



Case Report

Intraoperative use of ultra-low-field, portable magnetic resonance imaging – first report

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ABSTRACT

Background: Intraoperative use of portable magnetic resonance imaging (pMRI) has become a valuable tool in a surgeon's arsenal since its inception. It allows intraoperative localization of tumor extent and identification of residual disease, hence maximizing tumor resection. Its utility has been widespread in high-income countries for the past 20 years, but in lower-middle-income countries (LMIC), it is still not widely available due to several reasons, including cost constraints. The use of intraoperative pMRI may be a cost-effective and efficient substitute for conventional MRI machines. The authors present a case where a pMRI device was used intraoperatively in an LMIC setting.

Case Description: The authors performed a microscopic transsphenoidal resection of a sellar lesion with intraoperative imaging using the pMRI system on a 45-year-old man with a nonfunctioning pituitary macroadenoma. Without the need for an MRI suite or other MRI-compatible equipment, the scan was conducted within the confinements of a standard operating room. Low-field MRI showed some residual disease and postsurgical changes, comparable to postoperative high-field MRI.

Conclusion: To the best of our knowledge, our report provides the first documented successful intraoperative transsphenoidal resection of a pituitary adenoma using an ultra-low-field pMRI device. The device can potentially enhance neurosurgical capacity in resource-constrained settings and improve patient outcomes in developing country.

Keywords: Brain tumors, Portable magnetic resonance imaging (Portable MRI), Intraoperative magnetic resonance imaging (Intraoperative MRI), Ultra-low field magnetic resonance imaging (Ultra-low-field MRI)

INTRODUCTION

Pituitary adenomas account for 10–20% of all intracranial pathologies and the mainstay of treatment is surgery, most commonly through the transsphenoidal approach.^[6] Several studies have indicated that the extent of resection is one of the most important prognostic factors for patients with pituitary adenomas.^[2] This, however, is dependent on identifying the true extent of the tumor and its neighboring structures. Magnetic resonance imaging (MRI) is the modality of choice in this situation, but preoperative MRI scans cannot be accurately relied on after durotomy due to the phenomenon of dynamic brain shift.

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With recent development in technology and advances in neuroimaging, it has now become possible to conduct MRI intraoperatively. There are several intraoperative adjuncts available that enable surgeons to conduct safer and more effective tumor removal. One of the techniques that have been used in high-income countries (HIC) over the last two decades is incorporating an MRI into the procedure and assessing the extent of tumor resection intraoperatively. However, health-care delivery in a low-resource setting is fundamentally different from the more well-funded Western settings. Given their limited resources, hospitals in lower-middle-income countries (LMIC) are not privileged enough to dedicate an entire MRI suite for operating room (OR) purposes, let alone procure one. In addition to cost constraints, the World Health Organization estimates that 70% of medical equipment coming from developed countries does not work in hospitals in developing countries due to a lack of trained personnel, limitations with infrastructure, and a lack of spare parts or support for equipment.^[5] The MRI scanners in use are exorbitant and thus out of question for LMICs. Thus, a piece of medical equipment specifically designed for LMIC is needed to serve its problems.

The United States Food and Drug Administration (FDA) recently approved the Hyperfine Swoop, an ultra-low-field portable MRI (pMRI), for use in the clinical setting. Its small footprint, low cost, accessibility, intuitiveness, and low magnetic field (0.064 Tesla) can help break barriers toward the provision of top-quality patient care in LMICs for improved health outcomes. We present the first case of pMRI being used intraoperatively for transsphenoidal resection of pituitary macroadenoma in an LMIC setting.

CASE REPORT

A 52-year-old man presented with complaints of headache and blurring of vision in the right eye for the past 1 year, with gradual deterioration of vision. MRI showed typical findings of pituitary macroadenoma [Figure 1]. The patient underwent transsphenoidal microscopic resection of pituitary adenoma.

With a small footprint of less than 1.5 m × 1.5 m (5 ft x 5 ft), our pMRI machine requires minimal space and was parked in a corner inside the OR, with its ultra-low-field (0.064 T) magnet enclosed in a secure steel housing. Standard surgical instruments were used during the procedure, which includes microscopes, retractors, and drills. In addition, the monitors and anesthesia machines were not required to be MRI-compatible. After anticipated safe tumor resection, the patient underwent an intra-operative ultra-low-field pMRI scan to determine the extent of any residual tumor. This motor-powered pMRI scanner, controlled by a joystick, enables effortless maneuvering by a single technician, guaranteeing efficient and precise positioning without disrupting the operating room ecosystem. For safety, and to prevent any interference, the 5 Gauss (0.5 mT) field ring was extended. All the OR Equipments, such as IV pumps, ventilators, and other MRI-incompatible devices were placed outside this 5 Gauss (0.5 mT) line [Figure 2]. This field ring extends only 36 centimeters from the magnetic center. In our experience, ferromagnetic objects can be brought close to the scanner without any significant attraction being felt.

After the completion of the surgical resection, the patient remained in the same surgical position on a standard operating room table. The pMRI scanner was subsequently

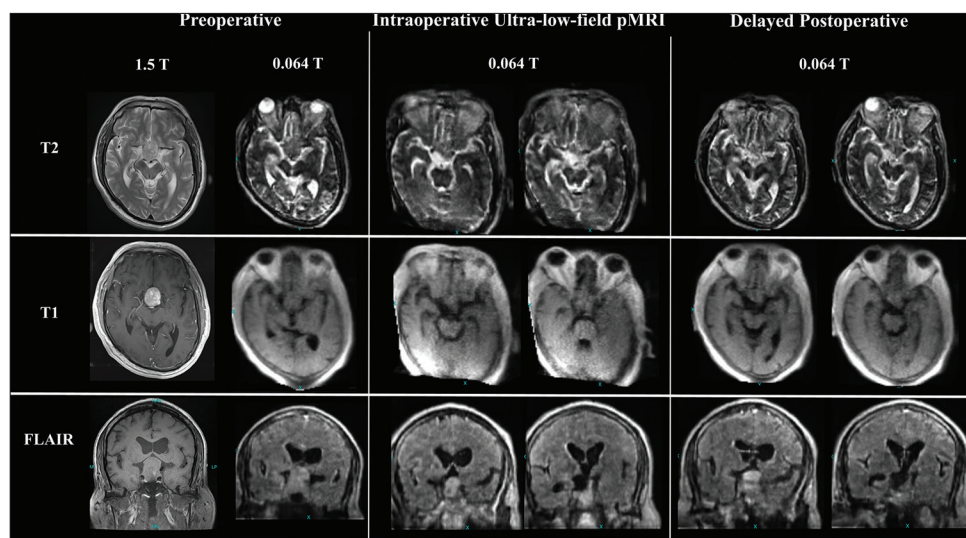


Figure 1: Preoperative scan, intraoperative scan, and delayed postoperative scans from magnetic resonance imaging scanner.



Figure 2: The portable magnetic resonance imaging (MRI) system in use in a standard operating room. Note that the operating room setup is not MRI compatible.

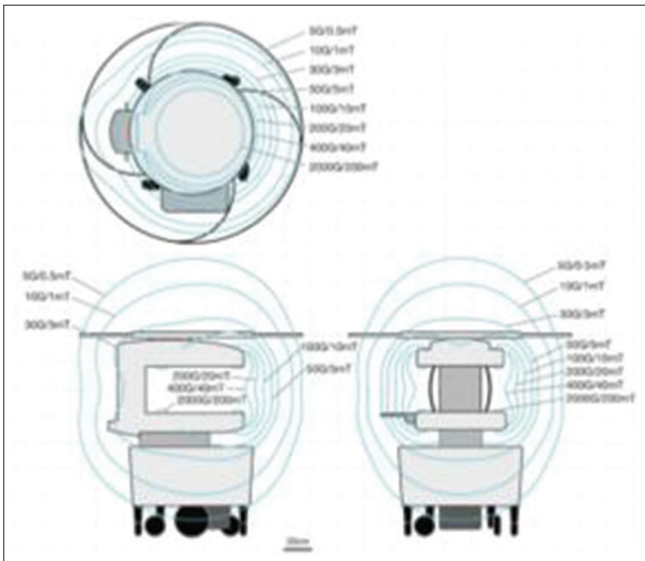


Figure 3: Representation of the Gauss field generated by the low-field portable magnetic resonance imaging scanner.

brought to the head end of the operating room table, and the technicians carefully positioned the patient's head inside the machine's head coil. This coil is specifically designed to enhance the signal-to-noise ratio of the acquired images. The scanner was then connected to a regular 110 V outlet before the initiation of imaging. Our imaging protocol for pituitary brain surgery was composed of a fluid-attenuated inversion recovery coronal, axial T1-weighted image without contrast and T2, Sagittal T2, and diffusion-weighted imaging and apparent diffusion coefficient sequences [Figure 1-Intraoperative MRI]. This process added 30 min to the overall duration of the surgery. The pMRI images obtained confirmed

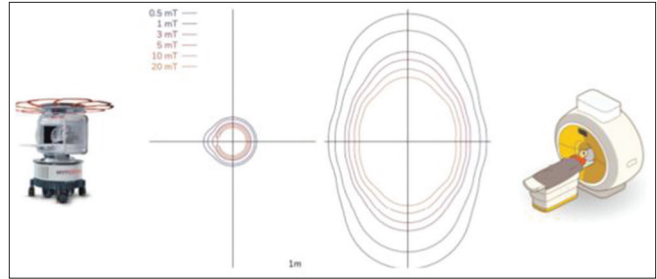


Figure 4: Comparison of the magnetic fringe field generated by the ultra-low-field 0.064 T portable magnetic resonance imaging scanner and a standard 1.5 T imaging scanner.

that the intended resection goal had been achieved. The whole procedure concluded very smoothly and without any complications. Postoperatively (after 24–48 h), ultra-low-field pMRI exam was performed alongside conventional MRI for comparison [Figure 1-Post-operative MRI]. pMRI performed on the 1st postoperative day showed comparable results.

DISCUSSION

Intraoperative MRI (iMRI) is a useful adjuvant technique to maximize the extent of resection because it can provide updated anatomic imaging during surgery to mitigate the changing environment when a brain shift occurs.^[8] However, its use in LMIC during intraoperative procedures has been debated for over two decades now due to its limited utility (including mainly resection control, correction of brain shift, complication avoidance, and navigation to small lesions) and inflated cost. Furthermore, during transsphenoidal reoperations, bony landmarks are difficult to identify. Surgical experience is often relied upon, but complications can occur even in experienced hands. Complications mainly result from inadvertently transgressing the cavernous sinus and its contents, including the internal carotid artery or floor of the anterior cranial fossa. Therefore, surgeons now prefer to use an intraoperative imaging modality, often in the form of an interventional MRI suite or a pMRI device, to confirm the correct approach in the sagittal plane. The discrepancy between the desired and actual extent of surgical resection dictates further resection. The decision for re-resection is primarily based on clinical judgment which directly correlates with experience. However, iMRI shortens this learning curve and provides alternate, real-time, and accurate evidence to decide on further resection. In our case, the decision to halt further resection was based on a clinical evaluation of the risks, benefits, and potential for complications such as cerebrospinal fluid leak. The iMRI validated the clinical acumen.

The Swoop pMRI device operates on a magnetic field of 0.064 T. This makes it one of the first devices employing such

a low field. This low-field system can be moved into a standard OR and integrated without needing any modification to the surgical environment. The portable nature of this device lowers the possibility of an inadvertent endotracheal tube or central/peripheral line dislodgement brought on by moving patients from the OR to the MRI suite [Figure 2].^[10] The use of magnetic fields in surgery necessitates MRI-compatible instruments and monitoring systems, which can be expensive and challenging to obtain, particularly in resource-limited settings. However, recent advances in portable low-field magnetic technology have transformed surgical procedures by eliminating the need for MRI-compatible instruments inside the OR. This breakthrough not only reduces costs and effort but also improves safety. The 5 Gauss marking ring of this pMRI device extends only 36 cm radially from the outer boundary of the device, unlike conventional scanners with a 5 Gauss line extending over 4 m radially [Figures 3 and 4]. This feature enables the safe handling of metal objects in its close vicinity without requiring specialized monitors or carts, improving surgical efficiency and safety. MRI safety is a concern for every hospital that employs this technology; being intimately involved with the OR adds another layer of possible errors and safety risks. Moreover, the portability allows it to be used in any OR without the need for a dedicated space or radiofrequency shielding, making it a game changer in the field of surgery.

However, this portability and small footprint come at the expense of a slightly decreased image quality. Due to its low field, this device has a lower spatial resolution than the conventional 1.5 T device. In our experience and as illustrated in [Figure 1], the pMRI produced well-defined images of the sella and the parasellar region. Although the sensitivity of ultra-low field MRI in delineating residual disease is yet to be established, in our observation the results are comparable, as shown in [Figure 1]. Artificial intelligence through machine learning has the capacity to synthesize higher-resolution images with greater anatomical details and better tissue contrast from low-resolution images, voiding the need for cost-prohibitive scanners, especially for LMICs.^[4] However, the data sets required to establish the algorithm for processing ultra-low-field MRI are yet to be built up. The resolution of images with pMRI can be enhanced using artificial intelligence and machine learning up to the standards that clinical decision-making can be made, just as with the standard MRIs.

A systematic review conducted by Patel *et al.* revealed that the utilization of low-field-strength (0.15T) pMRI contributes to a significant increase in the rate of gross total resection (GTR), ranging from 3% to 33%, in cases of nonfunctioning pituitary adenomas.^[7] Another study that employed intraoperative low-field MRI (0.15 T) for transsphenoidal resection of pituitary adenoma rendered 41.3% (43 cases)

of their patients free of tumor remnants. Similarly, the remission rates went up by 52.2%. It should be noted that this study used a low-field (0.15 T) MRI as opposed to an ultra-low-field (0.064 T). Their reported sensitivity compared to high-field MRI was around 31–33%.^[3] One study compared endoscopic visualization to images derived from a 0.3 T iMRI. The study found that iMRI could identify residual tumor that was not found with endoscopy in 15% of cases.^[12] Another study compared endoscopic visualization to images derived from a 1.5 T iMRI. This study revealed that the sensitivity and specificity of endoscopy in identifying residual tumors were 21% and 78%, respectively.^[1] iMRI has been praised for its capacity to boost the degree of tumor excision.^[9] This could potentially diminish the need for postoperative radiation therapy or repeat surgery to remove any remaining malignancies.

An increase in OR time is also a factor to consider. The literature states that intraoperative MRI increases OR time by 30–120 min.^[1,11] There is a steep learning curve for involved staff, including interpretation of imaging differences (e.g., dura not being closed, half-contrast dose, the air in the surgical cavity) and understanding that pMRI is point-in-time and not real-time imaging, as with iMRI. MRI safety is a concern for every hospital that employs this technology; being intimately involved with the operating room adds another layer of possible errors and safety risks. The resolution of images with pMRI can be enhanced using artificial intelligence and machine learning up to the standards that clinical decision-making can be made, similar to the quality of conventional MRIs.

CONCLUSION

This report highlights the importance of the widespread use of pMRI in resource-constricted environments and the technical nuances involved in its implementation. To the best of our knowledge, our report provides the first documented successful transsphenoidal resection of a pituitary adenoma using an ultra-low-field pMRI device intraoperatively. This device will open avenues for further research and its application for other procedures in similar low-income settings. Our experience with this device is intended to reduce barriers to adaptation and allow individuals with less specialized skills to effectively employ these techniques.

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Declaration of patient consent

Institutional Review Board (IRB) permission obtained for the study.

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Conflicts of interest

There are no conflicts of interest.

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