CASE REPORT

Utility of a Moveable 1.5 Tesla Intraoperative MR Imaging System

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ABSTRACT: ***Objective***: This study demonstrates the utility of a newly-developed moveable 1.5 Tesla intraoperative MR imaging system using a case report of a multi-lobulated parafalx meningioma. ***Clinical Presentation***: A 43-year-old female presented with progression of a multi-lobulated anterior parafalx meningioma several years following resection of a large left frontal convexity meningioma. ***Intervention and Technique***: Surgical excision of the lesion was undertaken. Following apparent total resection, intraoperative MR imaging revealed two residual dumbell shaped lobules. Using these updated MR images, the tumour was readily identified and removed. ***Conclusion***: The moveable 1.5 Tesla intraoperative MR system used in the present case provides rapid, high resolution MR images during neurosurgical procedures. Moving the magnet out of the surgical field during surgery permits the use of all standard neurosurgical instruments. The ease of use and quality of images combined with minimal interference on well-established surgical techniques makes this system a valuable adjunct in the neurosurgical treatment of intracranial disease.

RÉSUMÉ: Utilité d'un système mobile Tesla 1.5 d'imagerie par résonance magnétique extemporanée: à propos d'un cas. ***Objectif:*** Cette étude démontre l'utilité d'un nouveau système mobile d'imagerie par résonance magnétique (IRM) Tesla 1.5 au moyen d'un cas de méningiome multilobulé situé près de la faux du cerveau. ***Présentation clinique:*** Une femme de 43 ans s'est présentée avec un méningiome antérieur multilobulé situé près de la faux du cerveau, évoluant depuis plusieurs années suite à la résection d'un gros méningiome de la convexité frontale gauche. Intervention et technique: Une excision chirurgicale de la lésion a été entreprise. Suite à une résection apparemment totale, l'IMR extemporanée a révélé deux lobules résiduels en forme d'haltères. La tumeur a alors été facilement identifiée et excisée suite à l'information fournie par ces images extemporanées. ***Conclusion:*** Le système mobile d'IMR extemporanée Tesla 1.5 utilisé dans ce cas fournit rapidement des images de haute résolution pendant des interventions neurochirurgicales. L'aimant est déplacé hors du champ opératoire pendant la chirurgie, ce qui permet l'utilisation de tous les instruments neurochirurgicaux standards. La facilité d'utilisation et la qualité des images combinées à une interférence minimale dans les techniques chirurgicales standards font de ce système un instrument d'appoint précieux dans le traitement neurochirurgical des pathologies intracrâniennes.

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Decades following the introduction of pneumoencephalography[1] and cerebral angiography,[2] the inventions of computed tomography (CT) and magnetic resonance (MR) imaging ushered in the era of modern neurosurgery. They have become indispensable tools in the diagnosis, surgical planning and postoperative monitoring of lesions requiring neurosurgical management. Traditionally, the planning of surgical procedures has been based upon CT and/or MR images obtained well in advance of the procedure. Capitalizing on advances in the three dimensional manipulation and display of images, frameless navigational systems have improved the intraoperative localization of lesions.[3-7] It is recognized however, that craniotomy, CSF drainage and the surgical removal of tissue results in significant brain shift rendering preoperative imaging data inaccurate.[8,9] Intraoperatively acquired image data could update archived information thereby improving the accuracy of frameless stereotaxy.

Several intraoperative MR imaging systems have recently been developed. These use magnets of variable field strength (0.2-0.5T) which are fixed to the floor. Patients are either transported anesthetized[10,11] to the magnet or surgery is performed within the rings of the large magnet.[12] Both of these designs are plagued by a variety of technical and safety issues.

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Working directly in a magnetic field requires that all equipment be fully MR compatible, including head-holders, retractors, forceps, scalpels, curettes, electro-cautery, micro-instruments, high-speed drills, the operating microscope and anesthetic and monitoring equipment. Moving an anesthetized patient over great distances raises important issues with regards to surgical field sterility and the cardiovascular, pulmonary and neurological monitoring of the patient. While some of these issues have been solved, others remain problematic,[10-12] and combined with the high cost of development, the benefit of intraoperative MR imaging has been questioned.[10,13]

We present the case of a recurrent multi-lobulated anterior parafalx meningioma to discuss the utility of intraoperative MR imaging based on a moveable 1.5 Tesla MR imaging system.

TECHNICAL DEVELOPMENT

The system is located in a standard neurosurgical operating room (OR) with a small attached alcove, which houses the magnet when not in use. The magnet weighs 4-tonnes, is superconducting and has a field strength of 1.5 Tesla. Active self-shielding causes the fringe fields to drop below 5 Gauss at 2.9m radially. The magnet is moved into and out of the surgical field on overhead rails using a small electric motor. The inner bore diameter is 80 cm, which drops to 62.5 with the insertion of 15 mT/m gradient coils. This design eliminates the necessity for complete MR compatibility of instruments and anesthetic equipment as well as the need to shield the OR with steel. Radiofrequency (RF) shielding is provided by a silver tent draped over the patient during imaging (Figure 1).

Typically three sets of images comprise a series of intraoperative images. Surgical planning images are acquired after the patient is anesthetized and intubated. Interdissection images are acquired during resection of the lesion. Quality assurance images are acquired after the wound has been closed but the patient is still anesthetized and intubated.

During interdissection imaging, the surgical wound and field are covered with a sterile drape and the upper portion of an RF coil is placed over the head and locked into the lower portion (Figure 1). The lower portion of the RF coil is part of a hydraulically-driven titanium OR table. All non-MR compatible surgical tools, instrument trays and equipment such as stools, electro-cautery units and the microscope are moved beyond the 5 Gauss line and the magnet is moved into position for imaging. After the imaging studies have been acquired, the magnet is returned to the alcove and the upper portion of the RF coil and the sterile imaging drape removed.

Standard T_1, T_2 and gadolinium (Gd)-enhanced T_1 images in axial, sagittal and/or coronal planes are routinely obtained. Individual sequences take about 4.5 minutes for T_1-weighted and 10 min for T_2-weighted images. Total surgical interruption time is 30-40 minutes. The images are viewed and displayed on liquid crystal displays (LCDs) located in both the console room and the OR. Intraoperative anesthetic monitoring of all standard parameters is performed continuously.

CASE PRESENTATION

This 43-year-old female presented with a recurrence of her meningioma. A left frontal craniotomy was initially performed in 1993 for resection of a large left frontal convexity meningioma. Serial CT brain imaging showed the presence of several bilateral parafalx lesions and the patient subsequently returned for reoperation of residual and/or recurrent tumor.

Following the administration of a standard anesthetic and endotracheal intubation, the patient was positioned supine on the operating table. The upper portion of a RF coil was placed over the patient's head and the magnet moved into position for surgical planning imaging. T_1 and T_1 with gadolinium (Gd) enhancement sequences were obtained (Figure 2). Following return of the magnet to its alcove, the previous left craniotomy was exposed through a bicoronal scalp incision. The bone flap was re-elevated using a high-speed air drill (Midas-Rex®). The previous resection cavity was encountered as well as two left-sided meningiomas. Using microdissectors, bipolar electro-cautery and magnification these were resected. As the falx was incised a moderate-sized meningioma was identified and dissected from the medial right frontal lobe and removed with its falx attachment. Parafalcine exploration in both anterior and posterior directions failed to reveal any further tumor. Satisfied that the tumor had been resected, the surgical site was covered with sterile drapes, all instruments were moved from the surgical field and a sterile plastic drape was placed over the patient. The RF head coil was placed and the magnet moved into position for inter-dissection imaging. Again T_1, and Gd-enhanced T_1 images were obtained (Figure 2). The images showed two small residual components beneath the brain parenchyma further posterior along the falx. The magnet and imaging drapes were removed and surgery was resumed. The residual tumors were readily identified and dissected under magnification. Further exploration revealed no residual tumor. The craniotomy was closed using titanium plates and with the patient still under general anesthesia, quality assurance images were obtained (Figure 2) to confirm complete resection and the absence of acute intracranial complications. The patient was subsequently awakened and extubated.

DISCUSSION

This case demonstrates that intraoperative imaging identified residual tumor, which was not identified under microscopic magnification during the resection. These images guided the further resection of the *missed* tumor which otherwise would have been left unresected.

This moveable intraoperative MR imaging system acquires

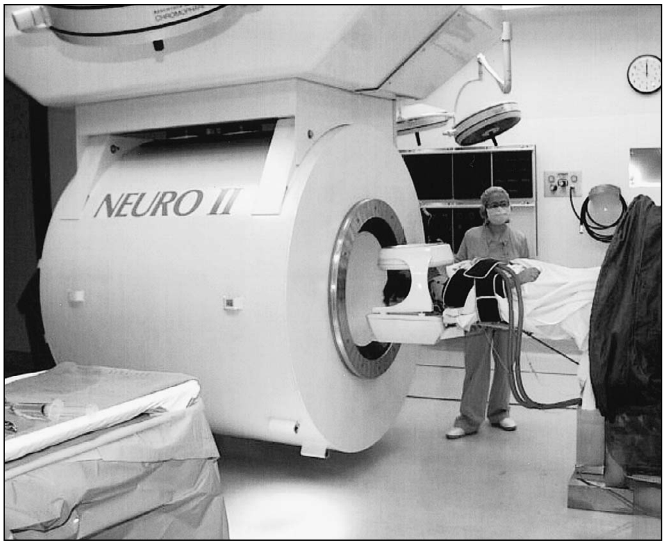

Figure 1: *Photograph showing the ceiling-mounted magnet being moved into position for a surgical planning image. The upper portion of the RF coil is visible in place over the head of the intubated and ventilated patient. The silver-impregnated RF tent will be draped over the patient once the magnet is in position.*

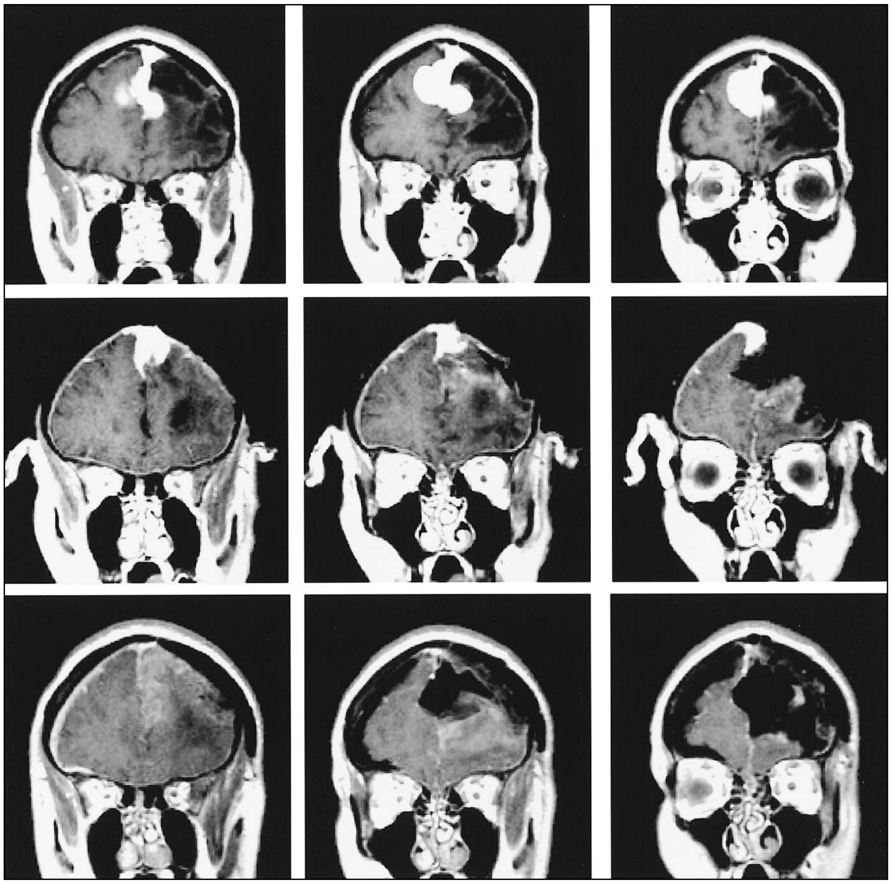

Figure 2: *Coronal T_1-weighted with gadolinium enhancement MR images.* ***Top Row:*** *Surgical planning images showing the previous tumour resection cavity and recurrent parafalx meningiomas.* ***Middle Row:*** *Interdissection image showing residual tumor missed on resection. Note reflection of scalp.* ***Bottom Row:*** *Quality assurance images after resection of residual tumour, replacement of bone flap and skin closure. Complete resection of tumour and absence of hemorrhage confirmed.*

high resolution images while allowing the neurosurgeon to operate with very little hindrance to standard neurosurgical techniques or minimal modification of standard instruments. In comparison to the other commercially available intraoperative MR imaging systems, this system has several significant advantages.

The production of MR-compatible surgical instruments and equipment such as the operating microscope and drill has been problematic and expensive.[10,12,14] With fixed, intraoperative open bore systems such as the GE Double Doughnut,[12] access to the patient and the surgical field by the surgeon and assistant may be highly restricted. Alternatively, moving the patient to a fixed MR imaging unit situated in an adjacent room[10,11] would increase the risk of contaminating the sterile field. In addition, problems could arise in maintaining the cardiovascular and pulmonary parameters important in managing intracranial pathology. These problems have been eliminated by the present system.

As frameless surgical navigational systems become commonplace in neurosurgical operating rooms, increasing attention is being focussed on the amount of brain shift occurring during craniotomy and the errors translated to the intraoperative accuracy of these systems.[8,9,15] CSF drainage together with brain shift results in up to 2.6 cm of cortical brain shift with a mean shift of 1cm.[9] Updating neuronavigational and stereotactic information with high resolution MR images acquired after craniotomy and CSF drainage would significantly improve the accuracy and efficacy of these systems.[9,15]

The signal-to-noise ratio (SNR) in MR imaging is directly related to magnetic field strength such that higher field strength delivers superior SNR which results in faster imaging times and higher image resolution.[16] The high magnetic field strength of this system parallels standard diagnostic MR imaging magnets and enables other MR methods such as angiography, spectroscopy, FLAIR and fast spin-echo to be performed. Other intraoperative MR imaging systems such as the 0.2T Magnetom Open (Siemens) or the 0.5T Double Doughnut (General Electric) are limited with respect to performing various MR techniques by their field strength.[10,12,13]

This case exemplifies the utility of the moveable 1.5T intraoperative MR system. In a manner similar to the addition of the operating microscope to the surgical armamentarium, this system has been introduced in such a way that does not compromise well-developed neurosurgical techniques. It is predicted that intraoperative imaging will maximize the surgical treatment of disease and may affect the rates of reoperation, hospital stay, morbidity, etc. It is possible that surgical planning and quality assurance intraoperative imaging studies could replace preoperative and postoperative MR evaluations. The scientific and financial efficacy of intraoperative MR imaging will require prospective randomized studies.

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