Usefulness of High Magnetic Field 3.0 Tesla MRI in Neurological Critical Care

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Abstract

Magnetic resonance imaging (MRI) is superior to computed tomography (CT) in terms of its capability to detect ultra-early lesions in the acute stage of cerebral infarction. However, in neurological critical care, CT is usually selected as the first-line technique of diagnostic imaging because of the reduced time necessary for imaging, fewer limitations for the patient, and higher safety and sensitivity in detection of bleeding. In January 2005, a 3.0Tesla MRI device for whole body imaging (Signa EXCITE 3.0, General Electric Company) was approved in Japan and was first installed in our hospital. Its full-scale operation was immediately started. Presently, it is often used for imaging of the head in combination with an additionally approved 8-ch coil. Compared to the currently available highest-level 1.5Tesla MRI device, the 3.0Tesla MRI device (hereinafter simply called "3.0T MRI device") has a two-fold higher signal to noise ratio, and requires only one fourth of the time for imaging. Furthermore, its high magnetization efficiency allows improved detectability of hemorrhagic lesions (subarachnoid hemorrhage, etc.). Making use of these characteristics of this new device, we have been taking MR images and MR angiograms of patients in the acute stage of stroke for the purpose of evaluation and diagnosis. We present the usefulness of 3.0T MRI device in the neurological critical care and the prospects for 3.0T MRI to replace the role of CT as the first-line technique of diagnostic imaging.

Keywords: 3.0 T MRI , neurological critical care , stroke

Introduction

According to the currently available guidelines on the diagnosis and treatment of stroke, i.e., the Guidelines for the Management of Stroke 2004 prepared in Japan [5] and the Guidelines 2005 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care prepared by the American Heart Association (AHA) [3], it is recommended that treatment of stroke begin within one hour of diagnosis. To improve the prognosis (survival rate and function) of these patients, it is essential to make precise diagnosis to begin treatment as soon as possible. Our Stroke Center provides early diagnosis and treatment to patients in ultra-acute and acute stages. To further improve the quality of stroke diagnosis and treatment, an ultra-high magnetic field 3.0T Magnetic resonance imaging (MRI) device was introduced to our facility. During the year following its introduction, a number of patients underwent imaging with this device. On the basis of the data collected during this period, this paper discuss the usefulness of 3.0T MRI in the field of neurological critical care and the prospects for 3.0T MRI to be extensively accepted as the first-line modality of diagnostic imaging in this field of care.

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Material and methods

In January 2005, a 3.0Tesla MRI device for whole body imaging (Signa EXCITE 3.0, General Electric Company) was installed. We used this device for imaging of the head in combination with 8-ch coil in 372 stroke patients from

February 2006 to January 2007. We studied whether shortened time of the MRI imaging would be useful to achieve information in the neurological critical care. In stroke patients, we tried sequences such as Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction (PROPELLER) and black blood method (carotid plaque imaging) in addition to the usual routine sequences, such as T2, T2*, T2-reversed images, diffusion weighted image and MR angiography.

Table 1 Summarization of 372 patients with stroke

	ICH				SAH	Cerebral infarction			
	Basal ganglia	Subcortical	Cerebellum	Brain stem		Lacunar	Atherosclerotic	Embolic	TIA
Total No.	48	21	5	6	22	106	63	39	62
Gender (male/female)	21/27	8/13	3/2	3/3	6/16	66/40	34/29	20/19	30/32
Age (mean±SD)	70.7±15.1	79.6±10.0	70.4±16.0	81.3±6.3	67.8±12.9	77.0±8.3	77.4±9.2	80.7±9.2	71.4±10.2
Sequence									
Emergency	48	21	5	6	22	106	63	39	62
+PROPELLER	12	2	5	0	9	7	5	6	2
+Black blood method	0	0	0	0	0	11	9	8	13

ICH= intracranial hemorrhage, SAH=subarachnoid hemorrhage, TIA=transient ischemic attack

Result

Imagings of all 372 patients were performed successfully and accurate diagnoses were

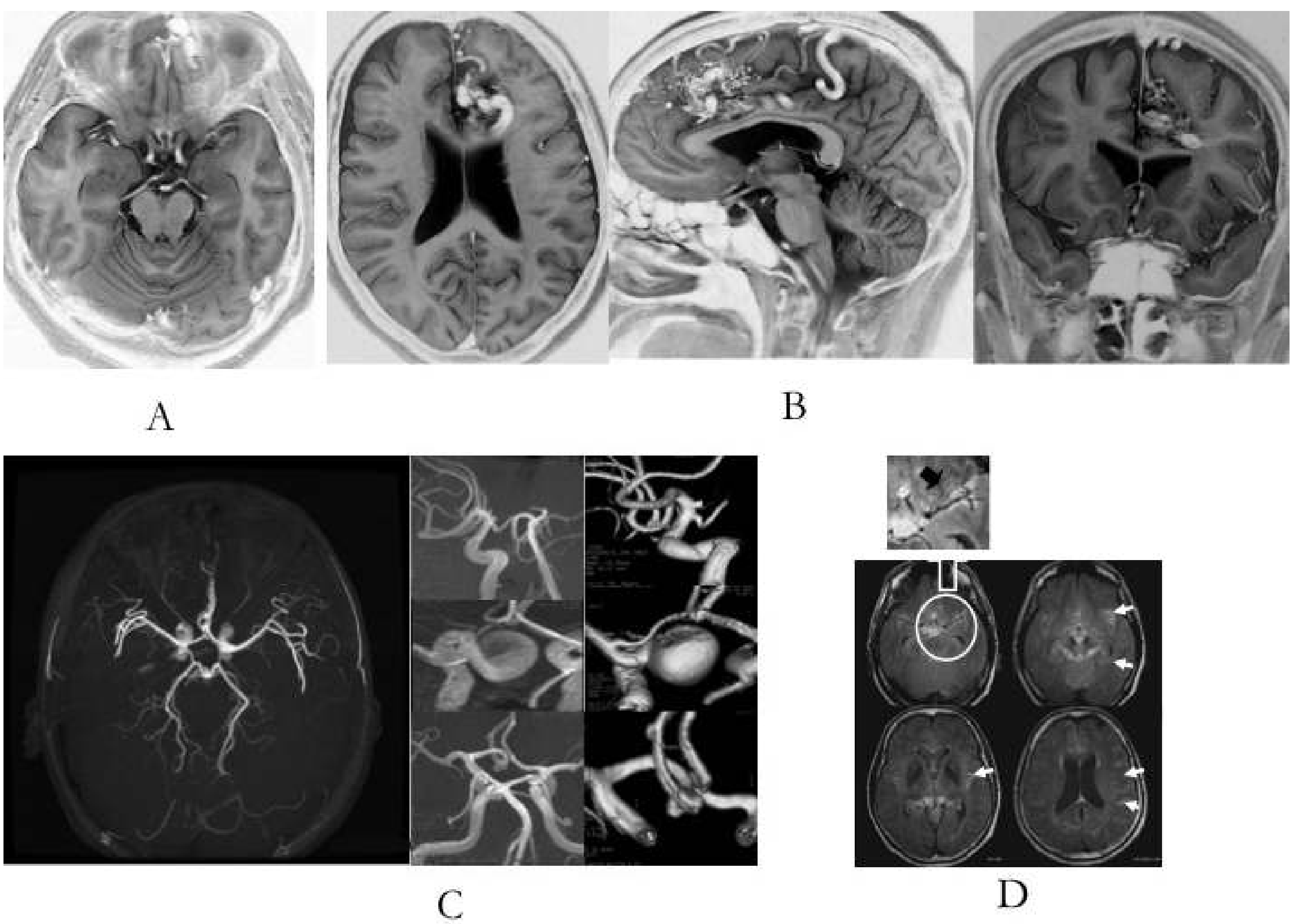


Fig. 1. (A) STIR (with short-inversion-time inversion recovery) image, (B) STIR images of a case of AVM, (C) High resolution MRA and MRA volume rendering of the aneurysm case, (D) FLAIR image of a case of SAH

achieved respectively(table 1).

The most striking characteristic of 3.0T MRI is its high SNR (about twice that of 1.5T MRI). High SNR allows images of higher resolution, yielding more anatomical information. A representative sequence for 3.0T MRI is short inversion-time inversion recovery (STIR). If reverse white-and-black images are taken with this sequence, the contrast of the images resembles that of T2-reversed images. Thus obtained images, resembling stained myelin sheath specimens, are rich in detailed morphological information pertaining to brain architecture, cerebral vessels, cranial nerves and intracranial lesions (Fig. 1A, B).

Head MR angiography (MRA), performed with this device, allows clear visualization of the anterior choroidal artery, perforating branches and cortical branches that are difficult to visualize with conventional modalities. These images yield higher quality than conventional techniques when used for detection of cerebral aneurysms in patients with SAH (Fig. 1C) [2]. Furthermore, the improved susceptibility effect enables easier diagnosis of hemorrhagic lesions [7]. Thus, the diagnostic capability of MRI for hemorrhagic lesions (particularly in cases of SAH) has been improved markedly, despite the present acknowledgement of lower diagnostic capability of MRI than that of CT for hemorrhagic lesions. Lesions can be detected even in cases of mild SAH, which tend to be overlooked by CT (Fig. 1D). The shortening of T2* with this modality enhances the low signal of hemorrhagic lesions, allowing detection of lesions responsible for asymptomatic intracranial bleeding. 1.5T MRI usually takes about 12 minutes, but to shorten this time in 3.0T MRI, we investigated possible differences in image quality depending on the time spent in taking images with fast spin echo inversion

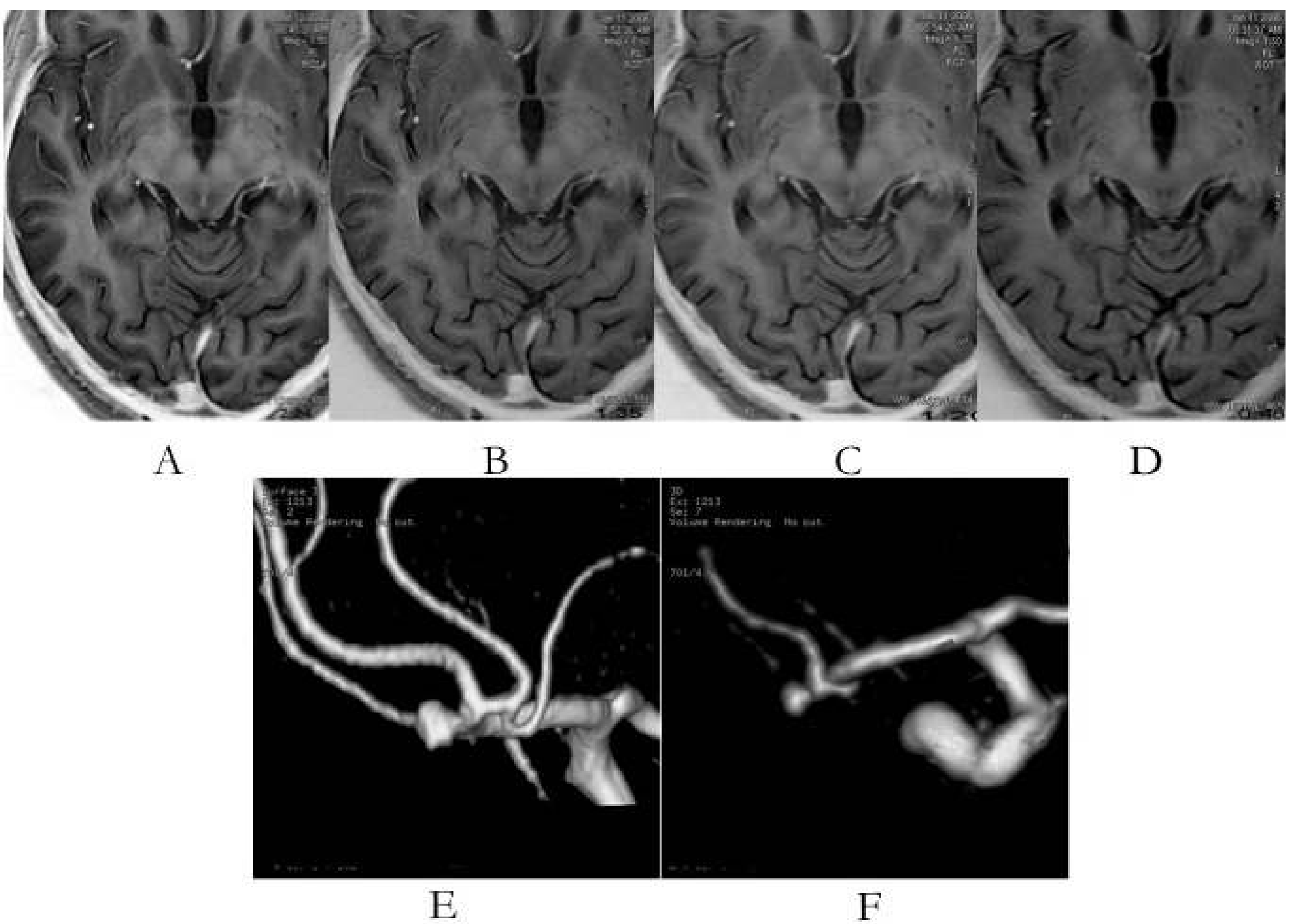


Fig. 2. Shortened scanning time. STIR images: 2 min 24 sec (A), 1 min 35 sec (B), 1 min 20 sec (C) and 48 sec (D). MRA: 6 min 36 second (E), 1 min (F).

recovery (FSEIR) sequence. This investigation revealed that even imaging within one minute allows adequate visualization of the brain structure of critical patients, which it is not in ordinarily images taken in more than 2 minutes (Fig. 2A, B, C, D). We further examined the possibility to shorten the time of MRA, which is the most time-consuming type of imaging. When

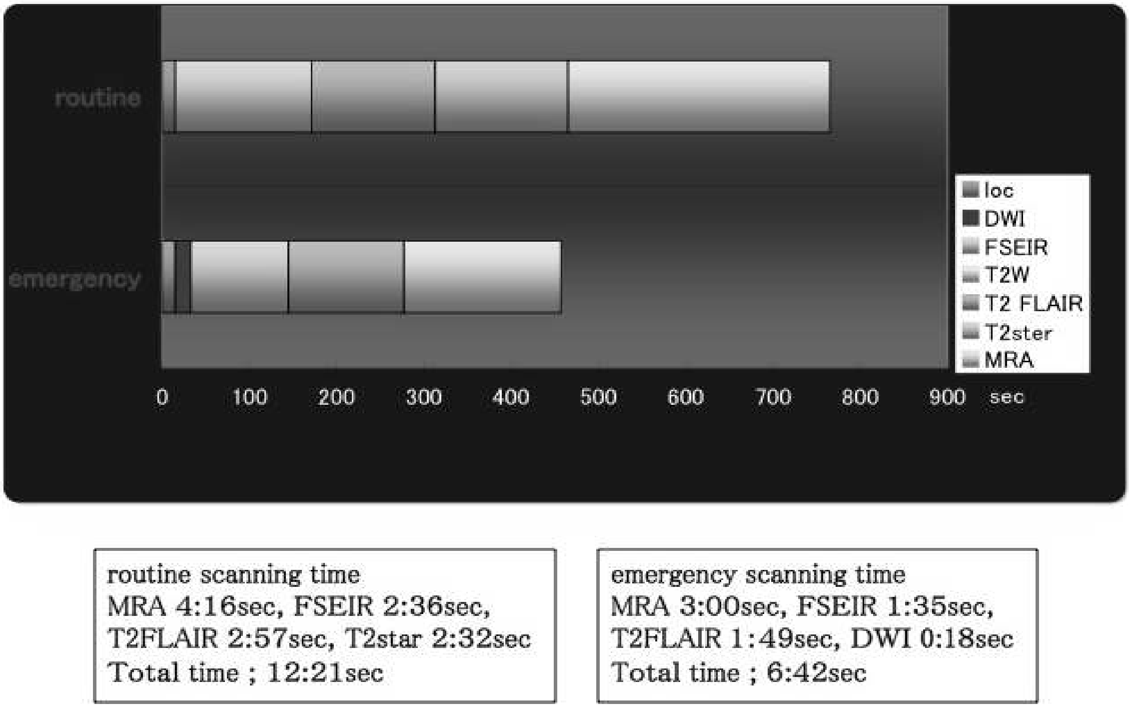


Fig. 3. Time and procedure for emergency scanning

more than 4 minutes are spent, it is usually possible to visualize even the finest perforating branches.

However, in critical patients, visualization of only major arteries and aneurysms will suffice, and these images were possible to obtain adequately in about one minute (Fig. 2E, F).

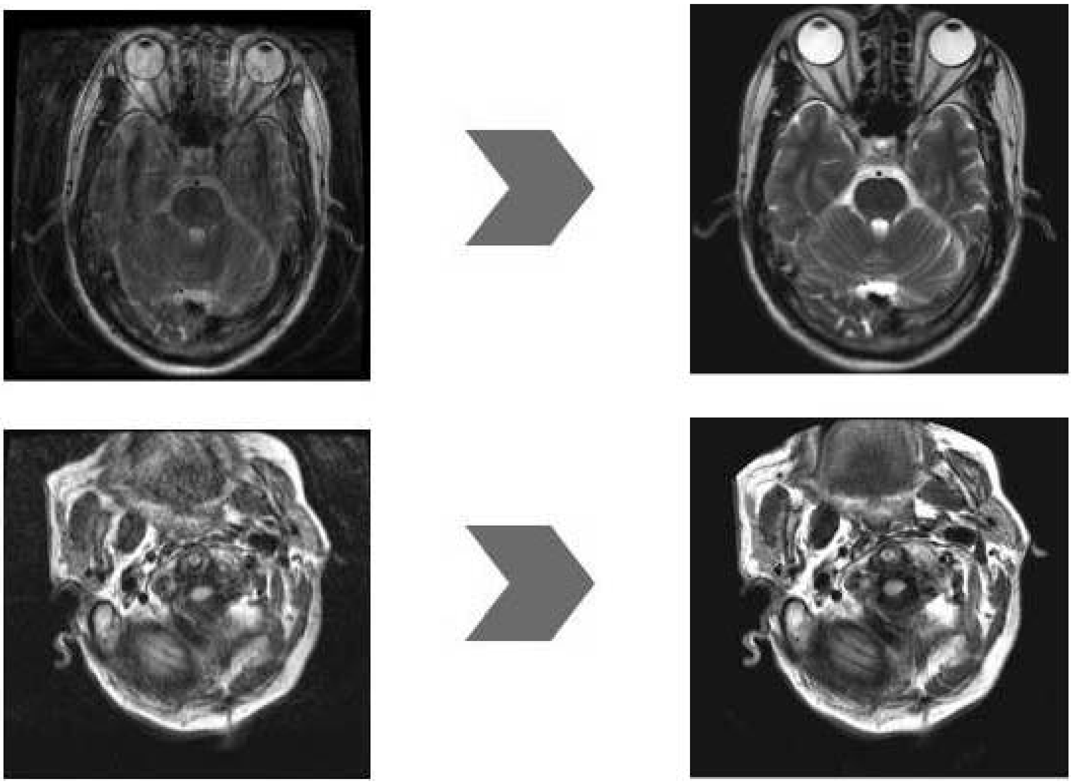
On the basis of these results, we formulated a sequence of imaging for patients requiring neurological critical care, while decreasing the time of imaging to less than 6 minutes (Fig. 3).

Propeller (Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction)

Since images taken in patients with deteriorating conditions or reduced levels of consciousness do not allow smooth diagnosis, we encountered a problem to suppress the bodily movement (including head movement).

For the diagnosis of hemorrhage, cerebral infarction, etc., relatively time-consuming sequences of imaging such as fluid attenuated inversion recovery (FLAIR) and spin-echo are required. When these sequences were used for patients showing frequent bodily movements, imaging often had to be repeated using sedatives. However, development of a new sequence has made it possible to conduct imaging smoothly even in patients showing certain of bodily movement (Fig. 4).

General Electric Company developed this sequence called PROPELLER. At the present, PROPELLER FLAIR, PROPELLER T2 and PROPELLER diffusion weighted images (DWI) are available. According to the principle of PROPELLER, the multiple parallel belt-shaped areas (blades), formed during the time of repetition (TR) and composed of spatial traces, are rotated around the center of space k by means of FSE-based radial scans (collection of data in a radial manner, passing through the point of origin within the space, while changing the gradient magnetic field). PROPELLER DWI is useful for image pooling, particularly in the posterior cranial fossa. Emergent imaging may be met by using a technique of imaging resistant to motion artifacts, due to movement of the



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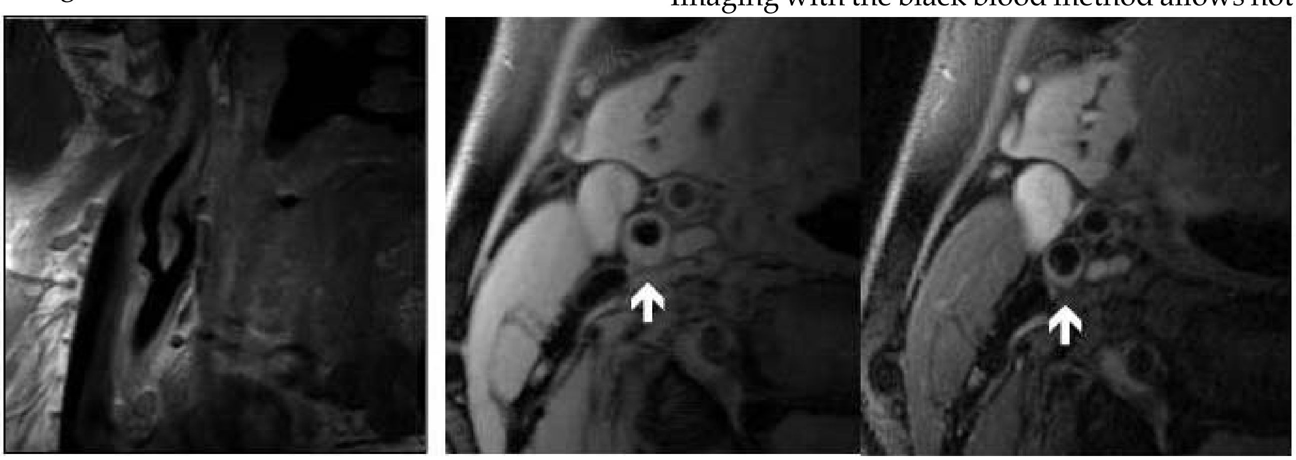
object and distortion of images. And susceptibility-associated artifacts can also be suppressed although more time is needed for imaging. PROPELLER is applicable to 1.5T MRI but is more suitable for 3.0T MRI in terms of shortening the time and improving the image quality.

Black blood method (carotid plaque imaging)

Black blood method is a technique of MRA designed to visualize blood flow in low luminance rather than in high luminance. This technique of magnetic resonance spectroscopy (MRS) suppresses the signal from the blood flow (the term "black" is used for this reason) unlike the ordinary MRA, which emphasizes the signal from the blood flow. This technique uses a neurovascular coil, capable of imaging the head to neck, to yield ECG-gated fat-suppressed T1-weighted images (T1WI) and T2-weighted images (T2WI) as well as 2D-TOF MRA images. Imaging with the black blood method allows not



T1 T2

A B

Fig. 5. Carotid plaque imaging. (A) Black blood method, (B) Fibrosis infiltration. Hyper signal in both T1 and T2 images(arrows)

only the detection of stenosed vascular lesions of the neck region but the evaluation of the fibrosis of the vascular wall, that are associated with atherosclerosis and fat deposition [4]. It has been shown that if a carotid artery lesion is depicted as a high luminance lesion in both T1- and T2-weighted images, the lesion is most likely a soft plaque that would cause embolism. The black blood method is thus useful for determining strategy in neurological critical care (Fig. 5).

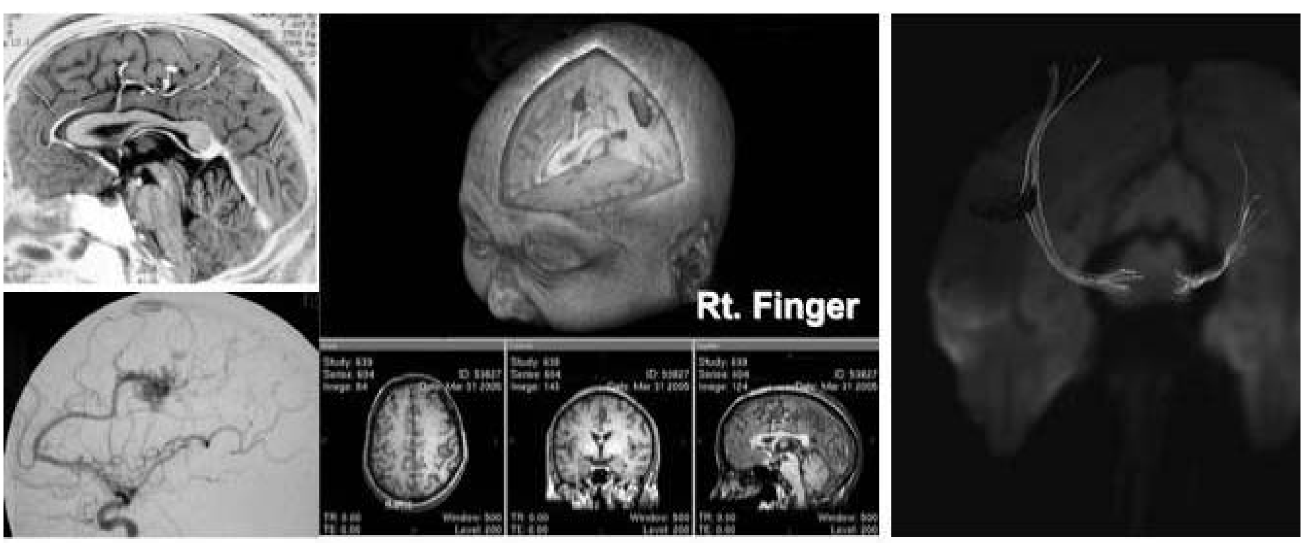
Discussion

In neurological critical care, diagnostic imaging is important not only in making accurate diagnosis, but also in determining the therapeutic strategy. CT, clinically introduced about 30 years ago, has contributed greatly to the advancing neurological care. Since then, it has become a standard routine test in neurological critical care, and is now a first choice routine in many facilities. MRI was clinically introduced later than CT. MRI supplies information, which cannot be obtained by CT and was initially viewed as an epoch-making new diagnostic modality. However, in the field of neurological critical care, MRI only serve as a secondary diagnostic means because of the time it consumes, and many restrictions it involves. As MRI became more advanced enough to detect acute ischemic lesions not detectable with CT, it caused a significant change in diagnostic imaging of early stage ischemic diseases. So far, as the conventional MRI devices of 1.5 or less Tesla are concerned, limitations associated with imaging time, body movement, capability to detect hemorrhagic lesions, etc., make it difficult for MRI to be adopted as the first-line diagnostic modality in neurological critical care. We recently introduced a high magnetic field MRI device (3.0T MRI) and applied it to many clinical cases. Time required for measurement can be shortened by using 3.0T MRI without reducing the image quality, thanks to the high SNR (about twice that of 1.5T MRI). Furthermore, the improved susceptibility effect of 3.0T MRI has made it easier to diagnose hemorrhagic lesions. Thus, 3.0T MRI is applicable as the first-line test for diagnosis of stroke. The use of an 8-ch coil currently available in combination with parallel imaging (by means of Array Special Selective Encoding Technique; ASSET) makes it possible to decrease the time necessary for imaging, to improve spatial resolution, to reduce artifacts and image distortions. The ASSET is a method of image reconstruction making use of the high sensitivity of a multiple number (8 at present) of receiver coils (phased array coils). With this technique, a sensitivity distribution map, yielded from reference scans, is used to compensate for the turn-up artifacts associated with the number of skipped phase encoding steps. This technique is advantageous in that it compensates for the significant unhomogeneity specific to superficial coils, improves the image quality through reductions in image distortion, motion artifacts (during high speed imaging) and echo train length (ETL), and finally, reduces SAR if used in combination with 3.0T MRI. If the 8-ch coil is compared with the conventional 1-ch coil, SNR is 40% higher with the 8-ch coil when used under identical conditions. It is thus possible to cut the time necessary for imaging by using the 8-ch coil in combination with ASSET. However, elevation in the magnetic intensity results in several problems. Because the specific absorption rate (SAR) is proportional to the square of the magnetic flux density, the radiofrequency heating effect of 3.0T MRI is four times greater than that of 1.5T MRI. There is no consensus over the effects of this kind of heating on the living body and whether or not metals implanted in vivo actually generate heat following 3.0T MRI. [8]0In any event, the 3.0T MRI device is equipped with an RF output monitor to prevent excess heating over the safety limit (3 W/Kg when a single coil is used and 2 W/Kg when an 8-ch coil is used). The resonant frequency increases in proportion to the magnetic flux density. Because permeation of RF across living tissue decreases as the frequency increases, the magnetic field within the living body is less homogeneous during 3.0T MRI scanning with high resonant frequency. As a result, imaging with this device is highly dependent on longitudinal magnetization, causing large variances in signals due to fluctuation of the flip angle when spin echo (SE) T1-weighted images are taken with this modality. Other problems encountered include image distortion, enhanced artifacts associated with susceptibility, noise and onset of transient dizziness in some patients. Though there are several problems of elevation in the magnetic intensity results like this, this new device is shown to be superior to conventional MRI devices in terms of the capability of accurately diagnosing all types of stroke (including hemorrhagic lesions) and to be useful as a means of determining therapeutic strategy in such cases. The conventional problems (much time needed for imaging and influence from bodily movement) may also be resolved by this new device. It supplies adequate information for neurological critical care in only approximately 6 minutes and is less affected by bodily movement. In addition, functional MRI and DTI are capable of providing functional information, which cannot be obtained with CT. The use of functional MRI for critical care is possible only in limited cases because the level of patients' consciousness is unstable. However, when this technique is applicable, functional MRI allows identification of neurological problems in lesser time, using a simple task [1,6]. This modality is therefore promising as a means of collecting useful information prior to emergent surgery (Fig. 6A). Diffusion tensor tractography (DTI) is usually aimed at three-dimensional analysis of anisotropic orientations and anatomical relationship of intracranial bleeding, cerebral infarction, brain tumor and other lesions of the nerve fibers (pyramidal tract, etc.) can be determined. The information obtained is also useful when performing surgery and predicting functional prognosis. Although an MRI device of 1.5 or less Tesla can be used for this method of imaging, the image quality is not high if the SNR is low. To resolve this problem measures were taken by increasing the frequency of summation of images, but this inevitably extended the imaging time. Therefore, a high magnetic field device such as the 3.0T MRI, which has a high, SNR are useful for neurological critical care since it improves the image quality and shortens the imaging time.

These devices are useful as a means of determining therapeutic strategy. Considering that the management of stroke list of the present Japanese and AHA guidelines recommend accurate diagnosis and early start of treatment as major factors determining the outcome of critical neurological cases, we may say that 3.0T MRI will be highly useful in the neurological critical care.

Conclusion

This paper dealt with the usefulness of a high magnetic field 3.0R MRI in neurological critical care. 3.0T MRI is expected to be established as the first-line technique of diagnostic imaging,



A B

Fig. 6. A case of right cerebral infarction. (A) Functional MRI during right finger tapping, (B) Diffusion tensor tractography of the pyramidal tract

taking the role conventionally played by CT in neurological critical care.

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