Reduction of Bolus Profile Artifacts in High Resolution Contrast-Enhanced MR Angiography Using CENTRA and SENSE

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Introduction

High resolution 3D contrast-enhanced MR angiography (CE-MRA) is commonly acquired during the first-pass of a T_1-shortening contrast agent bolus. During the acquisition, T_1 and therefore the signal intensity, varies as the bolus passes through the vessel of interest. To allow high spatial resolution acquisitions and suppress venous signal, a centric view order is used.[1] Such a method requires starting the acquisition at the peak of the bolus profile. If the acquisition is started prior to peak arterial enhancement, vessel ringing artifact (aka "too early" artifact) occurs in the MR image.[2]

Randomly segmented central k-space ordering (CENTRA) has been proposed as a method to reduce ringing artifacts in high resolution 3D CE-MRA.[3] CENTRA acquires the central portion of ky-kz space in random order, then acquires the periphery of ky-kz space in elliptical centric order (figure 1). This study evaluates CENTRA encoding for reduction of ringing artifacts in high resolution 3D CE-MRA.

Methods

A 3D CE-MRA acquisition using CENTRA encoding and time-varying bolus profile was modeled in 2D (y,z) using MatLab (The Mathworks, Inc., Natick, MA, USA). The simulated acquisition parameters were: TR=5ms, 400 x 400 x 35 mm^3 volume, matrix 384, 80% scan percentage with elliptical shutter, 35 slices, 1 mm thick. A Fermi filter was used to reduce truncation artifacts. SENSE factors ranged from 1 to 4, and the duration of the randomized encoding window varied from 0 to 10 sec. The time-varying bolus profile was modeled as described by Fain et al.[4], and a range of acquisition start times (8, 6, 4, and 2 sec prior to profile peak) were evaluated. The modeled phantom consisted of 3 vessels of differing diameters (4, 8, and 12 mm). Ringing artifacts were evaluated using a line profile through the vessels in the reconstructed magnitude images, and magnitudes were normalized to the average arterial signal within the reconstruction.

Results

Ringing artifacts were observed in every acquisition triggered prior to the peak of the bolus profile (figure 2). With a short (0-2 sec) central window, ringing was much more pronounced the earlier the scan was triggered. When triggering early (4-8 sec prior to peak), the use of CENTRA reduced the relative intensity of the ringing artifact. The artifact level decreased (up to a point) as the duration of the central window increased (figure 3). Additionally, the artifact level decreased with increasing SENSE acceleration factor (figure 4).

Discussion

While "too early" artifact was reduced by CENTRA encoding, the cost of randomizing the encoding order during the passage of the contrast bolus appeared to be addition of mottled noise throughout the image. In this simulation, the magnitude of mottled noise increased as the duration of the central window increased, however the artifact level stayed well below the magnitude of arterial signal. In addition, increased venous enhancement can occur if the veins begin to enhance during the acquisition of the central window. The desired exclusion of venous signal limits the duration of the central window to 4 to 6 sec in practice. Within this limit, CENTRA effectively reduces ringing artifact with little or no increase in venous enhancement or mottled noise.

The use of SENSE in combination with CENTRA encoding further reduced "too early" artifact for a given bolus profile. SENSE allows more rapid traversal of k-space, by skipping phase encodes, thus increasing the k-space diameter of the central window. Therefore, employing SENSE in combination with CENTRA further reduces arterial ringing while not increasing venous signal, as the central window temporal duration is not altered.

References

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3. Willinek W, et al. Radiology 2002;225:583-588.
4. Fain S, et al. MRM 1999;42:1106-1116.

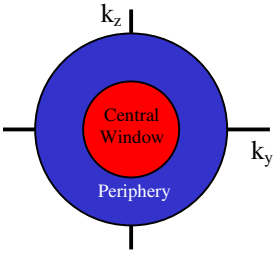

Figure 1. Schematic of CENTRA view order. First, the central window is acquired in random order, then the periphery of k-space is acquired in elliptical centric fashion.

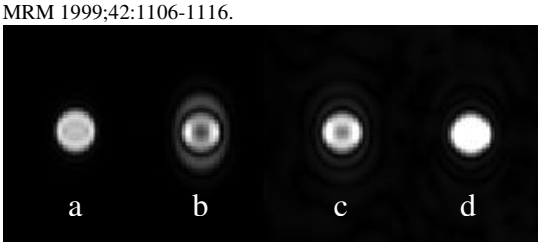

Figure 2. CENTRA model reconstruction of 12 mm vessel with a.) constant bolus profile, b.) 8 sec early trigger with 0 sec central window, c.) 8 sec early trigger with 4 sec central window, and d.) 8 sec early trigger with 8 sec central window. Ringing artifacts due to early triggering are reduced by the random encoding in the central window of the CENTRA acquisition.

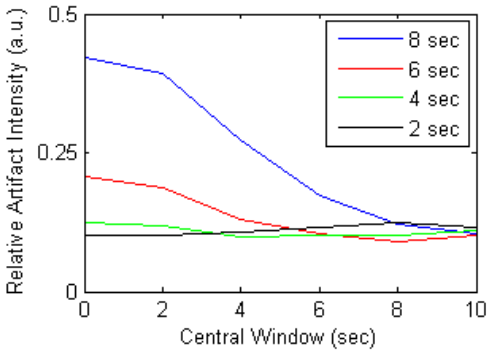

Figure 3. Artifact intensity vs. duration of central window. Each line represents a different acquisition triggering time (2 to 8 sec prior to the bolus profile peak). For early trigger times (4 to 8 sec), artifact levels decreased with larger central window duration.

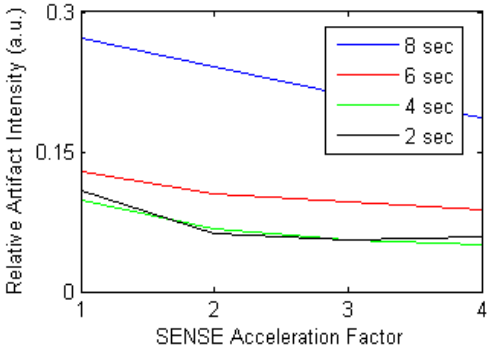

Figure 4. Artifact intensity vs. acceleration factor. Central window duration was set to 4 sec. Each line represents a different acquisition triggering time (2 to 8 sec prior to the bolus profile peak). For a similar bolus profile, ringing artifact levels were reduced with higher SENSE acceleration factors.