Rotational Projection Contrast-Enhanced MR Angiography

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Introduction

Elliptical centric-ordered 3D contrast-enhanced MRA (1) provides good venous suppression and SNR for first-pass imaging provided the timing of the contrast agent is accurate. To avoid the difficulties associated with contrast timing in some specific situations, such as the imaging of lower legs, TRICKS acquisitions (2) update low spatial frequency data at a high temporal rate (~4s/3D data set in PR-TRICKS (3)). High spatial frequency data acquired later at the steady state are added back in image reconstruction. This keyhole technique provides high temporal 3D data sets with acceptable high-frequency artifacts. If true high-spatial-resolution is desired, 2D projection imaging with complex subtraction (4) or polar encoded 3D imaging (5) is able to provide sub-mm in-plane spatial resolution at a high temporal rate. Vessel-overlapping issues can be overcome by performing projections from multiple angles (5,6). Rotational projection imaging provides a new way for real-time monitoring of the dynamic changes of 3D objects with high spatial resolution. Preliminary results of phantom and volunteer studies are discussed.

Methods

The phantom study demonstrates the feasibility of rotational projection imaging in acquiring sub-millimeter in-plane resolution at sub-second temporal resolution with 3D information. Omniscan (Nycomed) was injected at approximately 0.3 ml/s into a 1mm diameter plastic tube (flow rate ~40 cm/s) which was wound to form a 3D structure. Projection images were acquired by a modified 2D SPGR sequence (GE 3.0T Signa), head coil, FOV=40x20cm, 512x128 matrix (zero-padded to 512x256), TR=4.9ms, flip angle=30°, BW 125KHz, 0.6 s/frame. The slice encoding gradient was set to zero so all spins were excited. 64 projections were collected over 180^o in an interleaved fashion of 16 projections per round (every 11.25^o).

The volunteer study demonstrates the polar phase-encoded 3D version of rotational projection imaging (5). Due to the relatively slow flow in legs, a temporal resolution of 4 s is generally adequate. Therefore 6 phase-encoding steps were used in the projection dimension to more efficiently acquire data for 3D reconstruction at 4 s/angle interval. Data from three volunteers were acquired on a 1.5 T Signa TwinSpeed scanner (GE Medical Systems, Milwaukee, WI). After informed consent, 20 ml of contrast agent was intravenously administered. A 3D fast SPGR sequence was utilized with TR=3.4ms, 256x176x6 matrix, FOV =24x16x24 cm, 32 projection angles. Complex subtraction was used to suppress background signals. An off-line gridding reconstruction algorithm was used to perform the projection, MIP and 3D sliding window reconstruction. The off-center k-space lines can also be used to independently reconstruct projection images due to the insignificant dephasing of arterial signals. Therefore 2D projection images were reconstructed every 0.6 s, MIP of 6 PE every 4 s, and 3D data by sliding window every 4 s.

Results

With the sub-second temporal resolution and sub-mm spatial resolution, the dynamic contrast distribution in the phantom is clearly visualized (Fig.1. a-e). The overlap of the tubes in a single projection image makes it very hard to separate them. However, by viewing the projections acquired at different angles (f-h), the 3D structural information can be perceived. Fig. 2 shows the results of one volunteer study. 5 MIP images at angles 5^o apart were shown. The enhancement of the popliteal trifurcation was captured every 4 seconds at succeeding angles. The sub-millimeter in-plane resolution can be appreciated for successfully depicting the small arteries.

Discussion and Conclusion

Acquiring a few phase-encoding steps in the projection dimension can yield the same temporal resolution for projection images as in 2D rotational projection. Phase encoding is also more efficient for 3D reconstruction since it reduces the over-sampling of the center of k-space. However, dephasing will be an issue with more encoding steps. The advantage of 2D rotational projection is that it is more continuous when viewing the projections from different angles.

The challenge in rotational projection imaging is to develop algorithms to weight the projections at different angles to suppress venous signals in 3D reconstruction. Furthermore, if the fully reconstructed 3D data can be used as a priori knowledge, 3D data sets may be reconstructed from only a limited number of projections to improve the temporal resolution of 3D information. These will be investigated in future studies.

In conclusion, rotational projection provides a new way in imaging dynamic 3D objects with both high spatial resolution and high temporal resolution.

References

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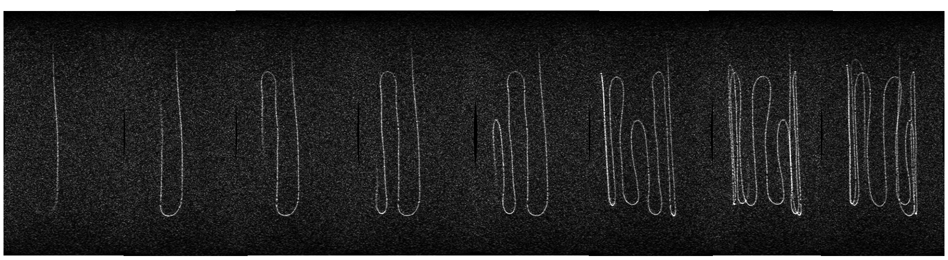

a. 0.6s, 0^o b. 1.3s, 11^o c. 1.9s, 23^o d. 2.5s, 34^o e. 3.1s, 45^o f. 6.3s, 101^o g. 8.2s, 135^o h. 10.0s, 169^o

Figure 1. Temporal data (0.6s/frame) of a 1mm diameter circuitous tube phantom. Gd was injected at approximately 0.3ml/s to create a flow rate about 40 cm/s. Sub-second temporal resolution and sub-mm spatial resolution were applied to dynamically monitor the flow. 64 projections were collected (2.8^o apart) in an interleaved fashion of 16 projections per round (every 11.25^o). 8 projections from the first 180^o were shown. The overlapping of the tubes can be distinguished by viewing the projections at different angles.

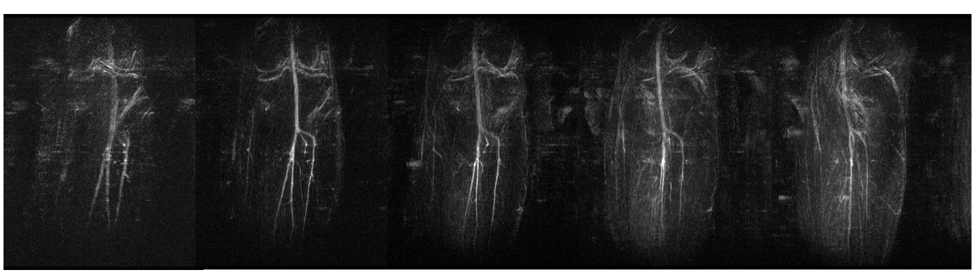

Figure 2. Volunteer data of polar-encoded 3D MRA. 6 phase-encoding steps were used to match the temporal resolution of 4 s/projection. 32 projections were collected over 180^o. 5 MIP images at angles 5^o apart are shown. The enhancement of the popliteal trifurcation was captured every 4 seconds at succeeding angles. The sub-millimeter in-plane resolution can be appreciated for successfully depicting the small arteries.