Intraoperative Ultrasound (IOUS) in Neurosurgery

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Editors

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From Standard B-mode to Elastosonography

Springer

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Preface

Seeing is believing: intraoperative imaging has always been of great help in finding and defining different brain and spinal lesions, and neurosurgeons have always had a great interest in its development. Many tools are available: neuronavigation has been for years a standard tool in almost every neurosurgical unit, but it has the limitations of being based on preoperative imaging which cannot be updated.

Intraoperative computed tomography (iCT) and magnetic resonance imaging (iMRI) have become a standard intraoperative tool, despite not being true real-time tools that can provide direct guidance, and being costly and time consuming; however, image interpretation is straightforward.

This is probably related to the fact that CT and MRI are the main diagnostic tool for CNS pathologies and all neurosurgeons are accustomed to it.

This is not the case of ultrasounds (US), which are scarcely used for adult cerebral and spinal diagnostics, except for some vascular diseases, and therefore represent a sort of "gray area" for neurosurgeons, neuroradiologists, and radiologists and for even those interested in ultrasound.

iUS has been used in neurosurgery since the 1960s, with the pioneering work of Dyck et al., and are still under development. Despite becoming more widespread, they still are far from being considered a routine tool and fully understood in their great potential by the neurosurgical community.

Some authors, prior to this work, tried to standardize this technique and define basic rules to apply into the neurosurgical theater, as it is the case for other parts of the human body. It has to be noted that it is difficult to transmit to the reader the multiple features and opportunities offered by US application in neurosurgery: images are usually taken from examinations that last for some minutes and represents only partially the findings. Videos obtained during the examination are by far more complete and contribute to the understanding of the underlying anatomy, but do not include the manual movement of the US probe that allows the surgeon to translate the two-dimensional US findings into the three-dimensional surgical field within the brain, spinal cord, and nerves. US is also an operator-dependant technique, and the ability to set different parameters is pivotal to obtain good quality imaging. Therefore the machine commands have also to be understood by the surgeon, which add further difficulties to an already complex task. In fact the intraoperative setting differs completely from its diagnostic counterpart and rules apply differently. Furthermore in the past, due to technical limitations, US imaging was very poor, especially compared to CT and MRI, and this also did not contrib-

ute to its use as a surgical tool. Moreover, the lack of standardization, specific knowledge, and training contribute to the consideration of iUS as an adjunct rather than a stand-alone tool in the neurosurgical armamentarium.

In the last years, there have been major technical advances which benefitted greatly the quality of US images that are now comparable in terms of spatial resolution and are by far superior in terms of temporal resolution and readiness to those obtained with iCT or iMRI.

The intraoperative use of US has been refined and made more understandable, for example, with the use of high-resolution power Doppler and 3D navigation, and interesting additional features, such as the use of ultrasound contrast agents or elastosonography, are under investigation.

Our aim of this book is to bring to the attention of the neurosurgical and radiological community the recent advances in sonology and their great potential for the application of intraoperative ultrasound in neurosurgery, relying on the experience gathered by leading experts in different fields.

We will address all the advantages and disadvantages of this great real-time intraoperative tool, always keeping in mind that the full exploitation is achievable through a synergistic effort between neurosurgeons, neuroradiologists, and sonologists, bringing together all different clinical needs.

Therefore, in the first part of the book, we addressed and explained the physics and basic principles of ultrasound, as well as its major clinical application.

We then explore the use of standard B-mode and Doppler, from the semeiotics to exam execution and machine setting in general radiology, and then we tried to translate this experience in the field of neurosurgery aiming at a standardization of the US experience: machine settings for brain, spine, and peripheral nerves evaluation, how to perform the examination, major anatomical topographical and pathological US findings.

In the following chapters, advanced US techniques such as fusion imaging for virtual navigation, contrast-enhanced ultrasound, and elastosonography are highlighted, discussing their application in already standardized body districts, such as the liver, and their application, potential role, and future exploitation in neurosurgery.

We truly believe that IOUS will progressively become a pivotal tool for intraoperative imaging in neurosurgery and that its multiple features and future development will lead to new frontiers in intraoperative imaging and therapeutics, such as the possibility to detect tumor remnants with CEUS or elastosonosgraphy, deliver chemotherapeutic agents using microbubbles, control tumor regrowth, or deliver high-focused ultrasound through artificial ultrasound compatible bone flap. We hope that this book will provide some explanations and answers to the most common questions in this regard, but also highlight the multiple possibilities still to be exploited.

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Busto Arsizio, Italy — Luigi Solbiati
Como, Italy — Alberto Martegani
Milano, Italy — Francesco DiMeco

Acknowledgments

I wish to thank Dr. Francesco DiMeco, my "Chief", for having recognized the value and potential of IOUS, and for continuously pushing towards improvement, and my mentor, Dr. Sergio Giombini, who encouraged the use of IOUS despite his diffidence towards new technologies. I am also indebted to Dr. Gigi Solbiati and Dr. Alberto Martegani, cutting-edge radiologists, who became interested in the application of US in neurosurgery, recognized its potential, and patiently shared their knowledge in the field during many discussions.

Credit should also be given to Luca Lodigiani, colleague and friend, who shared this obsession and endangered his job in order to pursue this project.

I would also like to thank my parents, particularly my father, recognized clinician, who kept on telling me to write clinical experiences. I hope this is enough.

A special thank you to Caroline and Antonia, my wife and daughter, who tolerate my absence, both physical and mental, and continuously support me in my endeavor to meet the demands of a job as challenging as neurosurgery, allowing me to have a "normal" life.

Francesco Prada, MD

About the Editors

Dr. Francesco Prada is staff neurosurgeon in the 1st Neurosurgical Division of the Department of Neurosurgery at the Fondazione IRCCS Istituto Neurologico C.Besta in Milan, Italy, where he received his surgical training with Professor S. Giombini, before starting to cooperate with Professor F. DiMeco.

Dr. Prada shares his interest between clinical practice and research, with main interest in skull base surgery and neuro-oncology.

He is currently leading the "Intra-operative Ultrasound in Neurosurgery Project", started in 2009, and has in fact performed more than 500 image-guided ultrasound procedures.

He particularly focuses on the intraoperative applications of ultrasound for the treatment of cerebral and spinal tumor and vascular lesions. He is currently developing advanced ultrasound techniques in neurosurgery, such as fusion Imaging for virtual navigation, contrast-enhanced ultrasound (CEUS), and elastosonography.

His interest for diagnostic and therapeutic US applications lead to his involvement in the "TheraGlio" project, aimed at the development of multimodal contrast agents.

He has further interest in alpinism and has obtained the diploma in mountain medicine of the "Union Internationale des Associations d'Alpinisme"; he is currently investigating the physiopathological mechanism of cerebral edema in high altitude mountain sickness.

Dr. Prada has published numerous original articles in peer-reviewed journals and chapters in textbooks of *Neurosurgery* and has been editor and reviewer of numerous scientific publications. He has given presentations and lectures at national and international meetings.

Luigi Solbiati was Chairman of the Department of Oncology and Head of the Division of Interventional Oncologic Radiology at the Hospital of Busto Arsizio (Milan, Italy) for 13 years and has been Contract Professor of Techniques and Methods of Diagnostic Imaging at the University of Milan since 1988. In July 2015, he became Professor of Radiology at Humanitas University and Research Hospital in Milan. His main fields of interest have always been small parts ultrasound, interventional procedures in oncologic diseases (particularly tumor ablation), imaging of the neck, and contrast-enhanced sonography. He was one of the pioneers of ultrasound-guided aspiration biopsies (1979), ethanol injection of solid tumors (1983), and fusion

imaging for the guidance of interventional procedures (2003). He has one of the largest world experiences in the treatment of liver malignancies with radiofrequency ablation (RFA) and, more recently, high-power microwaves, accounting for more than 2200 patients. Prof. Solbiati has published 112 original articles in peer-reviewed journals and 81 chapters in textbooks of Radiology, Interventional Radiology, and Oncology and has been editor of 11 books on small parts sonography, contrast-enhanced sonography, and ablative therapies. He has given more than 550 presentations at Meetings in 36 different countries. In 2006, Prof. Solbiati chaired the first World Conference on Interventional Oncology (Cernobbio, Italy) and in 2013 the first Interventional Oncology Sans Frontieres Congress (IOSFC) (Cernobbio, Italy). His H-index is currently 41, his impact factor exceeds 400, and his publications had more than 10,800 citations.

Dr. Alberto Martegani is Director of the Department of Radiology of the Valduce Hospital, Como. He started his career as a radiologist in 1981 under the guidance of Prof. Carlo Del Favero and Prof. Mario Bianchi, covering all aspects of the radiological fields, mainly focusing his efforts towards interventional neuroradiology. He then shifted his education towards musculoskeletal radiology, while, in the early 1980s began to work with ultrasound. His subject of interests became abdominal diagnostics, along with the study of continuous wave Doppler and Duplex technology. In the same period, he applied the use of ultrasound for the intraoperative localization of brain lesions, in a first fruitful cooperation within the field of neurosurgery. Further interventional procedures were *percutaneous* discectomy, embolization, and angioplasty of the peripheral *arterial* system.

In the 1990s, he followed his "maestro", Dott. Carlo Del Favero, in Como, where he became Director in 2006, becoming not only a cutting-edge clinician but also a key developer for industries.

He pioneered the studies aimed at the development of algorithms for contrast-enhanced ultrasound and its possible clinical applications, along with the first clinical experiences on real-time elastosonography and fusion imaging for real-time ultrasound-based navigation. He also participated in studies on tissutal characterization with ultrasound radiofrequency.

Since he became Director of the Department of Radiology, he also started to study socio-sanitary issues such as cost-effectiveness in the field of ultrasound.

Dr. Martegani has published numerous articles in peer-reviewed journals along with chapters in textbooks and is editor and reviewer of numerous scientific publications. He has given presentations and lectures at national and international meetings and leads theoretical-practical courses on Doppler imaging.

Francesco DiMeco, **MD**, achieved his medical degree *summa cum laude* at the University of Milan in 1988 and completed his neurosurgical residency in 1993 at the same University. Then, he attended a neurosurgical oncology fellowship at Johns Hopkins University from 1997 to 2000. He is currently Director of the Department of Neurosurgery and Director of the Neurosurgical

Oncology Division at the Fondazione Istituto Neurologico C.Besta of Milan. He is also appointed as Assistant Professor (adjunct), within the Department of Neurological Surgery at Johns Hopkins Medical School and as part-time Professor of Neurosurgery at the University of Milan. He is mainly interested in brain tumors and skull base surgery. His research areas of interest include identifying and testing novel antitumor agents, including anti-angiogenic factors locally delivered by polymers; combined use of different classes of anticancer drugs; use of genetically engineered stem cells to locally deliver antitumor agents for brain tumors; brain tumor stem cells; and intraoperative imaging for image guided resection of brain tumors. He is the coordinator of the Theraglio Project within the 7th Framework Program of the European Community. Francesco DiMeco has published several scientific articles in Medline indexed journals, among which four reviews and nine book chapters. He is also coeditor of a scientific textbook. He serves as ad hoc reviewer for several scientific journals and member of the editorial board of Journal of Neuro-Oncology.

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Part VI Elastosonography

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