Prospects for Acceleration and Dose Reduction in Selected MR and X-ray CT Cardiovascular Applications

C. A. Mistretta[1]

[1]University of Wisconsin, Madison, Wisconsin, United States

X-ray computed tomography and MR both enjoy a wide range of applications in the heart and vascular system. Although X-ray CT is widely agreed to be in the lead for the purpose of imaging coronary arteries due to its greater spatial resolution, MR is highly versatile and provides complementary information on cardiac function and perfusion and provides the opportunity for measurement of flow dynamics and pressure gradients as well as providing spectroscopic information. The relative merits of CT and MR will evolve as various techniques are developed to alter the SNR, spatial and temporal resolution, X-ray dose and contrast requirements of the two techniques.

In recent years there has been significant progress in the acceleration of image acquisition in CT through use of multi-detector systems. This will continue as larger detector arrays, cone beam geometries, and multiple source systems are introduced. In MR, significant improvements in coil design improve SNR and parallel imaging continues to provide useful increases in imaging speed by permitting the undersampling of k-space. In an alternative approach to achieving high acceleration factors, highly undersampled radial sampling has led to typical acceleration factors of 30 relative to complete Cartesian sampling [1].

Recently, it has been emphasized that, in the case of MR time–resolved imaging, the time frames contain highly correlated k-space data that need not be redundantly collected [2,3,4]. In his ISMRM plenary lecture [5] Jurgen Hennig discussed a limiting case in which the temporal variations in an image were spatially isotropic. In this limit, knowing the spatial distribution of signals, the temporal modulation of time frames can be completely reconstructed through measurement of a single central k-space point. This represents an effective violation of the Nyquist theorem by a factor of n^3. Within the context of undersampled radial acquisition, one might wonder how many projections must be measured per time frame to characterize the temporal behavior for the case where this behavior is spatially heterogeneous. In the recently introduced HYPR (HiglY constrained backPRojection) algorithm, it has been possible to characterizing this behavior with surprisingly few projections [6]. Using a composite image formed from all projections acquired in a series of time frames with interleaved projections, it has been possible to achieve acceleration factors typically ranging from 10 to 400 in selected MR applications. A surprising property of the method is that the SNR of individual time frames is proportional to the square root of the entire scan duration rather than individual frame times. Achievable acceleration factors depend on the sparsity of the data set and the extent of the deviation from the Hennig limit. In some cases dynamic composite images from a time window less than the entire scan must be used to maintain waveform fidelity, thus reducing the SNR gain.

Several simulations and in-vivo examinations have been carried out to test this combination of undersampled projection acquisition and the avoidance of redundant data acquisition. In peripheral MR angiography, applying HYPR to PR TRICKS [7], acceleration factors of 150 relative to non-accelerated Cartesian acquisition have been achieved. Using contrast enhanced HYPR VIPR, acceleration factors of 320 have been achieved. The method appears to be extendable to MR spectroscopy, diffusion tensor imaging, breast and cardiac perfusion, fmri, and X-ray CT. In the latter, simulations based on decimation of in-vivo data suggest significant dose reductions in X-ray perfusion CT.

In summary, we believe that new acceleration techniques that are becoming available for use in both CT and MR make it difficult to predict which modality will eventually dominate and, as usually occurs, there will be areas in which each will have valuable information to offer.

References

1. Barger AV et al., Time-Resolved Contrast-Enhanced Imaging with Isotropic Resolution and Broad Coverage Using an Undersampled 3D Projection Trajectory, Magn Reson Med., 2002; 48: 297-305.
2. Tsao J., Boesinger P. and Pruessman KP, k-t BLAST and k-t Sense: Dynamic MRI with High Frame Rate Exploiting Spatiotemporal Correlations, Magn Reson Med. 2003; 50 (5):1031-43..
3. Hansen M.S., Tsao J., Kozerke S., and Eggers H., k-t BLAST reconstruction from arbitrary k-t sampling: application to dynamic radial imaging, Abstract 684, 2005; ISMRM, Miami Florida.
4. Huang Y., Gurr D., and Wright G., Time-Resolved 3D MR Angiography by Interleaved Biplane Projections, , accepted for publication, Magn Reson Med.
5. Hennig J. Plenary Lecture, Fast Imaging Horizons in Rapid MR Imaging, ISMRM 2005.
6. Mistretta CA et al.,Highly Constrained Backprojection for Time-Resolved MRI, accepted for publication, Magn Reson Med.
7. Vigen KK, et al., Undersampled projection-reconstruction imaging for time-resolved contrast-enhanced imaging. Magn. Reson. Med. 2000; 43:170-176.