Effect of additional anatomical features of the head from high resolution 3D UTE images on focal intensity and location for Transcranial MR-guided Focused Ultrasound Surgery

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Target audience: 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 the focal location in the brain. CT imaging is currently used to correct for variations in the location and shape of the beam's focus due to the spatial heterogeneities of the calvarium[1]. Due to the minimal soft tissue contrast in CT images and lack of patient-specific tissue acoustic property values for additional anatomical features in the head, only the effect of the calvarium has been included when correcting for phase aberrations[1]. In this work, we use an ultrashort TE (UTE) sequence to segment anatomical features in the head such as skin, galea aponeurotica, subcutaneous fat, and bone marrow in addition to the cranium. This tissue model is input into a 3D ultrasound beam propagation technique; we study the effect of these additional features on the beam's focal quality. This work will provide a framework to a) assess the effect of additional anatomical structures at the focus, and b) determine patient-specific tissue acoustic properties using UTE images.

Methods: A 3D UTE pulse sequence acquired three echoes at 0.068ms, 1.788ms, and 3.348ms on a 1.5T GE scanner. The imaging parameters were 23.6 cm FOV, 1mm isotropic resolution, $10°$ flip angle, 125kHz BW, 8ms TR and 10.6min scan time, with flip angle chosen for maximum signal from cortical bone. A clustering algorithm[2] was used to create a tissue model; different tissue regions were established using the intensity decay profiles of the voxels over the three echo times. The centers of the clusters for the segmentation, denoting individual tissue types, were set manually. A segmented model with six tissue types is shown in Fig 1. The hybrid angular spectrum beam propagation routine[3], modeling the effect of reflection, refraction and attenuation of the ultrasound beam, was used to study the effect of these tissue types on the focal zone. The InSightec ExAbalate 4000 hemispherical transducer, with 1024-elements at 650 kHz (used for clinical tcMRgFUS treatments) was simulated.

Results: Longitudinal (on-axis, along the beam direction) pressure profiles through the center of the focus are shown in Fig 3. The effect of the tissue specificity is seen when comparing homogenous paths to that using all the segmented tissues (excluding the skull). The results shown in Fig 3 show a 2mm change in the on-axis location of the focus and a 20% decrease in the focal intensity compared to the homogenous tissue focal zone.

Discussion: In brain treatments where the localization of the energy is important, such a shift in the focal zone location and loss of energy could affect treatment. For future work, we will develop techniques to determine patient-specific tissue acoustic properties using image parameters from UTE images, by a) comparing clinical temperature data seen in tcMRgFUS treatments with simulations using a full-head model based on MRI images, and b) comparing co-registered UTE and CT images.

Conclusion: A segmented tissue model based on 3D UTE images of the head was used with simulations to demonstrate the effect of additional tissue anatomical features on the focal location and intensity in a clinical tcMRgFUS transducer. A 2mm focal shift and 20% decrease in the focal intensity was estimated due to MRI-derived additional anatomical features.
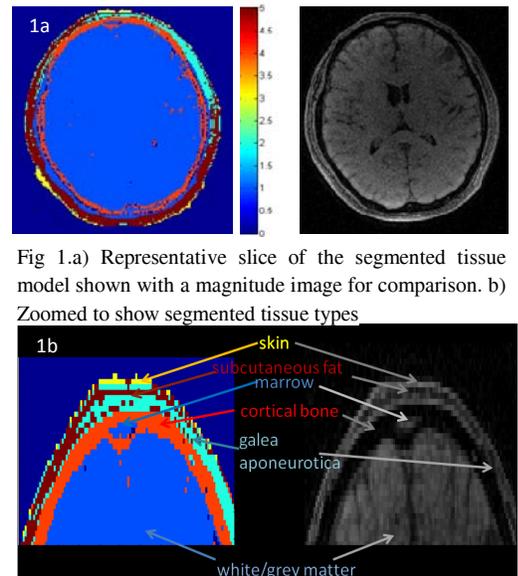
Fig 1.a) Representative slice of the segmented tissue model shown with a magnitude image for comparison. b) Zoomed to show segmented tissue types
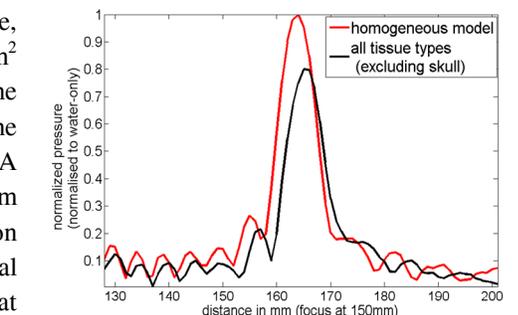
Fig 3 Pressure profile for the homogenous and the all tissue types model (without skull). Transducer at 0mm

Table 1 Acoustic Properties for Tissue Types[4]

Tissue Type	sound speed m/s	attenuation Np/cm/MHz	density kg.m⁻³
skin	1505	0.26	1090
galea (muscle)	1529	0.05	1050
fat, marrow, subcutaneous	1450	0.03	950
white/grey matter	1560	0.04	1040
homogenous model	1500	0.04	1000

References
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