A variable TR shells trajectory for better fat suppression in CE-MRA

Y. Shu[1], and M. A. Bernstein[1]

[1]Department of Radiology, Mayo Clinic College of Medicine, Rochester, MN, United States

Introduction A recently-developed 3D, non-Cartesian shells trajectory [1,2] was shown to have improved efficiency compared to Cartesian encoding, have favorable motion correction properties, and to be robust against undersampling artifacts. The center-out shells trajectory offers faster central k-space coverage [1, 3] than elliptical centric view ordering. These properties make the spherical shells trajectory a well-suited tool to contrast-enhanced magnetic resonance angiography (CE-MRA). Contrast enhanced MRA is typically performed with a short TR (2-10ms) for rapid acquisition and to suppress stationary tissue, and with a short TE to minimize T2* effects. Due to gradient hardware constraints, the shells trajectory described in [1-2] was designed with a relatively long readout (512 points in 4 ms), which yields a TR time of 8.5ms. The trajectory samples shells with increasing radii ranging from $0.5\,\Delta k$ to $(N/2)\,\Delta k$, where N is the number of samples in any direction. The spherical shells structure allows flexibility of many pulse sequence designs among all the shells. Each shell can be designed independently of others, so we can vary the readout length of the interleaves on a per-shell basis. For smaller radius shells, the readout length can be reduced without exceeding the slew rate limit. The shorter pre-phasing and re-phasing gradients further decrease the TR. Because the image contrast is dominated by the center of k-space, using shorter TR for the central shells can help to suppress the fat signal. As with spirals, fat suppression is important for shells because off-resonance signal causes image blurring. Due to the gradient hardware limits, the TR and readout time for shells with larger radii remain unchanged. This is illustrated in Fig. 1. The purpose of this work is to 1) demonstrate the feasibility of variable TR shells, and 2) show that can that it can improve fat suppression.

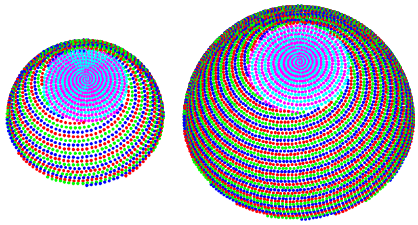

Fig 1. For variable TR, shells with larger radius are sampled with 8.5ms TR, 4ms readout time, while smaller shells at center of k-space are sampled with 5.7ms TR and 2ms readout.

Theory and Methods CE-MRA is commonly acquired with a spoiled gradient echo sequence. The obtained signal intensity can be described in the following equation:

$$S = \frac{M_0 \sin\alpha(1-e^{-TR/T1})}{(1-\cos\alpha\cdot e^{-TR/T1})} e^{-TE/T2^*}$$

, where M_0 is the equilibrium longitudinal magnetization, and α is the flip angle. In Fig. 2, S_{fat} (normalized at TR=8.5) is plotted versus TR for two values of the flip angle. For simplicity, we assume that TE is sufficiently short so that the T2* decay can be neglected. 260ms was used as T1 value of fat .

A phantom consisting of two bottles filled with Gd-DTPA solution (5mM) and vegetable oil, respectively, was imaged with the shells pulse sequences. Two types of shells sequences were used. The standard shells sequence was used as a baseline with a fixed TR = 8.5ms and a 4ms readout. The variable TR sequence has TR=5.7 ms and a 2 ms readout time for shells with radii ranging from $0.5\Delta k$ to $19.5\Delta k$. All the other larger shells use the same TR and readout time as the standard one. An angiography protocol was used, with imaging parameters are summarized in Table 1.

Table 1: imaging parameters for the two shells sequence

	Standard shells	***Variable TR shells***
TR (ms)	8.5	5.7/8.5
Readout (ms)	4	2 or 4
Flip angle (°)	15 or 45	15 or 45
No. Readout Pts.	512	256 or 512
FOV(cm)	24	
Matrix	240×240×240	
Bandwidth (kHz)	±64	
Acq. Time (s)	72	72

Under IRB approved protocol, a healthy volunteer was imaged in the head and neck region with both types of shells sequence. The imaging parameters are the same as used in the phantom study except only 45° flip angle was used. No contrast agent was administered in this experiment.

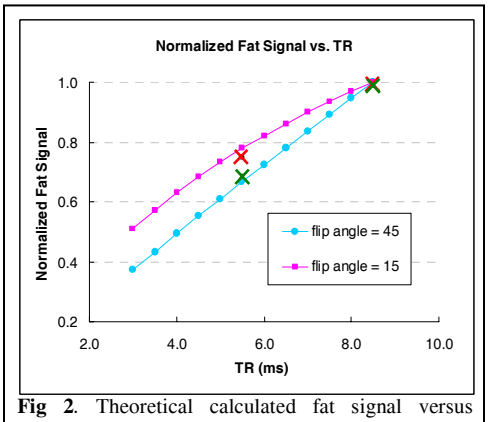

Fig 2. Theoretical calculated fat signal versus various TR time. The phantom experimental results are marked with red and green crosses.

Results The theoretical fat signals versus TR values are normalized and plotted in Fig. 2. The decrease of TR from 8.5ms to 3ms results in a substantial improvement in fat suppression (50% when flip angle is 15° and 60% when flip angle is 45°). In the variable TR shells acquisition, when the center shells are acquired at 5.7ms TR, Eq. [1] predicts that fat signal can be reduced by approximately 30% in both cases. This was verified by the phantom experiment results. The cross-section images of the two bottles are shown in Fig. 3. The signal decrease from the oil bottle with the variable TR shells acquisition can be observed, while the signal from the Gd-DTPA solution was reduced by only 7.3% with the flip angle 15° acquisition due to its short T1 (~40ms).We measured the average fat signal intensity in the ROI (indicated with yellow dotted circle) on ten cross-section images. The measurements are marked by red (flip angle = 15°) and green crosses (flip angle = 45°) in Fig. 2, which fall very close to the theoretical curves. We also measured the fat signal in the images data set acquired on the volunteer. The average improvement in fat suppression was 39%. Because of the absence of contrast agent, the images only contained suppressed tissue signal, so they are omitted here. A line profile was drawn along the axial image near the top of the head. The fat signal around the skull is shown as peak signals in Fig 4. They are better suppressed in variable TR acquisition.

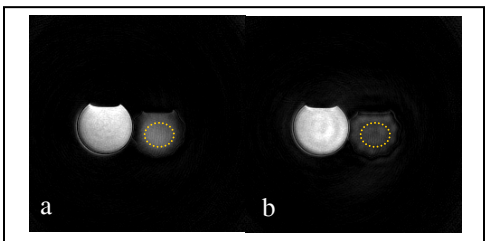

Fig 3. Cross-section images of two bottles filled with Gd-DTPA solution (left) and vegetable oil (right). Only the acquisitions with flip angle at 15° are shown here.

Discussion Feasibility of a variable TR shells pulse sequence has been demonstrated. It has been verified that using a variable TR shells sequence, fat suppression can be improved by approximately 25% compared with the standard shells acquisition. No increase in scan time is required. The technique could benefit shells CE-MRA applications.

Although T2* decay was neglected in the calculation presented in Fig 2, the variable TR technique has a shorter readout (e.g., 2ms vs. 4ms) when sampling the central shells, which should also help to reduce T2* and off-resonant artifacts.

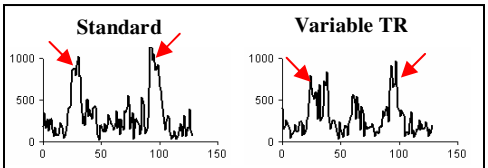

Fig 4. Profile across the skull indicates the reduction of fat signal. The peak signals (red arrows) are from the fat around the skull, which is suppressed better in the variable TR acquisition.

References

1. Shu Y, et al, MRM 2006; 56: 553. 2. Shu Y, et al, MRI 2006; 24: 739. 3. Bernstein MA, et al, MRA Workshop, Basel 2006.