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The Real Impact of an Intraoperative Magnetic Resonance Imaging—Equipped Operative Theatre in Neurovascular Surgery: The Sapienza University Experience

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Key words
- AVMs
- Brain aneurysms
- Cavernous angiomas
- DAVFs
- Intraoperative MRI

Abbreviations and Acronyms
AVM: Arteriovenous malformation
CA: Cavernous angioma
DAVF: Dural arteriovenous fistula
DWI: Diffusion weighted imaging
EOR: Extent of resection
IA: Intracranial aneurysm
MPRAGE: Magnetization prepared rapid acquisition gradient echo
MRA: Magnetic resonance angiography
MRI: Magnetic resonance imaging

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The fundamental role of technological instruments in contemporary Neurosurgery is undisputed, and intraoperative magnetic resonance imaging (MRI) represents one of the best examples. The use of a modern high-field magnet and the possibility to match the MRI with an operative microscope and an integrated neuronavigation system has led to successful results in the surgical treatment of different diseases. At our institute, we have performed surgery routinely with the aid of intraoperative MRI over the last 15 years. The aim of this article is to report our experience in the management of neurovascular lesions with the use of this device. We experienced that intraoperative MRI enhanced the surgical experience, leading to an improved postoperative outcome in the treatment of different lesions, such as arteriovenous malformations, dural arteriovenous fistulas, intracranial cavernous angiomas, and intracranial aneurysms. There are several advantages provided by the use of intraoperative MRI. The use of intraoperative MRI coupled with the planning station and the neuronavigation system allows one to obtain preoperative 3-dimensional reconstructions of the vessels, which aids the definition of the anatomy of each neurovascular lesion. Furthermore, the possibility performing an intraoperative scan allows a comparison with preoperative images and, subsequently, the updating of the surgical strategy. Intraoperative diffusion-weighted imaging can detect possible territorial ischemia that would be amenable to intensive treatment. Although increased costs, increased surgical times, increased anesthesiology times, and the possible increased risk of surgical infection may represent some major limitation, the use of intraoperative MRI—equipped operative theaters with integrated neuronavigation systems can prove extremely helpful in the management of neurovascular conditions.

INTRODUCTION

The increasing role of technology being used to achieve good results in contemporary neurosurgery is established and clear. The influence on the clinical postoperative results of the modern ultrasonic aspirators, the updated neuromonitoring systems, the intraoperative Doppler ultrasound probes, and the latest versions of neuronavigation systems are just a few examples.[1] Among new technologies, a special role has been gained by intraoperative magnetic resonance imaging (MRI).[2,3] Since the first experiences in the 1990s with low- and ultra-low-field magnets (0.2 and 0.5 T), the significance of intraoperative MRI has been described, especially regarding neuro-oncology and its unique possibility to improve the extent of resection (EOR) and to solve the problem of brain shift. In the authors' experience, it has become clear, since the dawn of intraoperative MRI—aided surgery, that instruments such as the operative microscope and the navigation probe could be coupled with the intraoperative MRI system. In addition, there is the possibility of updating the imaging intraoperatively to increase the accuracy of the navigation system itself. To date, our personal experience, encompassing 15 years of routine application of intraoperative MRI brought us to understanding its potential role in stereotactic surgery,[4] in intracranial aneurysm surgery,[5] endoscopic skull base surgery,[6] and eloquently and noneloquently located intra-axial tumors.[7-9]

We noticed that, despite the years passing and the long time since the introduction of intraoperative MRI—equipped operating theaters with integrated planning stations, few papers outline the potentially promising role of such a precious device and the notable advantages provided by its use in the surgical management of neurovascular conditions. The purpose of this article is therefore to report our relevant experience as we experienced during these years of clinical activity, straight as it came, through surgeries, words, and images.

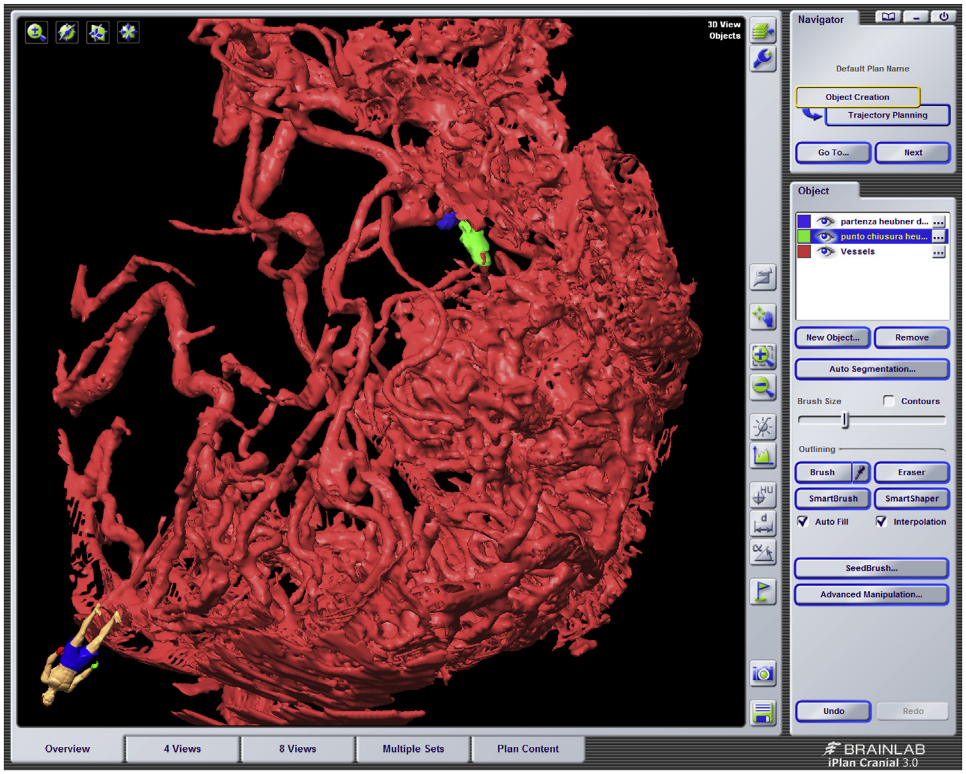

Figure 1. A 3-dimensional reconstruction of an entire arteriovenous malformation architecture. Major arterial feeders were coming from the homolateral Heubner artery and were drawn in a different color. The *green area* represents the safest exclusion point.

ARTERIOVENOUS MALFORMATIONS

Arteriovenous malformations are often regarded as the most anatomically complex and surgically challenging among the neurovascular conditions.[10] These lesions are composed of arterial feeders, moving high-pressure blood into a pathologic tangle of vessels, called a *nidus*, directly to ectatic and dilated pathologic venous collectors.[11] It presents a cumulative yearly risk of rupture of 2%–3%,[12] and the percentage of casualties related to the first rupture is as high as 10%.[12] Therefore, their natural history should be considered not benign. Factors especially linked with an increase in rupture risk are deep and infratentorial arteriovenous malformation (AVM) location, single draining vein, combined deep and superficial drainage, presence of varices, and coexisting aneurysms.[13] Surgical decisions are generally difficult to undertake because surgery implies a notable risk of death and new neurologic deficits.[11] Furthermore, the high-impact *A Randomized Trial of Unruptured Brain Arteriovenous Malformations* trial, with the major limitations of the relatively small heterogeneous cohort followed for just 33 months, outlined the superiority of the conservative management over interventional and surgical treatments.[14] Naturally, the cornerstone of the surgical indication is the Spetzler–Martin grading system (original and revised),[15,16] even if the lower grades (≤6) present a risk for neurologic impairment as high as 24%.[16] Therefore, in our opinion, the indications for surgical treatment of AVMs reduce as the awareness of its long-term consequences becomes increasingly high.

The intraoperative MRI systems can, in our experience, notably enhance the surgical experience in AVM management and, accordingly, increase the clinical results. The Planning Station of the BrainSUITE intraoperative MRI–equipped operative theater (the Sonata Magnet [Siemens, Erlangen, Germany] with an integrated neuronavigation system [VectorVision; BrainLAB, Feldkichen, Germany] and an integrated Planning Station equipped with Iplan 2.6 software [BrainLAB]) provides an opportunity for preoperative planning based on the preoperative computed tomography angiography and magnetic resonance angiography (MRA) images to obtain dynamic manipulable and updatable reconstructions (Figure 1), disclosing:

1. The arterial feeders' morphology and entry points. This feature is especially important in case of wider feeders, to understand and plan the safest and most distant point to apply the permanent clip in relation to the arterial course to avoid the possible concurrent collateral branches directed to the normal brain parenchyma.

2. The 3-dimensional morphology of the nidus to comprehend the morphology of the deepest part of the Nidus itself, which is the most difficult to expose