Artifacts due to Retrograde Flow in the Artery and Their Elimination in 2D TOF MR Angiography

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Dark band artifacts are often observed in angiograms of arteries obtained by 2D time-of-flight (TOF) angiography with saturation of veins by presaturation RF pulses. At some arteries the arterial blood velocity varies in a triphasic pattern during a cardiac cycle. The arterial blood, that is saturated by presaturation RF pulses in the saturation band, can flow back into the imaging slice during the retrograde flow phase of the triphasic variation. When such saturated retrograde flow occurs during the acquisition of the central part of the K space, a signal void can result in base images and consequently dark band artifacts can appear in angiograms. This phenomenon is experimentally demonstrated by varying the gap between the imaging slice and the saturation band. Furthermore, a new pulse sequence is proposed to eliminate the dark band artifacts by changing the profile of the saturation band from a rectangle to a ramp.

Index words: Time-of-flight angiography, retrograde flow, artifacts

Introduction

Time-of-flight (TOF) angiography is based on inflow enhancement to get a contrast of vessels over stationary tissues [1, 2]. The inflow enhancement can be nullified by saturating the inflow spins in vessels by use of presaturation RF pulses [3]. The artery can selectively be enhanced by saturating the venous inflow to the imaging slice because the flow direction in the artery is usually opposite to that in the vein.

We often observe artifacts of dark bands appearing along the artery in 2D TOF angiograms [4, 5]. The dark band artifacts appear in irregular intervals and can confuse a diagnosis. We explain the cause of the dark band artifacts and propose a pulse sequence to eliminate the artifacts.

Methods

It is generally known that a gradient echo sequence used in TOF angiography can result in a signal void due to phase dispersion in a voxel by local field inhomogeneity or turbulent flow. However, the dark band artifacts in 2D TOF angiograms cannot be explained by these effects.

Cause of the dark band artifacts

We assume that the dark band artifacts should be related to the saturation of the venous flow. In TOF arteriogra-
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A new pulse sequence without the dark band artifacts

One way of eliminating the dark band artifacts may be to put an enough gap between the imaging slice and the saturation band to prevent the saturation of retrograde flow in the artery. However, a wide gap can result in an incomplete saturation of the venous blood on the angiogram.

Another way is to modify the slice profile of the saturation band in a way to give less saturation of the retrograde flow while maintaining the saturation of the vein. A ramped profile shown in Fig. 3 can satisfy such condition. The slope of the ramped profile is set to face the imaging slice. In other words, the flip angle of the ramped profile increases as it becomes away from the imaging slice. The venous blood will be fully saturated by the ramp portion of larger flip angles and continuously saturated by the ramp portion of smaller flip angles. Therefore, the venous blood will be kept saturated at the imaging slice.

On the other hand, the arterial blood that flows from the imaging slice into the saturation band will experi-
ence partial saturation by the ramp portion of small flip angles. When the arterial flow direction is reversed, the arterial blood will still experience only small flip angles. Therefore, the retrograde arterial blood will flow into the imaging slice with partial saturation. Thus, the retrograde arterial flow will give the signal while the venous flow will still be saturated.

**Experimental Results**

Experiments were performed in a Medinus Magnum 1.0 T system using a knee tranceive RF coil [Dongbo Co.]. A MIP program in the Magnum 1.0 T system was used to get angiograms from base images. A gradient echo sequence based on Fig. 1B was used with a flow compensation for the slice selection gradient. A spoiler gradient was added to the slice selection axis to dephase out the signal from the saturation band.

We investigated the effects of retrograde flow on angiograms by varying the presaturation condition of a rectangular profile. A 2D TOF angiogram was obtained without the presaturation RF to be used for a reference. As seen in Fig. 4A, there were no perceivable dark band artifacts. Then, we obtained 2D TOF angiograms for different sizes of gap and the resultant angiograms are shown in Figs. 4B to 4D. The dark band artifacts were

**Fig. 3.** Presaturation with a ramped profile in 2D TOF angiography.

**Fig. 4.** Angiograms of a femoral artery with different presaturation conditions of a rectangular saturation band: *(a)* without presaturation, *(b)* gap = 15 mm, *(c)* gap = 10 mm, and *(d)* gap = 5 mm.
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getting more serious as the gap was reduced. These results clearly support the assumption that the dark band artifacts were caused by the retrograde flow in the artery.

To prevent a partial saturation of the imaging slice by the saturation band, a technique of dual saturation bands was employed (7). The thickness of the saturation band close to the imaging slice was 2 cm and that of another band was 8 cm. The presaturation for a wider band was followed by that for a narrower band in the sequence. The slice profile of the presaturation RF was rectangular with a flip angle of 100° and the RF bandwidth was 5 kHz. Imaging parameters were TR = 30 ms, TE = 9 ms, number of averages = 1, flip angle = 60°, slice thickness = 3 mm, RF bandwidth = 1 kHz, and FOV = 220 mm.

Then, we implemented the proposed ramped RF pulse for the saturation as shown in Fig. 5. With this ramped RF pulse the 2D TOF angiograms were obtained from the same volunteer. A single saturation band was used with a thickness of 10 cm and a bandwidth of 5 kHz. The flip angle at the peak of the ramp was 120°. As seen in Figs. 6A and 6B there were no dark band artifacts even without a gap. Imaging parameters other than the saturation were the same as those for Fig. 4. At a gap of 5 mm some of veins were enhanced as shown in Fig. 6A, which can be improved by optimizing the ramped profile to give more flat saturation in a distal part from the imaging slice.

**Conclusions**

The dark band artifacts in 2D TOF angiography were proven to be caused by the retrograde flow in the artery. This effect should be taken into consideration in the imaging and the diagnosis as well. The proposed ramped saturation may be more robust in obtaining the angiogram of artery without the dark band artifacts. The

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**Fig. 5.** RF pulse for the ramped profile. (a) Real and imaginary part of the RF pulse. (b) Profile obtained by solving a Bloch equation for a bandwidth of 5 kHz

**Fig. 6.** Angiograms of a femoral artery acquired with the proposed ramped RF for the saturation: (a) gap = 5 mm and (b) gap = 0 mm.
same effect and technique may apply to 3D TOF angiography as well.

Acknowledgments
This study was supported by Ministry of Health and Welfare (HMP-98-G7-1-028).

References