Whole-Body Functional CE-MRA to Track the Contrast Bolus with High Temporal Resolution and Real-Time Feedback Controlled Table Motion

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Introduction: A good quality MR angiogram depends upon proper timing of the 3D acquisition with peak concentration of the contrast agent. This is well recognized for single station MRA where a small amount of contrast agent is often used to measure the contrast arrival time at the site of interest. However, this is more complicated for a peripheral vasculature study as the arteries of interest span an extended longitudinal region. Previously a 3D time-resolved imaging technique with continuously moving table (CMT) was developed to observe the leading edge of the contrast bolus in coronal images and to measure the arrival time for the entire peripheral vasculature (1). In those studies, a non-constant bolus velocity along the peripheral vasculature was consistently observed for individual volunteers and highly variable velocities across different volunteers. Hence, to accommodate the non-constant bolus flow on an individual basis, we have developed 3D time-resolved imaging of an extended FOV with CMT in which the table velocity can be varied in real-time to track the leading edge of the contrast bolus. The temporal resolution in this technique was adapted to well under a second to reduce the temporal aliasing effects due to pulsatile flow observed with 2.5 sec time-resolved images.

Methods: *k-space Sampling:* A hybrid elliptical centric (EC) and projection reconstruction (PR) acquisition is used. The phase encoding k_Y-k_Z plane is divided into a central circular region R1 and five outer annular regions R2-R6. The views in the annular regions are further apportioned into multiple radial sectors. During sampling, a quarter of one of the regions R3-R6, half of R2 and all of R1 are sampled for every reconstruction in a manner similar to the TRICKS technique (2). This sampling pattern provides a temporal resolution of 0.6 sec with 128 (N_Y) × 8 (N_Z) phase encodes.

Variable Table Velocity: The k-space sampling is integrated with CMT technique as previously described (1). With the assumption that the table travels exactly one field-of-view (FOV_S) during the time it takes to acquire one complete cycle of phase encoding views, the table velocity (v_t) is given by Eq. [1] (3). Alternatively, the total number of views (N_{total}) can be replaced by the product of the number of views per reconstruction cycle ($N_{views\text{-}recon}$) and the number of updates ($N_{updates}$) that each pixel experiences before moving out of the imaging FOV. $N_{views\text{-}recon}$ was fixed at 128, corresponding to an update interval of 0.6 sec. Due to the inverse relationship between $N_{updates}$ and v_t, by choosing different integer values for $N_{updates}$, corresponding values of v_t are selected as shown in Table 1. Because of the high temporal resolution and real-time reconstruction, the table velocities can be changed at 0.6 sec intervals.

$$v_t = \frac{FOV_S}{N_{total} \cdot TR} = \frac{FOV_S}{N_{views\_recon} \cdot N_{updates} \cdot TR} \rightarrow [1]$$

Table. 1

FOV_S = 40 cm, TR = 4.8 msec	
$N_{views\text{-}recon}$ = 128, $N_{updates}$ = 16	
$N_{updates}$	table velocity (cm/sec)
11	5.92
12	5.43
13	5.01
14	4.65
16	4.07
18	3.62
21	3.10
24	2.71
26	2.50
32	2.03

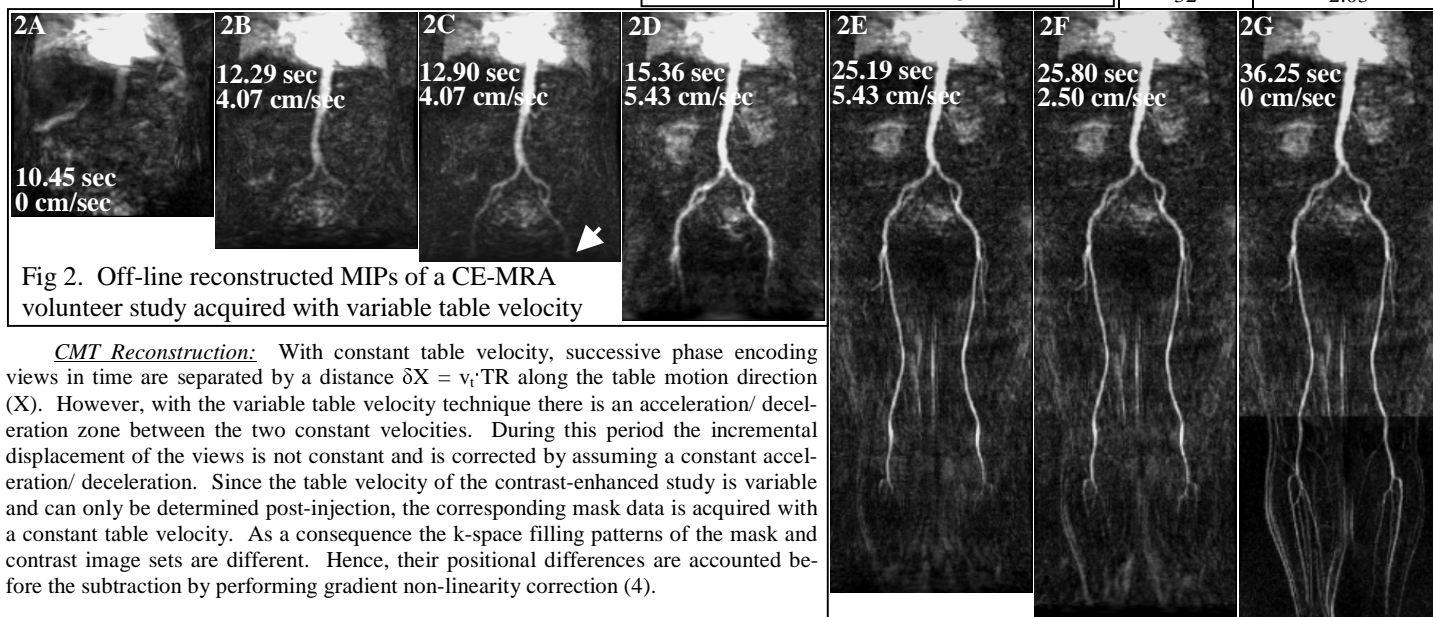Fig 2. Off-line reconstructed MIPs of a CE-MRA volunteer study acquired with variable table velocity

CMT Reconstruction: With constant table velocity, successive phase encoding views in time are separated by a distance $\delta X = v_t \cdot TR$ along the table motion direction (X). However, with the variable table velocity technique there is an acceleration/ deceleration zone between the two constant velocities. During this period the incremental displacement of the views is not constant and is corrected by assuming a constant acceleration/ deceleration. Since the table velocity of the contrast-enhanced study is variable and can only be determined post-injection, the corresponding mask data is acquired with a constant table velocity. As a consequence the k-space filling patterns of the mask and contrast image sets are different. Hence, their positional differences are accounted before the subtraction by performing gradient non-linearity correction (4).

Results: Fig. 2 shows the maximum intensity projections (MIPs) of a volunteer study acquired with variable table velocity technique. The post-injection times and the corresponding table velocities are shown on the images. Fig. 2A is the stationary image used to fluoroscopically trigger the table motion. Figs. 2B-2C are the images acquired with the initial table velocity of 4.07 cm/sec. Since the leading edge of the bolus was closer to the lower (leading) edge of the FOV (arrow in Fig. 2C), the table velocity was increased to 5.43 cm/sec. Figs. 2D-2E were acquired with this increased table velocity. Later as the bolus velocity decreased in the distal stations, the table velocity was decreased to 2.50 cm/sec and Fig. 2F was acquired at this velocity. Fig. 2G shows an image acquired after the table was stopped at the distal-most position.

Discussion: We have demonstrated time-resolved 3D imaging of an extended FOV during continuous table motion with real-time, dynamic control of table velocity. The temporal resolution was reduced to 0.6 sec to reduce the temporal aliasing effects due to pulsatile flow. In addition to accurately tracking bolus transit, this technique can be used in other real-time applications such as following a catheter over an extended FOV in interventional MRI.

References: [1] Madhuranthakam AJ, MRM 51:568 (2004). [2] Korosec FR, MRM 36:345 (1996). [3] Kruger DG, MRM 47:224 (2002). [4] Polzin JA, MRM 52:181 (2004).