# The Effects of Spatial Sampling Choices on MR Temperature Measurements

**N. Todd[1], J. De Bever[2], U. Vyas[3], A. Payne[4], and D. L. Parker[5]**
[1]Physics, University of Utah, Salt Lake City, UT, United States, [2]Robotics, University of Utah, Salt Lake City, UT, United States, [3]Bioengineering, University of Utah, Salt Lake City, UT, United States, [4]Mechanical Engineering, University of Utah, Salt Lake City, UT, United States, [5]Radiology, University of Utah, Salt Lake City, UT, United States

## INTRODUCTION:

MR temperature maps are necessarily a discrete representation of a physical quantity that is continuously varying in both space and time. Because thermal dose is a highly non-linear function of temperature, it is crucial that the measured temperature accurately reflect the underlying temperature distribution. In many acquisition techniques, the HIFU focal spot size is smaller than the voxel dimensions and there should be concern over the effect the relatively large voxel dimensions will have on the accuracy of temperature measurements. Due to averaging effects, it is likely that different choices for the sampling grid location, voxel size, and scan time will lead to variations in the measured temperature distribution. In this abstract we present simulation and experimental results quantifying the effects of the sampling scheme on maximum temperature and thermal dose, and show the effects of zero-filled-interpolation (ZFI) post-processing on the measured maximum temperature and thermal dose.

## METHODS:

*Simulations.* An ultrasound power deposition matrix with 0.1 $mm^3$ isotropic spatial resolution was created based on the geometry of a 256-element phased array ultrasound transducer and 100 W of electrical power[1]. This matrix was used in the Pennes bioheat equation[2] (thermal conductivity 0.47 W/m/°C, no perfusion) to produce 0.1 $mm^3$ temperature maps over 15 seconds of heating and 5 seconds of cooling. Complex k-space data was created assuming constant image magnitude over the region of interest and using the temperature maps for the image phase. Temperature maps of varying sampling grid location and spatial resolution were created by truncating the original k-space to a smaller matrix size and applying varying linear phases across the three k-space directions. The maximum temperature and total thermal dose were calculated.

*Experiments*. HIFU heating was performed on an agar phantom (50 W for 30 sec) and monitored with a 3-D segmented EPI gradient echo sequence at 2.0 $mm^3$ isotropic spatial resolution and 4.4 sec/scan temporal resolution. The original k-space was post-processed in two ways: applying different linear phases across all 3 directions to shift the sampling grid by varying amounts; and zero-filling the data to 2 and 3 times its original size to create images with 1.0 $mm^3$ and 0.67 $mm^3$ voxel spacing. Temperature maps were created from the manipulated k-space data sets and the maximum temperature and total thermal dose were calculated.

## RESULTS:

*Simulations.* The 0.1 $mm^3$ simulated temperatures had a maximum temperature rise of 23.3°C, the volume dosed to 30 CEM or greater ($V_{D30}$) was 30.2 $mm^3$, and the volume dosed to 240 CEM or greater ($V_{D240}$) was 10.8 $mm^3$. For simulated temperature maps averaged to 1.0 $mm^3$ and 2.0 $mm^3$ resolution, the location of the sampling grid had a significant impact on the measured maximum temperature and accumulated thermal dose. The ranges of values over all sampling grid locations are reported in Table 1.

| | Max Temp | 30CEM Volume | 240CEM Volume |
|---|---|---|---|
| Simulation, 1.0$mm^3$ | 20.3 – 23.3°C | 30 – 97 $mm^3$ | 10 - 35 $mm^3$ |
| Simulation, 2.0$mm^3$ | 14.0 – 20.6°C | 0 – 48 $mm^3$ | 0 – 24 $mm^3$ |
| Experiment, 2.0$mm^3$ | 15.9°C – 23.1°C | 40 – 96 $mm^3$ | 8 – 32 $mm^3$ |

**Table 1.** Range of max temps and dosed volumes for all sampling grid locations.

Three results for maximum temperature as a function of voxel size are shown in Fig 1: a 3D sampling scheme where the voxels were isotropic (green line) and two 2D schemes with 2.0 $mm^2$ in-plane resolution and variably thick slices that were oriented perpendicular (blue line) and parallel (red line) to the path of the ultrasound beam.

*Experiment*. The original 3D 2.0 $mm^3$ temperature maps reconstructed with no k-space processing had a maximum temperature of 17.6°C, $V_{D30}$ was 72 $mm^3$, and $V_{D240}$ was 16 $mm^3$. The effects of shifting the sampling grid are summarized in Table 1 and three example temperature maps are shown in Fig 2. Zero-filled interpolation to 1.0 $mm^3$ and 0.67 $mm^3$ voxel spacing increased the maximum temperature to 23.0°C and 22.9°C, respectively (Fig 3). For the 1.0 $mm^3$ voxel temperatures, $V_{D30}$ was 64 $mm^3$ and $V_{D240}$ was 28 $mm^3$, while for the 0.67 $mm^3$ voxel temperatures, $V_{D30}$ was 62 $mm^3$ and $V_{D240}$ was 28 $mm^3$.

## DISCUSSION:

When doing MR thermometry, the sampling grid location and voxel size have a significant impact on how the underlying temperature distribution is measured, effecting important metrics such as maximum temperature and thermal dose. Simple k-space post-processing techniques such as ZFI can mitigate these effects, making results more uniform across experiments.

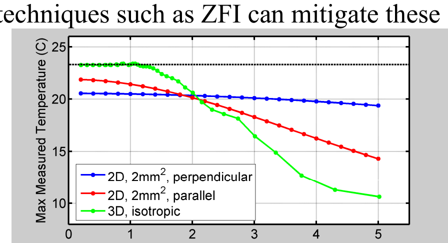


**Fig 1.** Simulation results. Maximum temperature as a function of voxel size. 3D temps are isotropic, 2D temps have variable slice thickness with the slices oriented parallel and perpendicular to the path of the beam.

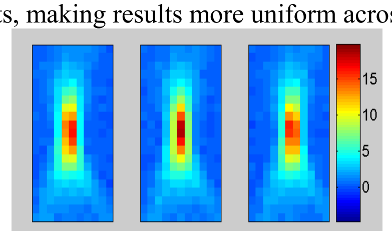


**Fig 2.** Experimental results. Different linear phases applied across $k_x$ shift the sampling grid in the left/right direction. 3 examples, max temps of 17.4°C, 19.3°C, and 15.9°C.

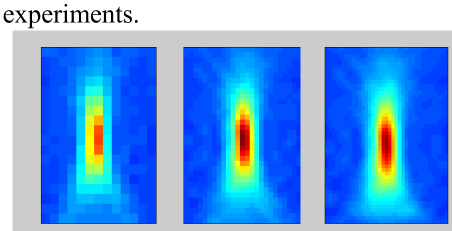


**Fig 3.** Experimental results. Temperature maps reconstructed with zero-filling to create 2$mm^3$, 1$mm^3$ and 0.66$mm^3$ voxels. Maximum temperatures of 17.6°, 23.0°, and 22.9°, respectively.

**REFERENCES:** 1. U Vyas, IEEE Proc. Eng and Med/Bio; 2008: 2526-2529 2. H Pennes, Appl Physiol 1948;1(2):93-122 3. DL Parker, MRM 33:156-162 (1995)
**ACKNOWLEDGEMENTS**: This work was supported by The Margolis Foundation, Siemens Medical Solutions, NIH grants F31 EB007892-01A1, R01 CA87785, and R01 CA134599.