraoperative images of the brain. This article presents an overview of intraoperative registration and highlights some recent developments at BWH.

Part II: Applications

Motor and Sensory Mapping 207

Andrei I. Holodny, Nina Shevzov-Zebrun, Nicole Brennan, and Kyung K. Peck

Functional magnetic resonance imaging (fMRI) enhances the understanding of neuroanatomy and functions of the brain and is becoming an accepted brain-mapping tool for clinicians, researchers, and basic scientists alike. A noninvasive procedure with no known risks, fMRI has an ever-growing list of clinical applications, including presurgical mapping of motor, language, and memory functions. fMRI benefits patients and allows neurosurgeons to be aware of, and to navigate, the precise location of patient-specific eloquent cortices and structural anomalies from a tumor. Optimizing preoperative fMRI requires tailoring the fMRI paradigm to the patient's clinical situation and understanding the pitfalls of fMRI interpretation.

Preoperative Prediction of Verbal Episodic Memory Outcome Using fMRI 219

Jeffrey R. Binder

This article focuses on an important neurosurgical problem for which functional imaging may have a role. Temporal lobe epilepsy surgery typically involves removal of much of the anterior medial temporal lobe, which is critical for encoding and retrieval of long-term episodic memories. Verbal episodic memory decline after left anterior temporal lobe resection occurs in 30% to 60% of such patients. Recent studies show that preoperative fMRI can predict the degree of verbal memory change that will occur, and that fMRI improves prediction accuracy when combined with other routine tests. The predictive power of fMRI appears to be at least as good as the Wada memory test, making fMRI a viable noninvasive alternative to the Wada for preoperative assessment.

Transcranial Brain Stimulation: Clinical Applications and Future Directions 233

Umer Najib, Shahid Bashir, Dylan Edwards, Alexander Rotenberg, and Alvaro Pascual-Leone

Noninvasive brain stimulation is a valuable investigative tool and has potential therapeutic applications in cognitive neuroscience, neurophysiology, psychiatry, and neurology. Transcranial magnetic stimulation (TMS) is particularly useful to establish and map causal brain-behavior relations in motor and nonmotor cortical areas. Neuronavigated TMS is able to provide precise information related to the individual's functional anatomy that can be visualized and used during surgical interventions and critically aid in presurgical planning, reducing the need for riskier and more cumbersome intraoperative or invasive mapping procedures. This article reviews methodological aspects, clinical applications, and future directions of TMS-based mapping.

Diffusion Tractography: Methods, Validation and Applications in Patients with Neurosurgical Lesions 253

Delphine Leclercq, Christine Delmaire, Nicolas Menjot de Champfleur, Jacques Chiras, and Stéphane Lehéricy

Diffusion tensor imaging (DTI) tractography is increasingly used in presurgical mapping in tumors located in eloquent areas since it is the only non invasive technique that permits in vivo dissection of white matter tracts. Concordance between the DTI tracts and subcortical electrical intraoperative mapping is high, and DTI tractography has proven useful to guide surgery. However, it presents limitations due to the technique and the tumor, which must be known before using the images in the operative room. This review focuses on the possibilities and limits of DTI imaging in intraoperative tumoral mapping and presents an overview of current knowledge.

Intraoperative Acquisition of fMRI and DTI 269

Christopher Nimsky

Multimodal functional navigation enables removing a tumor close to eloquent brain areas with low postoperative deficits, whereas additional intraoperative imaging ensures that the maximum extent of the resection can be achieved and updates the image data compensating for the effects of brain shift. Intraoperative imaging beyond standard anatomic imaging, that is, intraoperative functional magnetic resonance imaging (fMRI) and especially intraoperative diffusion tensor imaging (DTI), add further safety for complex tumor resections. This article discusses the acquisition of intraoperative fMRI, DTI, and imaging.

Identification of Neural Targets for the Treatment of Psychiatric Disorders: The Role of Functional Neuroimaging 279

David R. Vago, Jane Epstein, Eva Catenaccio, and Emily Stern

Neurosurgical treatment of psychiatric disorders has been influenced by evolving neurobiological models of symptom generation. The advent of functional neuroimaging and advances in the neurosciences have revolutionized understanding of the functional neuroanatomy of psychiatric disorders. This article reviews neuroimaging studies of depression from the last 3 decades and describes an emerging neurocircuitry model of mood disorders, focusing on critical circuits of cognition and emotion, particularly those networks involved in the regulation of evaluative, expressive and experiential aspects of emotion. The relevance of this model for neurotherapeutics is discussed, as well as the role of functional neuroimaging of psychiatric disorders.

Development of a Clinical Functional Magnetic Resonance Imaging Service 307

Laura Rigolo, Emily Stern, Pamela Deaver, Alexandra J. Golby, and Srinivasan Mukundan Jr

One of the limitations of anatomy-based imaging approaches is its relative inability to identify whether specific brain functions may be compromised by the location of brain lesions or contemplated brain surgeries. Of the many techniques available to the surgeon, functional magnetic resonance imaging (fMRI) has become the primary modality of choice because of the ability of MRI to serve as a "one-stop shop" for assessing both anatomy and functionality of the brain. This article discusses the specific requirements for establishing an fMRI program, including specific software and hardware requirements. In addition, the nature of the fMRI CPT codes is discussed.

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