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Preface

The human brain has been a mystery for thousands of years. The brain was first described by the ancient Egyptians in 3000 BC in the Edwin Smith Papyrus, where detailed examination, diagnosis, treatment, and prognosis of 48 surgical cases involving the central nervous system.^{1,2} Despite these early accounts, the brain was originally not considered a “special” organ.³⁻⁵ Ancient Egyptians used the transnasal exenteration technique for removal of the brain through the nostril during their mummification process.^{2,6} In the Western Hemisphere, the first evidence of trepanation on a living person as a neurosurgical procedure was performed in the Ancient Pre-Columbian Peruvian era dating back to 400 BC. Aristotle, in 335 BC, believed that the brain functioned as a cooling agent for the heart, and believed that thought came from the heart.³⁻⁵ However, during this same time period, with observation, the functions of the brain were becoming more elucidated. Galen hypothesized that the brain was responsible for thought based on the consequences of people he observed with head injuries.³⁻⁵ Hippocrates observed epilepsy cases and believed these events were due to disturbances in the brain, and that the brain was the seat of intelligence.³⁻⁵ Plato, in 387 BC, believed that the brain was the center of mental processes; and Herophilus, in 300 BC, believed that the ventricles were the seat of human intelligence.³⁻⁵

Human cadaveric dissection led to improved knowledge of the brain. In the 1500s, Leonardo da Vinci produced wax casts of the human ventricles, Vesalius (1543) described the pineal gland, and Varolio (1573) described the brainstem.³⁻⁵ In the 1600s, Thomas Willis described the vascular anatomy, cranial nerves, and the function of choroid plexus in producing cerebrospinal fluid.³⁻⁵ Carl Wernicke in 1874 described different types of aphasias, and Sir Victor Horsley published the somatotopic map of the monkey motor cortex.³⁻⁵ These advances led to intraoperative understanding of the human brain. In 1909, Harvey Cushing was the first to stimulate the human sensory cortex, and, the same year, Brodmann was able to describe 52 discrete cortical areas of the brain.³⁻⁵ Walter Dandy used air to elucidate the ventricles in 1918. From their work with electrical stimulation in 1957, Penfield and Rasmussen provided illustrations of the motor and sensory homunculus.³⁻⁵

The history of electrical brain stimulation is equally interesting. In 1791, Luis Galvani discovered that the nerves and muscles were excitable when he applied electricity to spinal nerves and elicited muscle contractions in frogs.⁷ Giovanni Aldini applied electrical currents to recently hanged and decapitated prisoners and erroneously thought he was stimulating the brain and spinal cord to induce movement, but it was concluded that he was actually directly stimulating the muscles.⁷ Luigi Rolando and Pierre

Flourens then used electrical stimulation to study brain localization of function. Rolando mistakenly concluded, based on stimulation, that the cerebellum was the source of limb movements.⁷ Even though they were erroneous, they indirectly showed that the central nervous system was excitable.⁷ The pioneering work of mapping the cortex with electrical stimulation was done in 1870s by Eduard Hitzig and Gustav Fritsch, where they stimulated the cortex of dogs and were able to obtain contralateral movement of the face and limbs.⁷ They were also able to decipher that movement occurred in hindlimbs with more medial stimulation, while forelimb movement occurred with more lateral stimulation.⁷ Based on this work, they were able to devise a somatotopic organization of the brain of dogs.⁷ This led to David Ferrier’s work in 1875 where he was able to map 29 different cortical functions in dogs and monkeys.⁷

The history of mapping the human brain, however, is more recent.⁷ This is mainly due to centuries of the human brain being thought of as “no man’s land” because of religious and medical ideologies, as well as the high morbidity and mortality associated with surgery in this area.⁷ Sir Charles Scott Sherrington and Harvey Cushing extensively mapped the cortex of great apes in 1901, which led to studies in humans. Roberts Bartholow stimulated the cortex from a patient with skull erosion down to the dura, and was able to induce contralateral limb movement.⁷ Krause stimulated patients’ brain and obtained the same localization as previously performed in animal experiments.⁷ Wilder Penfield and colleagues at the Montreal Neurological Institute proved this more conclusively when they devised the motor and sensory homunculus.⁷ At a similar time, Sir Victor Horsley and Robert Clarke were able to map the effects of stimulating deep-seated structures (i.e., limbic system, basal ganglia, thalamus) using a cartesian coordinate system.⁷ In the 1940s, Lars Leksell developed stereotactic devices, which allowed for the study of lesioning, including the globus pallidus, basal ganglia, and other deep-seated areas.⁷

The use of electrical stimulation is now commonplace for a variety of both cortical and subcortical intracranial lesions.⁸⁻¹⁰ In cortical areas, electrical stimulation is designed to identify motor and somatosensory cortices, language regions including Broca’s and Wernicke’s, as well as visual cortex, seizure foci, and cognitive function, among others.⁸⁻¹⁰ In subcortical areas, electrical stimulation is designed to identify different white matter tracts including projection (i.e., corticospinal tract), commissural (i.e., corpus callosum), and association fibers (i.e., superior longitudinal fasciculus, arcuate fasciculus, inferior frontal occipital fasciculus, inferior longitudinal fasciculus), among others.⁸⁻¹⁰ In meta-analyses, the use of electrical stimulation has been shown to improve extent of resection (gross

total resection: 75% vs. 58%) and reduce neurological deficits (3.4% vs. 8.2%).⁸ We have shown similar results with regional vs. general anesthesia for peri-Rolandic tumors in regards to achieving gross total resection (25.9% vs. 6.5%, $p = 0.04$) and decreased hospital stay (4.2 vs. 7.9 days, $p = 0.049$).⁹ In addition, we have showed decreased cost, increased quality of life, and improved postoperative neurological function for patients who undergo awake surgery with brain mapping as compared to those under general anesthesia.¹⁰

The human brain is perhaps the most complex of organs. While it accounts for only 2% of the body's total weight, it demands at least 20% of the body's total energy.^{11,12} Furthermore, the average brain only weighs three pounds, yet it is estimated to have roughly 86 billion neurons and glial cells that are in constant communication.^{11,12} Through patch clamping techniques, it is well understood that neurons transmit information via action potentials that have been recorded to travel at an impressive 268 miles per hour.¹³ The complexity of billions of neurons interacting to create over 100 trillion neural connections to define eloquent areas of the brain has made brain mapping a very appealing and challenging topic for neuroscientists and neurosurgeons alike.¹⁴

In brain tumor surgery, it is becoming well established that increasing extent of resection without developing a neurological deficit is associated with improved outcomes.¹⁵⁻²³ There have been several surgical developments to facilitate extent of resection including, but not limited to, intraoperative MRI, fluorescence-guided surgery, surgical navigation, and augmented reality.²⁴ In addition, there have been developments in imaging techniques to identify eloquent cortical areas and subcortical white matter tracts

including functional MRI, diffusion tensor imaging, and magnetoencephalography, among others.²⁵ Despite these advances, the only way of obtaining real-time information about critical cortical and subcortical areas with high sensitivity and specificity is brain mapping.^{26,27}

This book will serve as a comprehensive overview of the critical aspects of brain mapping from international experts. It will be divided into three sections. The first section will cover the preoperative aspects of brain mapping surgery. The second will feature aspects of brain mapping surgery. The third section will be on postoperative care after brain mapping surgery. In the first section, a review of the history of brain mapping will be given, as well as the anatomy of the eloquent cortical and subcortical regions. In addition, the various preoperative imaging techniques for identifying eloquent regions will be discussed including direct and indirect functional mapping, neurophysiology, and extra operative brain mapping. The second section will be devoted to what occurs in the operating room. It will describe anesthesia requirements, operating room setup, and awake and asleep brain mapping of the different cortical and subcortical regions. The last section will feature rehabilitation, neuroplasticity, and postoperative adjuvant therapy. We hope you enjoy this book as much as we enjoyed putting this book together with experts in the field in order to provide a comprehensive text for surgeons, residents, fellows, and other health providers interested in brain mapping and surgery in eloquent regions.

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Video Contents

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Video 9.2 Case Presentation 2: Left-sided awake craniotomy for temporal lobectomy and speech mapping

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Video 14.1 Awake monitoring of an anterior cingulate glioma surgery

Video 17.1 Intraoperative seizure mapping

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