MR Line Scan Angiography using Spectral Analysis

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Abstracts

In conventional line scan angiography, flow signal has been enhanced by the time_of_flight effect while the signal from stationary tissues has been suppressed by the saturation rf pulse followed by spoiling gradients. Due to the inhomogeneous rf field and the tissue dependent T1 relaxation time, however, stationary tissues can not be suppressed completely or uniformly, and the remnant stationary signal deteriorates the resultant angiogram. Here, the complete cancellation of stationary tissues is made possible by the spectral analysis of a series of repetitive line images of the same slice. The Fourier transformation of a set of line images results in the spectrum images, where stationary tissues are collected into the dc component while arteries are included in harmonic components because of the variation of the flow velocity and the resultant flow signal in arteries according to the cardiac cycle. The summation of harmonic components excluding the dc component results in the angiogram of arteries with the complete cancellation of stationary tissues.

Methods

Line scan imaging is not adequate for the normal slice imaging because it requires the previous setup of the slice. However, it can be used for the projection imaging like the projective angiography because the selected slice or line is projected to the axis of the read gradient. The projected line image is reconstructed by the 1-D Fourier transformation of the acquired projection data of the selected slice and 2-D projection image can be obtained by scanning different slice positions contiguously. Since the line scan imaging does not require the stepping of the phase encoding gradient and the Fourier transformation in the coding direction for the reconstruction, it has no flow artefact which is caused by the pulsatile flow in arteries. Therefore, the line scan imaging does not necessitate the ECG gating and can be used for the region of complicated flow like the heart. The line scan angiography has those advantages of the line scan imaging and will retains its own application area.

In conventional line scan angiography, the contrast between blood vessels and stationary tissues is obtained by the inflow of fresh blood spins after the saturation rf pulses followed by spoiling gradients [1,2]. However, stationary tissues can not be suppressed completely due to the various T1 components and the nonuniformity of the rf field over the excited slice. Also, averaging of several times is necessary to get uniformly connected arteries because the pulsatile flow in arteries can not give the enough flow enhancement when the velocity is too slow.

In the proposed method, multiple projection line images of a slice are acquired consecuitively covering the entire cardiac cycle or the full range of the flow velocity variation in arteries. When a slice is excited by repeating the same pulse sequence with slice selective rf pulses, the NMR signal from blood vessels is enhanced by the inflow of fresh blood spins during the interval between rf pulses while the signal from stationary tissues remains constant at the steady state. The amount of enhancement depends on the inflow rate or flow velocity during the rf interval. Since the flow velocity in arteries varies periodically in synchronization with the cardiac cycle, the signal intensity of arteries is also varied according to the velocity at that interval. Therefore, the pixel value of the i-th line image $f_i(n;x)$ is proportional to the instantaneous velocity $v_i(n;x)$;

$$f_i(n;x) \propto v_i(n;x), \quad n = 0, 1, \ldots, N-1 \qquad (1)$$

If an additional Fourier transformation is applied to N sets of $f_i(n;x)$ in the temporal direction of n, the spectrum images $F_i(k;x)$ of the i-th line are obtained [3];

$$F_i(k;x) = \sum_{n=0}^{N-1} f_i(n;x) \exp(-j\frac{2\pi}{N} nk), \quad k = 0, 1, \ldots, N-1 \qquad (2)$$

where k represents the harmonic component. Arteries are included in harmonic components while stationary tissues as well as vessels with constant velocity are collected into the dc component $F_i(0;x)$. The angiogram $A_i(x)$ of arteries in the i-th line can be obtained by the summation of harmonic components as follows [3];

$$A_i(x) = \sum_{k=1}^{N-1} | F_i(k;x) | \qquad (3)$$

Since the velocity of arteries and the resultant image intensity varies slowly during the cardiac cycle, the summation of just a few lower frequency components of the spectrum images may be satisfactory for the angiogram of that slice. The entire cardiac cycle are sampled for this angiogram, so that there is not the problem of disconnected arteries due to the pulsatile flow as in the conventional methods. Extented angiogram can be obtained by scanning different slice positions.

Experiments and Discussions

A gradient echo pulse sequence with the slice selective rf pulse is used without the stepping of the phase encoding gradient as shown in Fig. 1. For the selected slice, a series of data (N=8 or 16) are acquired after the steady state has been reached by several preceding dummy pulses. A weak projection dephasing gradient $G_C(y)$ is applied in the phase encoding gradient or the projection direction to reduce the huge signal from stationary tissues within the selected slice. The proposed method has been studied for human arteries with KAIS 2.0 Tesla whole body NMR system and usually acceptable angiograms of arteries are obtained with the complete and reliable cancellation of stationary tissues. The angle of the rf pulse was set to 90 degrees in order to get maximum flow signal while minimizing the signal from stationary tissues.

In Fig. 2 the resultant angiogram of arteries for human legs is shown. In this case, 16 samplings of each line were acquired with the repetition time of 100 ms and the slice thickness of 2 mm. By repeating the same sequence for different slices, 90 slices were scanned. From the spectrum images, all the harmonic components except the dc component were added together for the angiogram.

By changing the axis of the slice selection, arteries of any orientation can be detected. The superposition of two angiograms obtained with different axes of the slice selection gradient will be the better angiogram. To reduce the signal dephasing from flowing spins, flow compensated waveform may be used for both the selective and read gradient.

Conclusions

Exploiting the pulsatile nature of arteries, more reliable cancellation of stationary tissues is made possible by applying the Fourier transformation to a series of projected line images of the same slice. However, veins with constant velocity can not be obtained by this method. Since the line scan method does not have the problem of flow artefacts in contrast to the Fourier imaging method, it does not require the ECG gating and has its own application area of imaging the artery around the complicated flow like the heart.

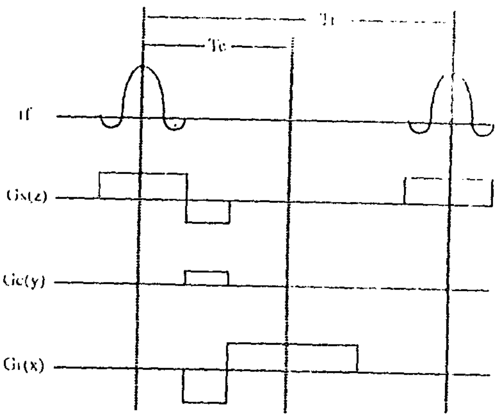

Fig.1 Pulse diagram of the refocused gradient echo sequence with the weak projection dephasing gradient in the projection direction (y) instead of the phase encoding gradient. The sequence is repeated freely regardless of the ECG gating pulse. Tr and Te denote the repetition time and the echo time, respectively.

Fig.2 An angiogram of arteries in human legs synthesized by the summation of harmonic components except the dc component from the spectrum images. The number of scanned slices is 90 with the slice thickness of 2 mm and the horizontal resolution is 0.86 mm.

References

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