INTRODUCTION

Utility of intraoperative imaging

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SEEING is fundamentally critical to guide surgical interventions. As new imaging technologies have emerged to allow us to see previously invisible anatomical and pathological details, neurosurgeons have been able to perform increasingly more accurate and effective surgeries. Since the advent of ionizing radiation, imaging devices have been used by physicians not only for diagnostic but also for therapeutic purposes, guiding different invasive procedures. Intraoperative imaging has been used for many years in the neurosurgical community for real-time guidance to find, define, and understand different brain and spinal pathologies, and neurosurgeons have always had a great interest in its development.

This potential of imaging as a surgical tool has led to the adoption of different diagnostic imaging devices into the operating room; these devices range from plain radiography to more complex intraoperative computed tomography (iCT) and intraoperative magnetic resonance imaging (iMRI) machines and intraoperative ultrasound (iUS)-based systems. Optical imaging (OI) is an emerging option due to the development of fluorophores, visible with specific filters in the operative microscope, allowing the visualization of blood flow and pathological tissues. These modalities and other optical technologies promise to open the frontiers of real-time intraoperative cellular and chemical/molecular imaging.

These tools are complex and their development and deployment have been rapid. The inherent potential of intraoperative imaging technologies has yet to be fully realized. Multimodality imaging is seldom used and synergies between the technologies have not yet been understood. The appropriateness of different imaging modalities to different clinical problems is still being explored. The number and range of imaging technologies make it quite difficult for a single neurosurgeon to follow all the fast advancements in this field.

Therefore, the current issue of *Neurosurgical Focus* on the impact of intraoperative imaging is a great occasion to bring to the attention of the neurosurgical community the latest advances of this intriguing field. We tried to cover the multiple aspects of this field. The issue contains papers on fusion imaging; neuronavigation guidance; iCT and iMRI applied not only to tumor resection but also to other pathologies; advances in real-time US such as 3D navigation and use of contrast agents, as well as in optical imaging; and new imaging modalities such as Raman spectroscopy and confocal microscopy. Throughout the issue we also tried to stress the pivotal role of cooperation among neurosurgeons, radiologists, and engineers, carefully balancing clinical and practical needs.

We were pleased to receive 56 submissions from around the world, all of outstanding quality. Limited to 16 articles and 2 editorials, we were forced to make difficult choices. We have selected articles encompassing all major aspects and current state-of-the-art intraoperative imaging.

Catheter placement, especially with slit ventricles, is always a challenging procedure. The synergistic use of stereotaxy, neuroendoscopy, and iCT for catheter placement in idiopathic intracranial hypertension is analyzed by Yim et al.

iMRI has great potential and has established itself as a pivotal tool for brain tumor resection in adults, especially in cases of low-grade glioma. This paradigm is confirmed for the pediatric population by Roder et al., while Ghinda et al. describe the clinical impact of high-field iMRI coupled with electrophysiology in awake adult patients undergoing cerebral glioma resection. Scherer et al. analyze factors that guide glioma resection using iMRI and their impact on the extent of resection, with a commentary provided by Fahlbusch and Samii. Roessler et al. report the vast experience of the Erlangen group in the use of iMRI for guidance in epilepsy surgery. Another interest-

ing iMRI application is described by Serra and colleagues for pituitary surgery, showing its ability to detect tumor remnants, while Zaidi et al. also point out the importance of the synergistic use of endoscopy and iMRI in a multimodal operative suite.

iUS has been in use in neurosurgery since the '60s, with the pioneering work of Dyck et al. and other authors. Its use is increasing steadily in the neurosurgical community, but it is still far from being considered a standard tool, and its full potential has yet to be realized. Moiyadi and Shetty describe the use of 3D US navigation as a real-time guidance in neurosurgery, a technique that allows navigation on an acquired 3D US volume—a different approach from how US is used in the radiological community. Lekht et al. offer a technical note on the different possibilities offered by US contrast agents (USCAs), providing an analysis of their interesting case series, while Prada et al. explore the potentials of contrast-enhanced US (CEUS) not only for glioblastoma visualization prior to resection but also for residual tumor detection during resection.

Optical imaging (OI) uses light to detect vessels and parenchyma in areas that are accessible by the optical imaging device. These devices are able to probe cellular and molecular function and can be sensitive imaging tools for the detection of different pathologies. Valdes et al. provide an overview of these interesting tools and their clinical applications. Takai et al. describe how indocyanine green (ICG) angiography can guide surgical decision making in the treatment of difficult entities such as spinal perimedullary arteriovenous fistulas. Martirosyan

and colleagues illustrate the possible role of intraoperative confocal endomicroscopy in the detection of tumoral tissue in a large series of patients undergoing resection of various brain neoplasms. The application of intraoperative Raman spectroscopy in brain tumor surgery is illustrated by Hollon et al. Finally, Selbekk et al. highlight in their editorial the importance of cooperation and communication between physicians and engineers to achieve technical developments.

For certain, intraoperative imaging guides and facilitates the difficult tasks that we encounter daily in our practice, but it will never substitute for careful clinical judgment. However, with rapid technological improvements, we truly believe that intraoperative imaging in neurosurgery will further become a pivotal tool and that its multiple features and future development will lead to new frontiers in the treatment of different pathologies. Indeed, different pathologies will benefit from different techniques, but also the synergistic use of these technologies should be explored, as should their unconventional application. We hope that this issue of *Neurosurgical Focus* will provide a comprehensive overview of the major aspects of intraoperative imaging in neurosurgery and also highlight the multiple possibilities still to be exploited.

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Disclosures

The authors report no conflict of interest.