Featured Articles

Open MRI for Neurosurgery

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OVERVIEW: An open MRI system is one in which the gantry does not enclose the patient, with models in the 0.2-T to 0.4-T range being widely used, particularly for diagnostic imaging. The features of open MRI include a high level of safety, being able to perform imaging without exposure to radiation and featuring spaciousness, low magnetic field intensity, and a low level of magnetic field leakage. By checking for brain tissue deformation after the skull is opened and providing imaging data updates to the neurosurgery navigation system, the installation of a Hitachi open MRI system in a neurosurgery theater provides a system that helps achieve precision in neurosurgical procedures. Furthermore, the low level of magnetic field leakage means conventional surgical instruments can still be used.

INTRODUCTION

RECENT years have seen an increasing number of advanced neurosurgical procedures performed in Japan and elsewhere. Because of the precision these procedures require, it is common practice to use a navigation (guidance) system. Among the challenges of removing a brain tumor in particular is to complete the procedure without damaging the motor nerves and other critical brain functions. This has led to widespread use of intraoperative navigation systems that use magnetic resonance imaging (MRI) images captured pre-operatively. One of the problems with this approach, however, is when the surgical procedure results in brain shift[*1].

This article describes an operating theater system that can capture intraoperative MRI images using an in-theater MRI system.

CURRENT SITUATION AND CHALLENGES FOR NEUROSURGERY

Past brain tumor surgery has involved supplying magnetic resonance (MR) image data taken prior to the operation to the navigation system and removing the tumor with the aid of a microscope. The problems with this are as follows:

(1) The problem of the brain shifting after the skull is opened or brain tissue being deformed during the process of removing a tumor has meant that experienced surgeons have had to make allowances for these phenomena during surgery.

(2) Highly malignant glioblastomas in particular occur in the cerebrum and spread into (infiltrate) the surrounding brain, making the distinction between diseased and normal tissue unclear to the naked eye.

(3) As the removal of excessive brain cell tissue can result in a loss of function, the practice has been to remove small amounts at a time and perform pathology testing during surgery to identify whether the removed material contains normal or cancerous cells. This takes a long time and involves a lot of work.

(4) The only way to check whether a tumor has been fully removed without any remaining cancer tissue has been to perform a post-operative MR scan.

(5) Because of the very high risk of relapse if the malignant tumor is not fully removed, five-year survival rates have been remarkably poor.

USE OF OPEN MRI CONSTRUCTED IN THEATER

To overcome these problems, an open MRI system was constructed in an operating theater at Tokyo Women's Medical University Hospital in 1999 to improve the neurosurgical treatment of malignant tumors by enabling intraoperative MRI (see Fig. 1).

However, because operating theaters contain a lot of other equipment, surgical instruments, and special systems that are not present in a normal diagnostic

*1 The physical movement or deformation of the brain. The significant deformation of brain tissue that occurs when the brain is exposed.

MRI: magnetic resonance imaging

Fig. 1—Operating Theater MRI System (Source: Tokyo Women's Medical University Hospital).
By using a permanent magnet MRI that features minimal magnetic leakage, it is possible to perform neurosurgery adjacent to the MRI system.

MRI room, special measures needed to be taken based on the following two considerations.
(1) Prevent the magnetic field and high-frequency electromagnetic radiation from the MRI system from interfering with theater equipment.
(2) Prevent electromagnetic interference (EMI) from the theater equipment (such as noise or changes in the ambient magnetic field) from interfering with the MRI system.

Through its involvement in installing the system at Tokyo Women's Medical University Hospital, Hitachi was able to build up system implementation engineering know-how, including consulting with doctors, nurses, technicians, information technology (IT) staff, and other users about their requirements and establishing working arrangements and quality control with the other companies involved in the project, such as peripheral and other equipment suppliers.

The system at Tokyo Women's Medical University Hospital was a major success, quickly collecting evidence on treatment performance that was presented at academic conferences (see Table 1). It routinely achieves a 90% or better tumor removal rate, and has demonstrated its ability to attract brain tumor patients from around Japan, with an increasing number asking to be treated at a hospital where the operating theater is equipped with an MRI system[1].

INTRAOPERATIVE IMAGING OF NERVE FIBERS IN BRAIN

The two ways in which MRI images are used in neurosurgery are pre-operative use for planning and intraoperative use for monitoring. The concept behind equipping an operating theater with an MRI system is to achieve the following four key expectations (see Fig. 2).
(1) To be able to obtain imaging data in a timely manner in an operating theater equipped with an MRI system and use it to update three-dimensional data for image-guided surgery ("navigation").
(2) To be able to use conventional practices and instruments without requiring special surgical instruments by adopting open MRI.
(3) To achieve a high rate of full recovery.
(4) To enable evidence-based treatment while reducing the risk of medical error and law suits.

TABLE 1. Five-year Survival Rates for Different Grades of Brain Tumor (Source: 66th Annual Meeting of the Japan Neurosurgical Society)
The malignancy of a brain tumor is indicated by a grade, with grade 4 being the most malignant. Surgical success is typically assessed by five-year survival rates, with Tokyo Women's Medical University achieving roughly three times the average for this measure in Japan.

Tumor malignancy	Five-year survival rate	
	Average for Japan	Tokyo Women's Medical University
Grade 2	69%	90%
Grade 3	25%	75%
Grade 4	7%	19%

Fig. 2—Use of MRI as an Intraoperative Imaging System.
A neurosurgery operating theater equipped with an open MRI system. The dotted line on the floor indicates the magnetic field safety zone with a threshold of 0.5 mT (approximately 10 times the Earth's magnetic field). Conventional surgical instruments can be used outside this zone.

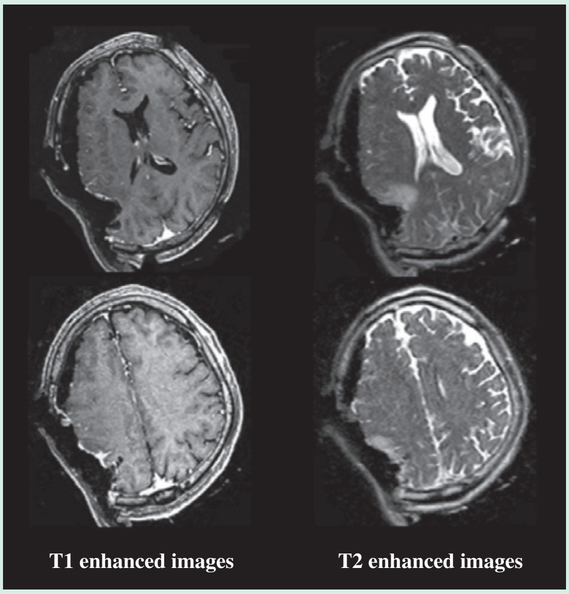


Fig. 3—Images Captured by Intraoperative MRI Imaging (Source: Kagoshima University Medical and Dental Hospital).
The photograph shows two sets of cross-section cranial images with different contrast. Image data is captured in three dimensions and sent to the surgery navigation system.

Improving the five-year survival rate for brain tumor removal requires both maximizing the proportion of tumors removed and preserving brain function to minimize post-operative complications. MRI imaging is an effective way to identify the relative locations of a tumor and normal tissue. Similarly, surgery navigation systems are able to provide surgeons with accurate information about the site of the surgery by using an optical or other measurement device to detect the location of surgical instruments and display the location of the instrument tip on the brain image.

Furthermore, diffusion-weighted imaging (DWI) is a non-invasive MRI imaging technique that can provide information about the orientation of nerve fibers in the brain. This technique provides a way to determine the orientation of nerve fibers associated with particularly important motor functions in the vicinity of the tumorous lesion. Because the physical shape of the brain changes during the process of an operation, it is desirable to provide data updates through the use of intraoperative DWI. This use of intraoperative DWI images to determine nerve locations for surgery navigation helps avoid damage to patient motor functions. This helps make open brain surgery possible while minimizing brain nerve damage(2).

Fig. 3 shows cranial images captured during neurosurgery. Images captured while the skull is open show how the removal procedure causes the repositioning of brain tissue.

WIDER ADOPTION OF SYSTEM AND GUIDELINES ON ITS USE

Following the installation of the Tokyo Women's Medical University system, in parallel with seeking to deploy the system at the neurosurgery departments of other major university hospitals, Hitachi also took the lead in establishing a society for intraoperative imaging based around neurosurgeons in Japan who are recognized as key opinion leaders (KOLs)*2. This led to similar systems being installed at a total of 10 hospitals in Japan, including at Nagoya University and Kagoshima University.

The society for intraoperative imaging has since been upgraded to a full academic society under the title, Japan Society of Intraoperative Imaging, with its 15th conference being held in 2015.

A committee of the Japan Society of Intraoperative Imaging set up to formulate guidelines for intraoperative MRI published its draft Guidelines for Intraoperative Use of MRI in July 2014(3).

These guidelines divide MRI installations into two types depending on whether the system is in the operating theater (a "dedicated system") or an adjacent room (a "2-room system").

Table 2 compares the two configurations.

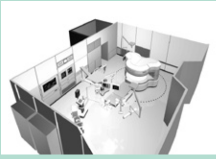
The limited magnetic field leakage from open MRI systems that use permanent magnets means they can be installed in-theater. This should reduce safety incidents by shortening the distance that patients undergoing open brain surgery need to be moved. Hitachi is also working on measures that minimize the durations of interruptions to surgery by developing functions such as a rotating operating table that facilitates the repositioning of patients when they are moved between the surgery and imaging positions. Surgeons recognize that it is important to minimize any additional burden imposed on surgical personnel by the MRI imaging process, and that any problems with safety or with the effort and time required will lead to less frequent use of the MRI imaging that the equipment is there to perform.

Accordingly, it is recognized that dedicated systems are necessary if extensive use is to be made of MRI systems.

*2 Medical practitioners with extensive influence in the healthcare industry.

Table 2. Comparison of “Dedicated” and “2-room” Operating Theater MRI Systems

Dedicated systems can be located in the operating theater because they use open MRI, which has a low level of magnetic field leakage, thereby enabling more extensive use of MRI systems, with less time and effort required for imaging, and fewer safety problems.

		Open MRI (low level of magnetic field leakage)	Cylindrical MRI (high magnetic field strength)
Dedicated system (MRI in operating theater) 		Advantages: Short patient movement distance (either using a rotating configuration or a movement of less than 2 m), convenient for taking multiple images Disadvantages: Not suitable for use as a diagnostic MRI	Measures need to be taken to deal with magnetic field leakage. Poor return on investment
2-room system (MRI in adjacent room) 	Movable MRI system		Advantages: No need to move patient Disadvantages: Expensive, difficult to manage problems associated with magnetic field (leakage field movement)
	Movable operating table		Advantages: Can be used for diagnostics as well as surgery Disadvantages: Safety problems associated with large amount of patient movement

CONCLUSIONS

The demands placed on the intraoperative use of MRI in neurosurgery are high and the market is a dynamic one. The advantages of MRI for intraoperative monitoring include the lack of exposure to radiation and the high-contrast images it provides of tumors, meaning that precise surgical navigation is possible using MRI image data that can be updated during surgery by taking advantage of these features.

There is a demand for precise surgery navigation systems that use intraoperative MRI systems as a way of achieving reliable tumor removal without damaging healthy brain tissue.

REFERENCES

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(3) “Guidelines for Intraoperative Use of MRI,” Japan Society of Intraoperative Imaging, http://jsii14.umin.ne.jp/images/guideline.pdf in Japanese.

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