Value of Balanced Fast Field Echo-assisted Three Dimensional Time-of-flight to Diagnose Intracranial Arterial Stenosis

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ABSTRACT

Magnetic resonance angiography (MRA) is a non-invasive vascular imaging technique. It can resolve the 3D morphology and structure of the circle of Willis when used in conjunction with three dimensional time-of-flight (3D TOF) and maximum intensity projection (MIP) technology. However, slow blood flow or saturation effects will cause signal loss in 3D TOF, and affect the accuracy of diagnosis. The balanced fast field echo (BFFE) technique employs a fully-balanced gradient waveform along all three axes, which allows magnetization to reach a steady state, providing fluids with good signal-to-noise ratios (SNRs) and excellent tissue contrast. Balanced fast field echo can then be used as diagnostic pulse sequence for blood vessels or fluid-filled tissues. Two case reports illustrate the value of BFFE-assisted 3D TOF to diagnose intracranial arterial stenosis.

Keywords: Balanced fast field echo, magnetic resonance angiography, maximum intensity projection, three dimensional time-of-flight

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INTRODUCTION

Intracranial arterial stenosis restricts the blood supply to the brain, leading to impaired brain function. When intracranial arterial stenosis occurs, patients experience symptoms such as numbness of the hands, dizziness and even hemiplegia (1). Atherosclerosis, hypertension, diabetes mellitus, dyslipidaemia, smoking and a history of heart disease are all common risk factors for intracranial arterial stenosis (1). Other possible risk factors include aortic dissection, fibromuscular dysplasia and radiation injury (2).

Angiography is the well-validated means of diagnosing cerebral arterial stenosis (3), and computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are the two most commonly used diagnostic tools (Table 1).

Magnetic resonance angiography can be further classified into contrast-enhanced magnetic resonance angiography (CE MRA) and non-contrast-enhanced MRA [such as three dimensional time-of-flight MRA (3D TOF MRA)]. Of these methods, 3D TOF is commonly utilized to detect blood flow signals. Maximum intensity projection (MIP) reconstructs the raw images of the 3D TOF to reveal the 3D structure of the circle of Willis and detect-stenosis or occlusion viewed from different perspectives. However, slow blood flow and saturation effects will cause signal loss in 3D TOF, leading to overestimation of a stenosis.

Balanced fast field echo (BFFE) is a technique for diagnosing blood vessels or fluid-filled structures [such as cerebrospinal fluid within the ventricles, intraperitoneal free fluid, gallbladder and common bile duct] (4). Balanced fast field echo typically obtains strong signals from blood and fluid, and the combined use of 3D TOF and BFFE can detect vascular stenosis (5, 6).

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Table 1: Baseline characteristics for haemophilia patients, in Martinique

Method		Advantages	Shortcomings	Remarks
CT scan		Short scanning time, enables immediate inspection of intracranial situation	Involves radiation and use of an injected imaging agent	Fastest and most convenient examination method, enables immediate inspection of intracranial situation
MRI scan	3D TOF	No radiation, non-invasive, high resolution	Relatively time-consuming, not sensitive to slow blood flow	Has the best resolution of any examination method; an effective means of screening for vascular diseases of the head, neck and brain
	CE MRA	No radiation, relatively accurate	Requires injected imaging agent, involves a certain degree of risk	
Angiography		Clear and accurate imaging of blood vessels	Involves radiation, relatively invasive, relatively high risk.	Has greater risk than the previous two methods, and a physician must perform an assessment before examination. Whether the carotid arteries and other blood vessels of the brain have any obstruction or stenosis can be clearly seen from photographs of the blood vessels, making this the "gold standard' for diagnosis of vascular diseases of the brain.

In this study, we present two cases of patients to demonstrate the differences between 3D TOF and BFFE vascular imaging obtained using a 1.5T NMR scanner, and to compare those imaging results with CE MRA.

CASE REPORTS

An 80-year-old man presented to our otorhinolaryngology clinic complaining of impaired hearing. Due to the patient’s renal dysfunction, a brain MRI without contrast was performed. In addition to conventional T1-weighted, T2-weighted, and fluid attenuation inversion recovery (FLAIR) imaging, 3D TOF MRA and BFFE sequences were also performed. Three dimensional time-of-flight parameters included: TR: 22 ms, TE: 6.9 ms, FOV: 170 x 105 mm^2, and spatial resolution: 0.7 x 1 x 2 mm^3. BFFE parameters were: TR: 6.9 ms, TE: 3.5 ms, flip angle: 50°, spatial resolution: 0.6 x 0.6 x 1 mm^3, and FOV: 150 x 40 mm^2.

Maximum intensity projection MIP of the raw 3D TOF images showed obvious signal loss at the petrous segments of both internal carotid arteries, indicative of arterial occlusion (Figs. 1a and 1b). An examination of the raw images confirmed severe signal loss (Fig. 1c), but comparison with BFFE images at the corresponding levels revealed no evident stenosis (Fig. 1d).

The second case report involved a 62-year-old man who also sought otorhinolaryngology care for impaired hearing. Since this patient's kidney function was normal, an MRI of the brain with contrast was performed. Three dimensional time-of-flight revealed mild stenosis (Fig. 2a), and MIP images revealed discontinuity of the internal carotid artery (Fig. 2c), while BFFE (Fig. 2b) and CE MRA images (Fig. 2d) turned out to be no stenosis.

DISCUSSION

Our first case involving an elderly male patient with abnormal renal function who underwent MRI of the brain without contrast agent revealed the value of BFFE in 3D TOF diagnosis of cerebral vascular pathology. Three dimensional time-of-flight is the most commonly used sequence in MR angiogram because it does not require injection of a contrast agent. When MIP is used to display projections from different perspectives, the resulting images can provide a good perception of 3D structure and the impression. However, complex (*eg* turbulent flow) or slow blood flow will result in signal loss, which may lead to incorrect estimates of *foci* based on their appearance on the images. For example, an aneurysm may be underestimated or a vascular stenosis may be overestimated (8), which may lead to diagnostic errors.

The BFFE signal strength (SBal) formula can be expressed as (9):

$$S_{Bal} = M_0 \text{ Sin } \alpha \frac{1}{(1+\cos\alpha)+(1-\cos\alpha)(T1/T2)} e - TE/T2 \approx \frac{1}{2} M_0 \sqrt{\frac{T_2}{T_1}};$$

where S_{Bal} is the signal strength, M_0 is the magnetic moment, α is the flip angle and TE is the echo time. According to this formula, signal strength is determined by the T2/T1 ratio. The T2/T1 ratio is low in the majority of tissues and is high in the case of fluids (Table 2).

Table 2: T2/T1 ratios of various tissues [10]

Tissue	T2/T1
Muscle	0.05
Liver	0.08
Brain	0.11
Fat	0.30
Fluid	0.70

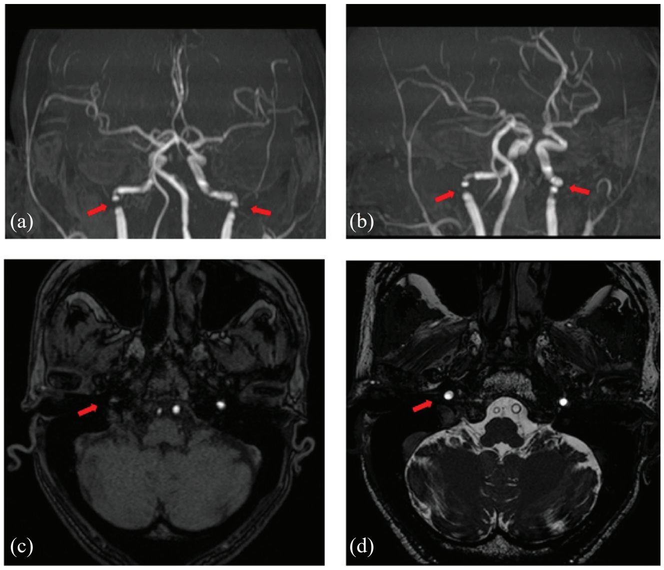

Fig. 1: Dimensional time-of-flight (3D TOF) and balanced fast field echo (BFFE) images from an 80-year-old patient. (a, b) There are segmental signal losses in the petrous portion of the bilateral internal carotid arteries on maximum intensity projection (MIP) images, findings that cause concern for arterial occlusion (c) 3D TOF image shows signal loss in the right internal carotid artery (arrow). (d) Balanced fast field echo image obtained at the same level shows blood flow signal of the right internal carotid artery without evidence of occlusion. It can therefore be inferred that the "pseudo-occlusion" seen on the MIP may actually be artifacts.

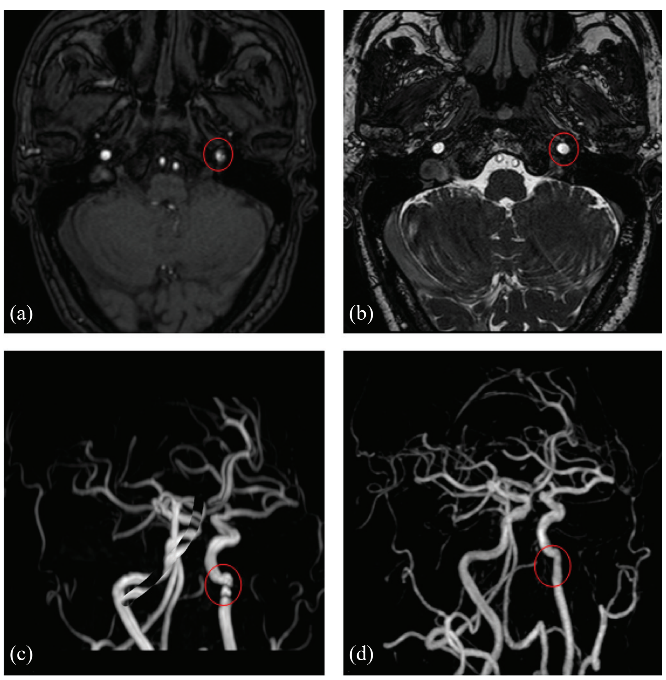

Fig. 2: Dimensional time-of-flight (3D TOF), balanced fast field echo (BFFE) and contrast-enhanced magnetic resonance angiography (CE MRA) images from a 62-year-old patient. (a) There appears to be mild stenosis of the left internal carotid artery in this 3D TOF image (red circle). (b) No evident stenosis is visible in this BFFE image at the same level. (c) Discontinuity of the artery is visible in this maximum intensity projection image. (d) This CE MRA image reveals that there is no stenosis of the left internal carotid artery.

Consequently, fluids have high signal strength in BFFE and form a strong contrast between the surrounding tissues. The main advantages of BFFE include (11, 12): 1) rapid scanning, since TR can be reduced without diminution of the signal (TR < 5 ms) based on the above formula [where signal strength is unconnected with repetition time (TR)]; 2) intensification of signal strength due to a fully-balanced three-axis gradient magnetic field (Fig. 3) which allows the magnetic moment to remain in-phase within a TR; and 3) inherently automatic flow compensation (Fig. 3).

However, a shortcoming of BFFE involves its extreme sensitivity to magnetic field inhomogeneity. Since magnetic field homogeneity is more difficult to achieve in large areas, unpredictable banding artifacts will appear (Figs. 4a and 4b), and signal loss may occur in blood vessels (Figs. 4c and 4d). However, the degree of blood vessel signal loss will not be as severe as in the case of 3D TOF.

Patients may be allergic to contrast agents and/or have impaired renal function. In addition, the use of contrast agents is accompanied by a certain degree of risk, especially in the elderly. The use of 3D TOF or BFFE imaging sequences, however, provides adequate diagnosis of blood vessels without the use of a contrast agent. Since 3D TOF may lead to vascular signal loss, BFFE, with its features of fully-balanced gradient and flow compensation, can be employed as an auxiliary or to provide verification.

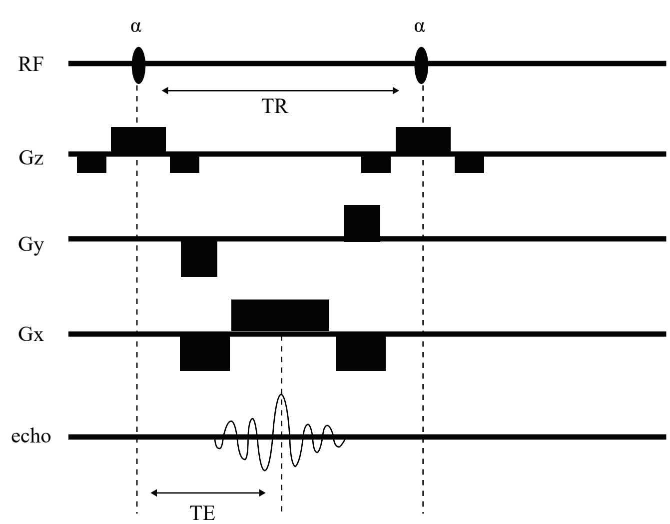

Fig. 3: Balanced fast field echo pulse sequence diagram. Balanced fast field echo has a fully-balanced gradient waveform, permits the magnetic moment to achieve a steady state and has inherently automatic flow compensation. Abbreviations: RF = radiofrequency, Gz = slice selection gradient, Gy = phase encoding gradient, Gx = frequency encoding gradient.

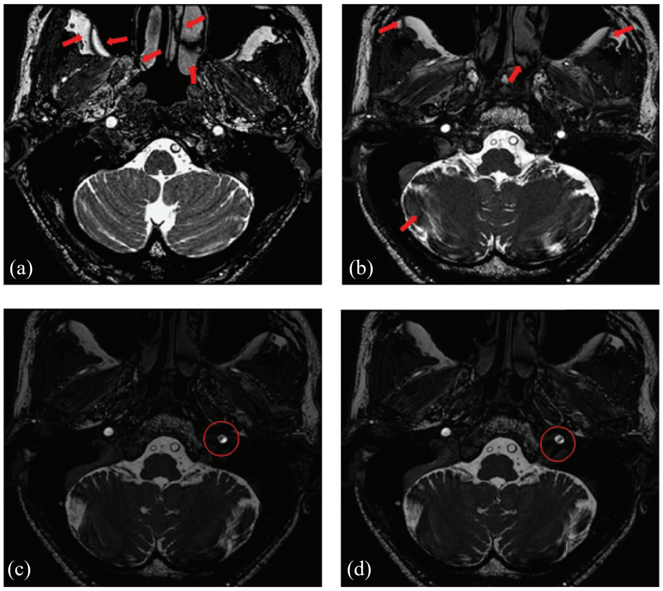

Fig. 4: Magnetic field inhomogeneities at different locations within field of view. (a)(b) Unpredictable imaging artifact in the form of banding has appeared in the image (arrows); (c)(d) and blood vessel signal loss (red circle) has also occurred.

However, since BFFE is extremely sensitive to magnetic fi eld inhomogeneity, unpredictable banding artifacts will appear on the images. As a consequence, both 3D TOF and BFFE have their own strengths and weaknesses. Thus, if the interpretation of a 3D TOF image is indeterminate, BFFE can be used as an auxiliary. However, the most accurate means of diagnosing vascular pathology is to inject a contrast agent.

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