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Editorial

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Multimodal Magnetic Resonance Imaging for Neurosurgical Planning

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Editorial

The history of magnetic Resonance Imaging (MRI) includes decades of work of many researchers who contributed to the discovery of nuclear Magnetic Resonance (NMR) and described the underlying physics of MRI, starting early in the twentieth century. The American physicist Isidor Isaac Rabi who won the Nobel Prize in Physics in 1944 for his discovery of NMR, which is used in MRI. MR imaging was invented by Paul C. Lauterbur who developed a mechanism to encode spatial information into an NMR signal using magnetic field gradients in September 1971, her theory was published in March 1973 [1,2]. Over several decades, the development of MRI has encompassed key milestones in spatial encoding, hardware and software design, and accelerated functional techniques. Notable advances include magnetic field gradients, ultra-high-field systems, and, more recently, the applicability of artificial intelligence. As a diagnosis technique the MRI is a safe, radiation-free diagnostic test using strong magnets and radio waves to create detailed images of soft tissues, organs, and joints. It is widely used to detect, stage, and follow up on conditions affecting the brain, spine, and muscles. In neurosurgical pathologies its gold standard specially in brain tumors, spine degenerative and tumors diseases. Multimodal neuroimaging, in the particular case of the MRI, allows for non-invasive examination of human brain structure and function across multiple scales. Precision neuroimaging builds upon this foundation, enabling the mapping of brain structure, function, and connectivity patterns with high fidelity in single individuals. High field MRI, operating at magnetic field strengths of 7 Tesla (T) or higher, increases signal-to-noise ratio and opens up possibilities for gains spatial resolution.

Multimodal MRI has transformed and change the point of view in neurosurgical planning by integrating structural, functional, and physiological information into a single preoperative assessment, enabling a more comprehensive understanding of intracranial pathology [3]. Moreover, multimodal MRI supports multidisciplinary decision-making and contributes to maximizing the extent of safe tumors resection while preserving neurological function and quality of life [3]. Functional MRI identifies eloquent cortical regions, diffusion tensor imaging delineates critical white matter pathways, while perfusion imaging and magnetic resonance spectroscopy provide complementary information regarding tumor vascularity and metabolism [4]. The combination of these techniques improves lesion characterization, facilitates individualized surgical strategies, and enhances neuronavigation accuracy, thereby reducing the risk of postoperative neurological deficits [4]. Recent advances in artificial intelligence and image-processing algorithms are further increasing the precision and clinical applicability of multimodal MRI, reinforcing its central role in precision neurosurgery and promoting better surgical outcomes for patients with complex intracranial pathologies [5].

MRI has revolutionized modern neurosurgical planning by providing a comprehensive understanding of brain anatomy, function, and pathology. Unlike conventional MRI, which primarily depicts structural abnormalities, multimodal MRI integrates advanced techniques such as Diffusion Tensor Imaging (DTI), functional MRI (fMRI), Magnetic Resonance Spectroscopy (MRS), and perfusion imaging. This combination enables neurosurgeons to visualize critical neural pathways, assess functional brain regions, and characterize tumor biology before entering the operating room. The primary advantage of multimodal MRI lies in its ability to support personalized surgical strategies. DTI helps identify white matter tracts that must be preserved to maintain neurological function, while fMRI localizes eloquent cortical areas responsible for language, motor, and sensory functions. MRS provides metabolic information that assists in differentiating tumor recurrence from radiation-induced changes, whereas perfusion imaging evaluates vascular characteristics and tumor aggressiveness. Together, these modalities improve diagnostic accuracy and facilitate safer surgical approaches in association of intraoperative tools and devices. The integration of multimodal MRI into neuronavigation systems has significantly enhanced surgical precision, reducing postoperative neurological deficits and increasing the extent of safe tumor resection. Furthermore, advances in artificial intelligence and image fusion technologies are improving the interpretation of complex imaging datasets, allowing surgeons to make more informed intraoperative decisions.

Despite these advantages, challenges remain, including high costs, longer acquisition times, and the need for specialized expertise in image interpretation. Standardization of imaging protocols and broader accessibility are essential for widespread clinical adoption. Actually, multimodal MRI represents a cornerstone of contemporary neurosurgical planning. By combining structural, functional, and metabolic information, it enables more accurate diagnoses, individualized treatment strategies, and improved patient outcomes, ultimately setting a new standard for precision neurosurgery. The use of these preoperative techniques, combined with all available intraoperative technologies (ultrasound, neuronavigation system, intraoperative CT or MRI, 5-ALA, fluorescence, augmented reality, exoscopy), aims to achieve better clinical outcomes by anticipating and facilitating surgical decisions. Establishing easily replicable workflow protocols for the use of the different components, especially as their use increases, reduces the overall time required.

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