Comparison of 3D UTE- and CT-Based Phase Aberration Correction for Transcranial MR-Guided Focused Ultrasound Surgery

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Target audience: The target audience for this abstract is groups working on transcranial MR-guided Focused Ultrasound Surgery (tcMRgFUS) treatments of the brain.

Purpose: In tcMRgFUS treatments, a high intensity ultrasound transducer is used to create a region of necrosis at a focal location in the brain. Variations in the shape, thickness and density of the calvarium can cause aberrations in the location and shape of the beam's focus. CT imaging is currently used clinically to correct for these aberrations[1]. In this work, we assess the utility of ultra-short echo time (UTE) imaging for tcMRgFUS in the brain, specifically using rapid automatic segmentation of cranial contours to provide phase-aberration correction information for tcMRgFUS planning and correction. We compare these phase aberrations with those predicted using CT imaging.

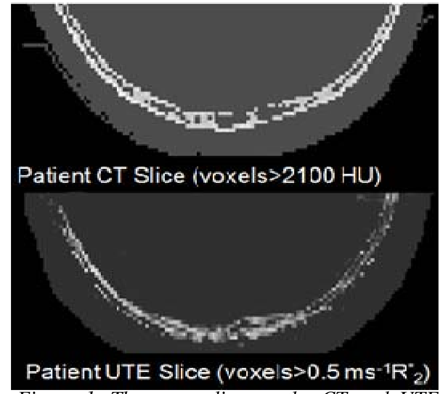

Figure 1. The same slice on the CT and UTE images is shown depicting similar bone contours.

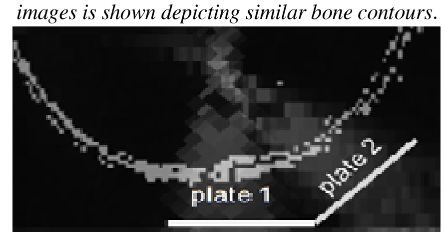

Figure 2. Figures overlays the extend of the ultrasound beam from plates 1 and 2 in water. The two plates were simulated with both the CT and UTE bone contours and aberrations were

Methods: In one patient to be treated with the InSightec ExAbalate 4000 650 kHz brain system on a 3T GE scanner, both a CT and a UTE scan were obtained, neither with immobilization of the head. A 3D UTE pulse sequence acquired four echoes at 0.042ms, 1.442ms, 2.242ms, and 3.642ms. The imaging parameters were 28 cm x 28 cm x 39.2 cm FOV, 1.1mm isotropic resolution, 18˚ flip angle, 125 kHz BW, 8ms TR and 7.5 min. scan time, with flip angle chosen to maximize signal from cortical bone. R2* maps were obtained from the first two echoes. K-means clustering used the intensity evolution of each voxel in the 4 echoes to separate out the tissue (e.g., fat) that had short T2 in the first two echoes but had increased signal in the later two echoes. Region growing and thresholding algorithms were used to create an air mask to remove voxels from outside the head. The subsequent R2* map was converted to a bone contour map, with voxels with an $R2^* > 0.5 ms^{-1}$ considered as bone.[2] The CT scan of the patient was similarly converted to a bone contour map, with voxels with HU>2100HU considered as bone. Both bone contour maps (shown in Figure 1) were used in the hybrid angular spectrum method[3] to predict the effect of the skull on the focal spot, with acoustic properties of bone (speed of sound =3200 m/s, attenuation= 0 Np/cm, density =1930 kg/m^3). Simulating two plates (out of the 6, 4 plates were not simulated due to patient tremor motion) of the transducer, phase aberrations were predicted for the full CT model. In a subsequent simulation, these aberrations were corrected with the terms found from the cortical bone only CT and UTE models. For these two cases, the intensity, shape, and location of the focal zone were predicted.

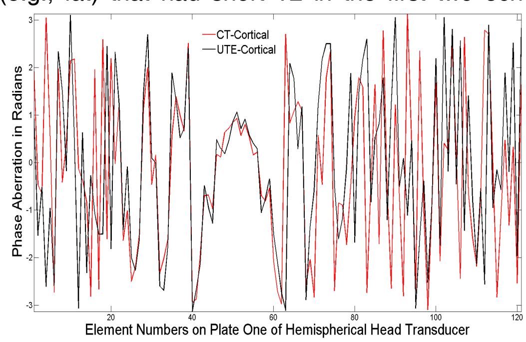

Figure 3. Comparison of phase aberrations predicted for elements of plate 1 using CT (cortical only) model (red) and the UTE model (black)

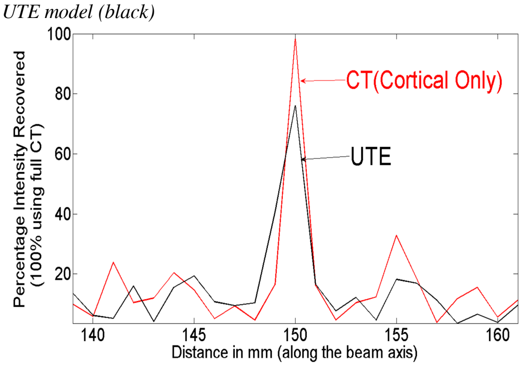

Figure 4. Intensity at the focal zone recovered after correcting aberrations derived using CT (cortical only) (red) model and UTE model (black) for both plate 1 and plate 2.

Table 1. Acoustic Properties for Full CT Model[4]

Tissue Classification	Speed of Sound m/s	Density Kg/m^3
1500<HU<2100	2423	1300
2100<HU	3200	1930

Results and Discussion: Figure 1 demonstrates the similarity between the high-density bone contours from the CT scan and the bone contours from the UTE. Figure 3 compares the phase aberrations (of elements on plate 1) that were predicted using the CT and UTE bone contours. Figure 4 demonstrates that the cortical bone only CT model recovers 98% of the intensity and UTE recovers 75% of the intensity (neglecting losses due to attenuation). Future work will include using the entire dynamic range of the CT and UTE data, rather than thresholded bone values used here.

Conclusion: We show that in brain treatments where the localization of energy is important, UTE images result in recovering 75% of the intensity lost due to phase aberration caused by the calvarium.

Acknowledgements: FUS Foundation, P01 CA159992, Stanford Neuroventures **References:** **[1]** Elias, N. Engl. J. Med., vol. 369, no. 7, pp. 640–648, 2013. **[2]** Keereman, J. Nucl. Med., vol. 51, no. 5, pp. 812–818, May 2010. **[3]** Vyas, IEEE Trans. Ultrason. Ferroelectr. Freq. Control, vol. 59, no. 6, pp. 1093 –1100, Jun. 2012.**[4]** Fairchild, *J. Acoust. Soc. Am.*, vol. 105, no. 2, pp. 1324–1324, 1999.