Optimization of Three-dimensional Time-of-Flight Magnetic Resonance Angiography of the Intracranial Arteries

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Abstract

The signal-to-noise ratio obtained from arteries in three-dimensional (3D) time-of-flight (TOF) magnetic resonance (MR) angiography is often too low to allow clinical diagnosis because the radiofrequency pulse decreases the magnetization of protons in the blood and suppresses the in-flow effect in the slab. The present study adjusted the position of the head coil to boost arterial signal intensity. Ten healthy volunteers, eight men and two women aged 24–78 years, underwent 3D TOF MR angiography of the intracranial arteries with the same standard GE transmit-receive birdcage head coil using both normal and half position (lower edge of the coil level with the mouth) methods. Our subjects were divided into Group 1 consisted of five relatively young volunteers aged 24–42 years (mean 31.2 years), and Group 2 consisted of five older volunteers aged 70–78 years (mean 73 years). The following four arteries were chosen for analysis: the internal carotid artery (ICA), the proximal middle cerebral artery segment (M1), and the two distal middle cerebral artery segments (M2, M3). The half position method increased the signal-to-noise ratio in the ICA, M1, M2, and M3 by 15%, 25%, 36%, and 44%, respectively. In general, this method resulted in the generation of stronger signals in the M2 and M3 in younger subjects and in all arteries examined in older subjects. The half position method can provide better MR angiograms in certain brain regions of younger people, and in all brain regions in older patients.

Key words: magnetic resonance angiography, time of flight, stroke

Introduction

Magnetic resonance (MR) angiography is a noninvasive method for the visualization of vascular disease, and is rapidly becoming a critical tool for evaluating the condition of intracranial vessels. This imaging technique enhances the signals of the arterial blood flow and suppresses the signals from stationary tissues, resulting in a phenomenon known as the in-flow effect. Recent advances in technology such as stronger magnets and sophisticated software have helped to increase the image contrast, but the signal obtained from the blood flow in the intracranial arteries is still rather weak.

Volume coils such as the birdcage coil, which is a standard type of head coil, provide better radiofrequency homogeneity and higher sensitivity than surface coils, which are both desirable features for MR angiography. Even so, in clinical practice, signals obtained from peripheral and main arterial branches in the head are generally too indistinct to allow for the establishment of a clinical diagnosis. One problem is that the radiofrequency pulses extend beyond the target field using the three-dimensional (3D) gradient echo sequence, resulting in reduced longitudinal magnetization of the protons in the blood flow in the proximal vessels. Such weak magnetization accounts for the reduced in-flow effect in the recording slab.

In the present study, the position of the head volume coil was adjusted to reduce the effects of the radiofrequency pulse in the proximal region, thus preventing the reduction in the longitudinal magnetization of protons in the proximal artery.

Methods

I. Preliminary MR imaging studies

MR imaging was performed using a clinical 1.5T GE Signa LX MRI scanner (General Electric Medical
Systems, Milwaukee, Wis., U.S.A.) with Echospeed imaging gradients (23 mT/m maximum amplitude, 120 mT/m/msec slew rate), running 8.3 software, and using a standard GE transmit-receive birdcage head coil.

The DQA phantom (General Electric Medical Systems) used for preliminary experiments was 17 cm in diameter and filled with an aqueous solution of NiCl₂·H₂O. Axial images were acquired using a single shot fast spin echo sequence (echo time [TE] = 100 msec) and a matrix size of 256 × 192. A 60 mm thick slice was imaged at a bandwidth of 15.6 kHz. The field of view was 200 mm.

A cylindrical phantom was created to measure the signal-to-noise ratio profile for the standard GE transmit-receive birdcage head coil (Fig. 1A-1). The phantom had a radius of 8.8 cm and was 16.1 cm long, and was filled with 4 l of a solution containing 1.955 g/l CuSO₄·5H₂O and 3.34 g/l NaCl. Sagittal images were acquired with a fast spin echo sequence of 400/11 msec (repetition time [TR]/TE). The matrix size was 320 × 256. A 50 mm slice was imaged, and the bandwidth was 15.6 kHz. The field of view was 200 mm.

MR angiography used axial images acquired with a 3D time-of-flight (TOF) magnetization transfer saturation and fat suppression sequence. The imaging parameters were 34/6.9 (TR/TE) with a flip angle of 20°. The matrix size was 256 × 192. A 60 mm thick slab was imaged with a slice thickness of 1.0 mm, and the bandwidth was 15.6 kHz. The field of view was 180 mm. Zero-filled interpolation processing was applied in the slice direction to double the number of reconstructed images.

A static water flow was scanned with the MR angiography sequence, as shown schematically in

Fig. 1 Photographs showing the positioning of the standard GE transmit-receive birdcage head coil with the phantom (A-1), and the patient’s head in the normal (B-1) and half positions (C-1). Sagittal T₁-weighted magnetic resonance images of the cylindrical phantom (A-2) and a subject obtained with the normal (B-2) and half positions (C-2). Signal-to-noise ratio (SNR) was plotted against distance from the lower edge of the coil (A-3). The signal in the slab (white rectangle) was sufficient to obtain a sagittal image in both the normal (B-3) and half positions (C-3).

Fig. 2 Schematic representation of the static water flow phantom (A). Maximum intensity projection images of the water flow (10 cm/sec and 20 cm/sec) using the normal position are shown in B and D, respectively, and images using the half position are shown in C and E, respectively.
Fig. 3 Sagittal $T_2$-weighted magnetic resonance images of the whole DQA phantom (left column) and axial $T_2$-weighted images of the target (right column) showing that the target was visualized if positioned in the middle of the slab (A), at the edge of the slab (B), or outside the slab (C), but not if positioned far from the slab (D). The scan area (slab) is indicated by the white rectangle. Scale bar = 5 cm.

Results

I. Preliminary MR imaging studies

Our DQA phantom experiment clearly confirmed that the geographical range of the radiofrequency pulse is wider than that of the slab. The target was demonstrable if positioned in the middle of the slab, at the edge of the slab, or outside the slab (Fig. 3A–C). In fact, the target was not visualized only if positioned far from the slab (Fig. 3D).

MR angiography is generally thought to require more than 80% of the maximum signal-to-noise ratio value. A cylindrical phantom was imaged using the standard GE transmit-receive birdcage head coil, and the signal-to-noise ratio profile indicated that
Fig. 4 Signal-to-noise ratio (SNR) profiles of the maximum intensity projection images shown in Figs. 2B (■, 10 cm/sec normal position), C (▲, 10 cm/sec half position), D (△, 20 cm/sec normal position), and E (▲, 20 cm/sec half position). The SNR of the slower water flow (10 cm/sec) was greatly improved with the half position method.

Fig. 5 Axial collapse maximum intensity projection images obtained from Groups 1 (A, B) and 2 (C, D) using the normal (A, C) and half position (B, D) methods.

Fig. 6 Signal-to-noise ratios (SNR) plotted at each region of interest in Groups 1 and 2. ICA: internal carotid artery; M1, M2, and M3: M1, M2, and M3 segments of the middle cerebral artery, respectively. ■: Group 1, normal position; □: Group 1, half position; ○: Group 2, normal position; △: Group 2, half position. Error bars indicate the standard deviation. *p < 0.05.

II. MR angiography in subjects

Figure 5 shows representative MR angiograms for Groups 1 and 2. Images taken in the half position were clearly superior in both groups. The proximal intracranial arteries (ICA and M1) were well visualized in Group 1 by both methods, but the half position yielded higher signal intensities in the distal areas (M2 and M3). The half position provided higher signal intensities at all points in Group 2.

Figure 6 compares the signal-to-noise ratio at regions of interest in Groups 1 and 2. The signal-to-noise ratio increased in the ICA, M1, M2, and M3 by 15%, 25%, 36%, and 44%, respectively.
Discussion

TOF MR angiography has often applied a relatively wide slab (e.g., 60 mm) to allow scanning of the base of the skull from vertebral artery through the distal arterial branches. However, the signal intensity is low in the blood vessels within such a slab because of inappropriate proton excitation that occurs outside the slab which results in spin saturation within the slab. Our phantom experiments confirmed this finding in the following two ways. First, the DQA phantom experiment clearly indicated that the target could be visualized, even when the target was outside the slab. Second, our water flow phantom study showed that the signal intensity of water flow was reduced in distal areas when the flow velocity was relatively low (10 cm/sec).

Two methods are currently in clinical use to mitigate the above-mentioned spin saturation phenomenon: multiple slabs, each with a reduced range, and multiple images that are reconstructed after data acquisition. The multiple slab method provides improved visualization of selected intracranial vessels compared to single volume 3D TOF, but results in venetian blind artifacts. The multiple image reconstruction method uses paramagnetic contrast agents such as gadopentetate dimeglumine which shorten the T1 relaxation time of blood and reduce the saturation of slow flow in the small arterial branches. The disadvantage of using gadolinium is the associated enhancement of the signal intensity of veins and soft tissues which may obscure the arterial signals.

The half position method of single volume 3D TOF used in this study increased the signal intensity profile in the slab and reduced the excitation of protons on the proximal side of the slab. Our cylindrical phantom study showed that more than 80% of the signal intensity was obtained above 65 mm from the lower edge of the coil. This technique may be used in the facilities that utilize a transmit-receive birdcage head coil (even in lower magnetic field), when axial slabs are located from the pontomedullary junction (≥80% of the signal intensity) to the upper edge of corpus callosum.

The mean flow velocity in the intracranial arteries is reported to be about 20–40 cm/sec. However, arteries that do not have a straight course through a visualized slab display reduced flow velocity. Therefore, the distal MCA is unlikely to be well visualized even in young people. The half position method markedly reduced inappropriate excitation of protons and allowed visualization of slow water flow (10 cm/sec) in the water flow phantom study, and improved the signal-to-noise ratio in the distal MCA in young patients. Perhaps more importantly, this method also greatly improved the signal-to-noise ratio in the main and peripheral arteries in older people, who often have reduced intracranial arterial blood flow.

References

12. Yang JJ, Hill MD, Morrish WF, Hudon ME, Barber


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Commentary

The purpose of this paper is to introduce a new technique namely “the half position method” for improving the image quality of 3D-TOF MR angiography of the intracranial arteries. The half position method is a very simple technique, only adjusting the position of the lower edge of the birdcage head coil at the level of the patient’s mouth, not the level of the chin in the usual position. The authors concluded that this method could provide better MR angiograms by reducing the effects of the radiofrequency pulse and preventing the reduction in the longitudinal magnetization of protons in the arteries. This effect is well known in clinical daily MR examinations by radiologists of experience. That is to say, especially in patients with much fat and a short neck, the entire head of the patient cannot be placed in the transmit-receive birdcage head coil, but the MR angiography has a much better image quality. The authors proved the mechanism of this effect by three types of phantom experiments including DQA phantom experiment, cylindrical phantom study, and water flow phantom study, and also by clinical data. One gets the impression that this method seems to be very valuable for clinical use, but further clinical studies are needed for world-wide adoption.

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