Precomputation of hundreds of transducer positions for real time, patient specific simulation based tFUS neuronavigation and planning

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Introduction

- We pre-compute hundreds of transducer beam profiles through the skull of two subjects, before the tFUS session, in order to 1) determine the optimal transducer position and 2) perform real time, simulation based tFUS neuronavigation.

Methods

- MRI MPRAGE input, no CT scan required
- Skull CT map estimated using the pseudo-CT method of Burgos et al. [IEEE TMI 2014]
- Hounsfield unit to acoustic parameter scaling (ζ is bone porosity):

  $$\boldsymbol{c},\boldsymbol{\rho},\boldsymbol{\alpha}=\boldsymbol{c_{water}},\ \boldsymbol{\rho_{water}},\ \boldsymbol{\alpha_{water}}\boldsymbol{\zeta}+\boldsymbol{c_{bone}},\ \boldsymbol{\rho_{bone}},\ \boldsymbol{\alpha_{bone}}(\boldsymbol{1}-\boldsymbol{\zeta})$$

  c_{water}=1482 m/s, ρ_{water}=1000 kg/m^3, α_{water}=7×10^{-5}T Np/m

  c_{bone}=3100 m/s, ρ_{bone}=2200 kg/m^3, α_{bone}=20T Np/m
- Mesh scalp using iso2mesh uniform cgal-based mesh routines [Fang IEEE ISBI 2009].
- Simulated ultrasound beam created by transducer (200kHz, 61mm aperture, 80mm focal depth) at the vertices. Normal derived from the mesh. Simulator is a GPU accelerated FDTD code based on the Westervelt Lighthill equation [Yoon PMB 2018].
- Wrote a Matlab GUI for real time display of the tFUS beam and deep brain nuclei structures, derived from the MPRAGE using Freesurfer [Fischl Neuroimage 2012]. The GUI interfaces with a Localite navigation system sending the 3D coordinates and orientation of the transducer every 100ms for display refresh.

Results

- Scalp meshes had 932 and 962 vertices for subjects 1 and 2, respectively.
- Each transducer position solved in ~1.5min resulting in ~24 hours total computation.
- Fig. 1 shows that the optimal transducer placement is contralateral to the target for subject #2 when targeting the thalamus. When the target is the R amygdala, the optimal transducer position is ipsilateral to the target for this subject.
- For subject #1, these conclusions were reversed (transducer ipsilateral to R thalamus target and contralateral to R amygdala target).

- For both subjects, scalp map shows broad areas of near optimal transducer positions for the thalamus target, whereas for the amygdala target the optimal areas are small.

Conclusion

- Pre calculation of hundreds of transducer locations is feasible and allows real time tFUS simulation based neuronavigation (Fig. 2)
- Effect of the skull can be modeled without CT scan using the pseudo-CT method.
- This approach reveals very different optimal placements of the transducer depending on the target and subject head size and geometry.

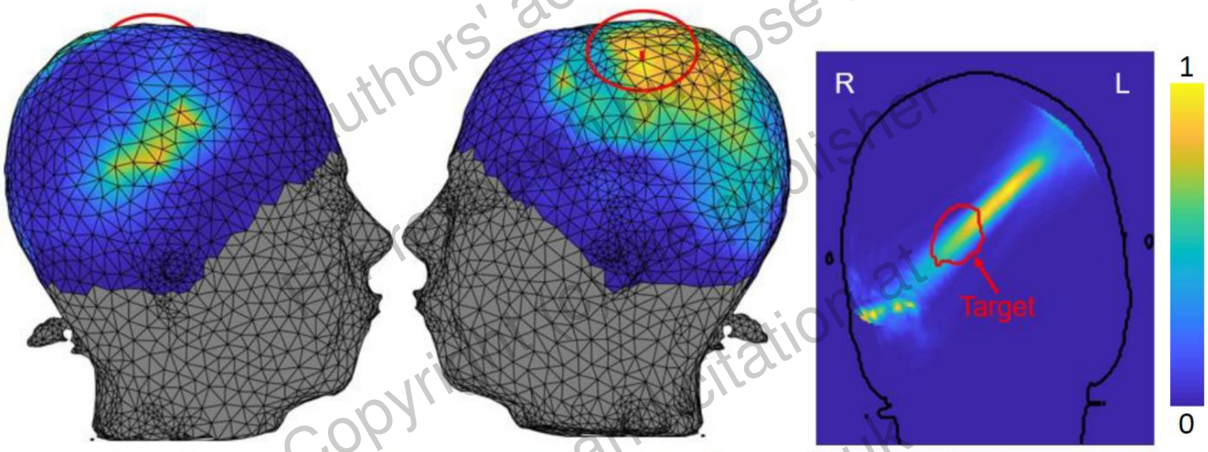

Fig. 1: ***A:*** *Scalp map of tFUS intensities in the right thalamus (subject #2).* ***B****: Coronal MIP tFUS beam corresponding to the maximum intensity scalp map solution (red transducer in A).*

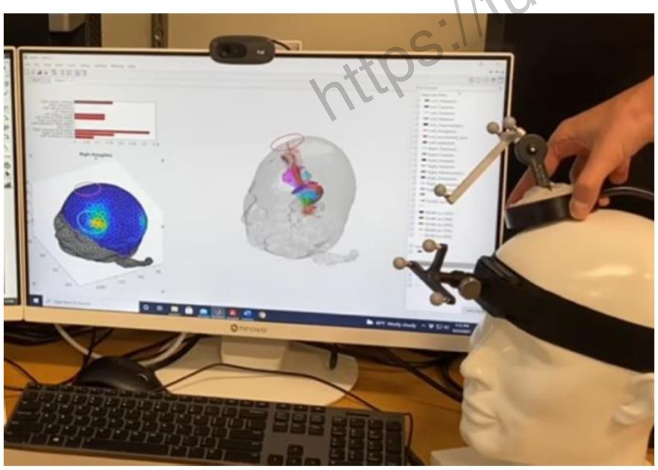

Fig. 2: Matlab-based navigation GUI. The tracking tool and camera is a Localite system that sends the 3D coordinate and orientation of the transducer to the GUI every 100ms. The beam is displayed in real-time along with the deep brain structures and basic tFUS sonication metrics for the different deep brain nuclei.