Final Progress Report
Real-time 3D MR Thermometry for Focused Ultrasound Surgery

The specific aims of this project were the following:

1. Develop a 3D thermometry method based on spiral-in-out k-space scanning.

2. Develop an accelerated 3D thermometry method based on the Kalman filter.

3. Develop real-time reconstruction and display of the 3D temperature maps acquired using the methods of Aims 1 and 2.

Overall, we achieved these aims during this project. Retraced spiral-in/out 3D thermometry results in minimal blurring of the hot spot. Conventional low-bandwidth 2D Cartesian images show substantial shift of the hot spot, whereas 3D spiral images show no shift. The 3D spiral-in/out sequences were able to dynamically resolve the hot spot and matched the quantitative temperature measurements obtained from the standard 2D Cartesian sequence. In vivo, the 3D spiral sequence allows 4-dimensional monitoring of thermometry, with an update time of 7.7 seconds without Kalman acceleration. The Kalman acceleration provides a method for accelerating the spiral scans further by a factor of 2-4. In phantom studies, Kalman acceleration results in good aliasing artifact suppression and better temporal fidelity than conventional view sharing methods. The Kalman acceleration method does not require separate training scans, because it adaptively trains its parameters.

These methods warrant further study. Retraced spiral-in/out 3D thermometry has substantial speed advantages over conventional Cartesian methods and provides more accurate hot spot localization. Initial in vivo studies show reasonably good precision and accuracy, but further improvement in precision is needed. The initial studies were performed using body coil reception, so that the signal-to-noise ratio in vivo was suboptimal. Initial experiments with a surface coil have yielded substantially improved SNR and higher precision than with conventional techniques; this should be validated in a larger in vivo study. 3D thermometry thus provides strong motivation for developing a human head coil compatible with the transducer. The temporal resolution of the 3D spiral thermometry method needs to be improved by a factor of 3-4. We have demonstrated this amount of acceleration using the Kalman filter in phantom studies. Future studies are needed to validate this combination in vivo. When combined with surface coil or head coil reception, the combined method should meet or exceed all of the desired specifications for treatment monitoring.

Publications resulting from this project to date

1. Fielden S, Zhao L, Miller G, Feng X, Wintermark M, Butts Pauly K, Meyer C. Accelerating 3D spiral MR thermometry with the Kalman filter. Proceedings of the International Society of Magnetic Resonance in Medicine, Milan, Italy; 2014. p. 2346.
2. Fielden S, Zhao L, Miller G, Feng X, Wintermark M, Butts Pauly K, Meyer C. Spiral-based 3D MR thermometry. 4th International Symposium on Focused Ultrasound, Bethesda, MD; 2014. P117-BR.

3. Zhao L, Fielden S, Miller G, Feng X, Wintermark M, Butts Pauly K, Meyer C. Accelerated MR thermometry using the Kalman filter. 4th International Symposium on Focused Ultrasound, Bethesda, MD; 2014. P139-BR.
4. Fielden S, Feng X, Miller W, Pauly KB, Meyer C. Real-time 3D spiral MR thermometry. Proceedings of the International Society for Magnetic Resonance in Medicine, 2015, p. 1631.
5. Fielden S, Mugler JP III, Miller W, Pauly KB, and Meyer C. Detecting signal changes in heated bone with a 3D spiral ultra-short echo time sequences. Proceedings of the International Society for Magnetic Resonance in Medicine, 2015, p. 1632.

Patent application resulting from this project

C.H. Meyer, S.W. Fielden, L. Zhao, G.W Miller, M. Wintermark, KB Pauly. "Systems and Methods for Accelerated MR Thermometry." U.S. Patent Application Serial No. 14/677915. April 2, 2015.