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 nulled 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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phy the venous flow is saturated by presaturation RF pulses (Fig. 1). This assumes that the flow direction in vessels is constant during imaging time. However, the velocity variation of the pulsatile arterial flow can be triphasic during a cardiac cycle in some arteries (6). According to a Doppler sonogram of a femoral artery by use of an ultrasound scanner (SonoAce 600C, Medison Co.), the velocity variation is triphasic as seen in Fig. 2. There is a short period of retrograde flow in early diastole.

The arterial blood that flows into the saturation band can flow back into the imaging slice during the phase of retrograde flow in consequent scanning. Since the blood spins in the saturation band are saturated out by presaturation RF pulses, the retrograde flow cannot give the inflow enhancement. If such retrograde flow happens at a time close to the DC point of the phase encoding in Fourier imaging, then the artery will result in a signal void appearing as dark band artifacts. However, when the retrograde flow happens at the scanning for the outside of the central part of k space, the artery could still maintain a signal on a reconstructed image. Since the cardiac cycle is not synchronized with the phase encoding of Fourier imaging in general, the dark band artifacts appear irregularly along the artery.

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-

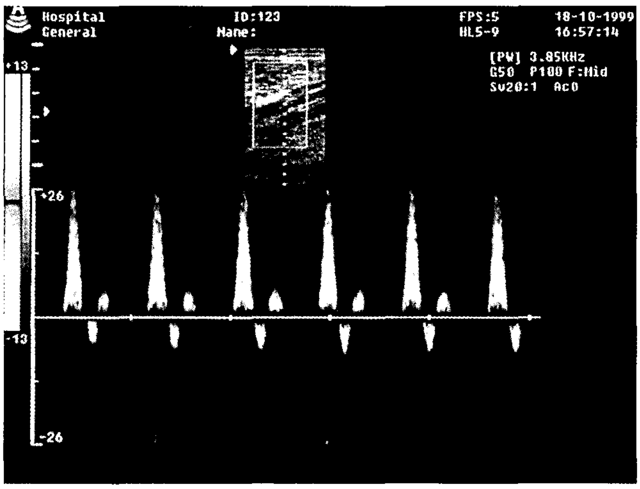
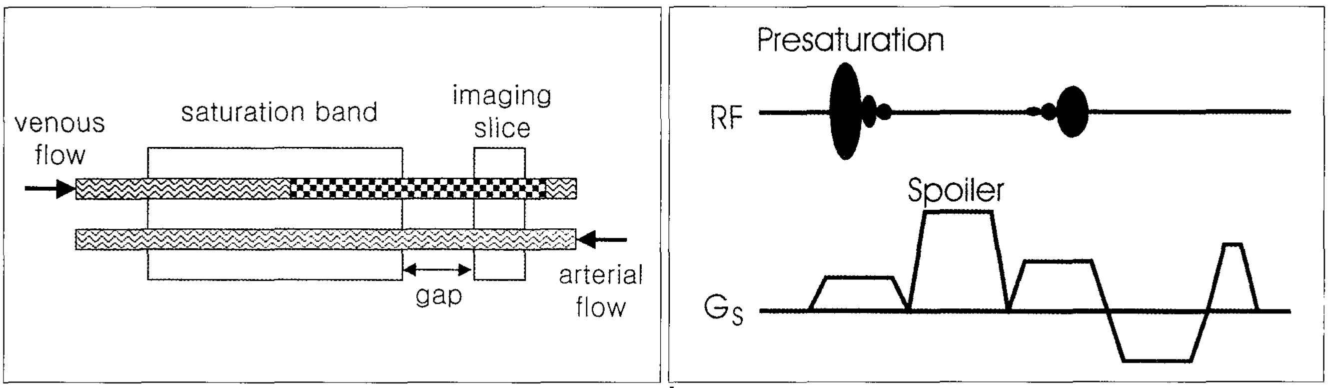


Fig. 2. A doppler sonogram of a femoral artery. The velocity varies in a triphasic pattern during a cardiac cycle.



a **b**

Fig. 1. Presaturation of the vein in 2D TOF angiography for obtaining the artery. (**a**) A relationship of the saturation band to the imaging slice. The venous blood saturated by the presaturation RF pulse, which is marked by a checker pattern, enters into the imaging slice before the excitation RF pulse. (**b**) A part of the pulse sequence. Gs stands for a slice selection gradient.

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.

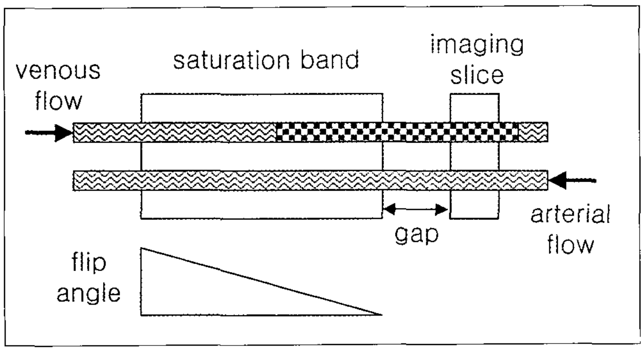


Fig. 3. Presaturation with a ramped profile in 2D TOF angiography.

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

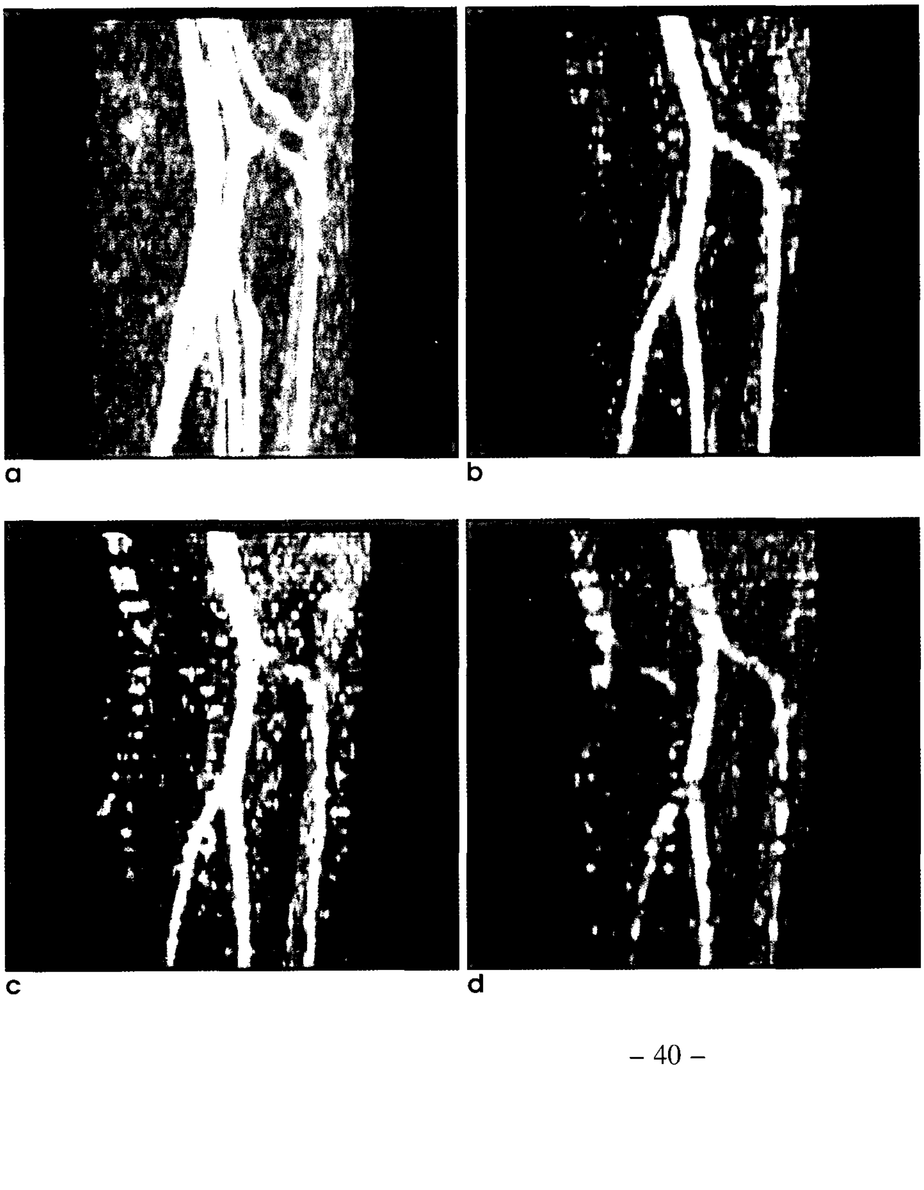


Fig. 4. Angiograms of a femoral artery with different presaturation conditions of a rectangular saturation band: **(a)** without presaturation, **(b)** gap = 15 mm, **(c)** gap = 10 mm, and **(d)** gap = 5 mm.

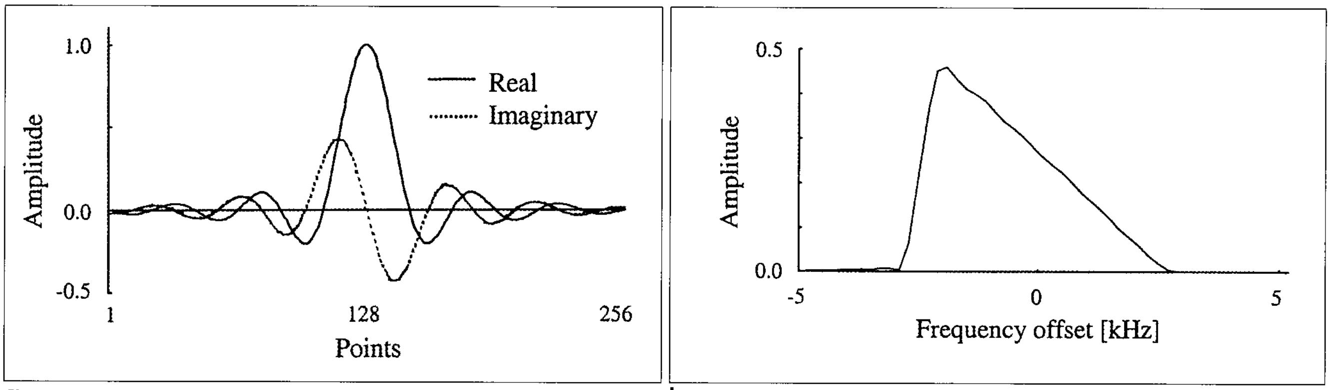
getting more serious as the gap was reduced. These results clearly support the assumption that the dark band artifacts were caused by the retrograde flow in the artery.

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.

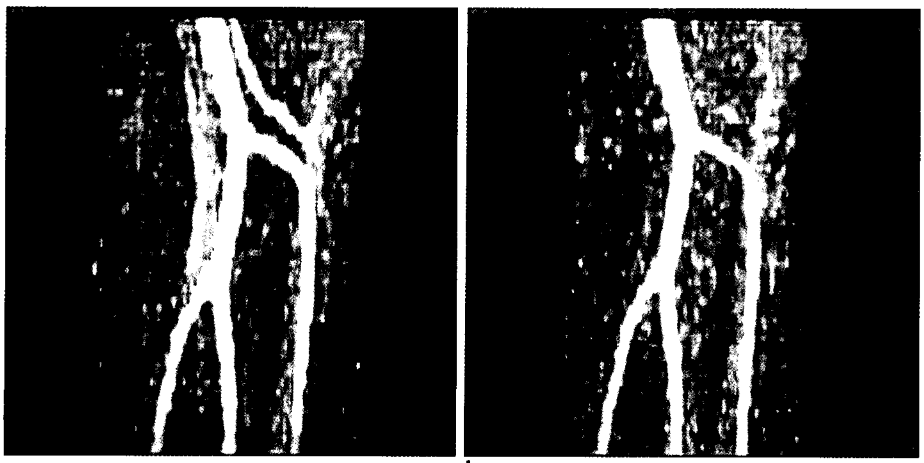
Conclusions

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



a b

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



a b

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

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2D TOF 자기공명 혈관조영술에서 동맥혈류의 역류로 인한 영상훼손과 이의 제거

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2D TOF 혈관조영술에서 presaturation RF 펄스를 사용하여 정맥피에서 나오는 MR 신호를 제거하고 얻은 동맥 angiogram에는 band 형태로 동맥이 끊어져 나타나는 현상이 자주 보인다. 일부 동맥에서 피의 흐름은 한 심장 주기 동안에 3번의 펄스를 갖는데, 이 중 가운데 펄스는 짧은 기간 동안 역류를 한다. 이 역류하는 동맥피는 정맥피와 같은 방향이기 때문에 presaturation RF 펄스에 의해 정맥피 처럼 saturation이 되어서 imaging slice로 흘러 들어가게 될 수 있다. 특히 이러한 경우가 phase encoding step의 dc 부근에서 발생하게 되면 그 때의 단면 영상에서 동맥이 강조가 될 수 없게 되어, 결과적으로 angiogram에는 그 단면을 지나는 동맥의 신호가 없어서 band 형태로 핏줄이 끊어져 나타나게 된다. Imaging slice와 saturation band와의 간격을 변화 시켜 가면서 angiogram을 얻어 봄으로서 이러한 현상을 실험적으로 확인하였다. 나아가 saturation band를 rectangle 형태에서 ramp 형태로 변경함으로써 이러한 artifacts를 제거 할 수 있는 방법을 제시하였다.

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