Reduction of Motion Artifacts in MRgFUS in the Brain using Hybrid Thermometry

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Introduction MR guided focused ultrasound promises to be a highly accurate, noninvasive alternative to conventional treatments, and is especially appealing for use in the brain. Advancements in MR-guided temperature imaging have accelerated the use of focused ultrasound in clinical brain treatments, although the currently used proton resonance frequency (PRF) baseline subtraction method is highly susceptible to motion, which can occur despite the use of stereotactic head frames [1]. The hybrid algorithm [2] uses both multibaseline [3] and referenceless [4] thermometry to produce improved temperature measurements in moving organs. The purpose of this work was to determine how many baseline images should be acquired for the multibaseline portion of the hybrid processing algorithm to adequately reduce motion artifacts.

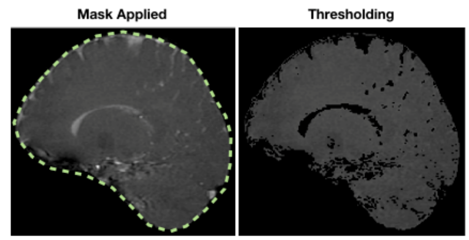

Fig 1. Sagittal magnitude images with applied mask (left) and pixel thresholding (right). Temperature information from pixels outside the mask's border (green outline) and those above and below the mask's thresholds are not considered in analysis.

Methods A gradient echo sequence was used to collect 80 sagittal images from 3 volunteers under no heating using a quadrature head coil (TE = 12ms, TR = 24ms, flip angle = 30-40, FOV = 20-30cm, BW = 12 kHz, Matrix Size: 256x128). Volunteers were not physically attached to any head apparatus, but pads were fitted around each volunteer's head to minimize head motion. Neither respiratory nor cardiac gating was used during scanning. The first 30 images served as a baseline library, and the final 50 were used for temperature comparisons. A mask was applied to the regions outside the brain, as well as to pixels with low and high relative magnitude intensity values (Fig.1). For statistical analysis, a threshold value was calculated from the distribution of magnitude pixel intensity values across the brain, excluding pixels 2 standard deviations away from the distribution's sample mean. This eliminates regions with both high and low signal magnitude (e.g. CSF, blood vessels, noise). Comparisons were made between temperature information gathered using the multibaseline and hybrid techniques at varying library sizes.

Results Example images from one volunteer (Fig.2) show the absolute maximum temperature across 10 time-points using multibaseline and hybrid techniques with a varying number of baseline images. At a library size of 3, the hybrid algorithm (b) has smaller temperature error compared to only multi-baseline processing (a). Increasing the library size results in significant improvements up to 15 baseline images (c) with diminishing returns at a library size of 30.

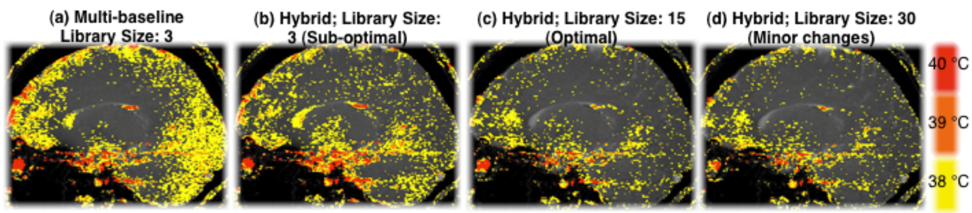

Fig 2. Maximum temperature overlay measuring using multi-baseline and hybrid reconstruction methods at varying baseline libraries.

Averaging across three volunteers, absolute mean temperature and temporal uncertainty measurements calculated across 10 time-points are shown in Fig 3. Across all 30 tested library sizes, the hybrid algorithm performs better than multibaseline alone at reducing motion artifacts. Incorporating signal thresholding to information gathered using the hybrid method eliminates pixels likely to produce inaccurate temperature measurements (e.g. vessels), thus resulting in noticeably lower temperature error across all library sizes. Both with and without signal thresholding, a baseline library of 13 images is sufficient to achieve upwards of 90% obtainable reductions in temperature error. Achieving an additional 9% in reduction requires up to 11 extra baseline images with high signal thresholding, and 9 extra without. This calculation uses the absolute mean temperature measurement from a library size of 30 as the assumed lowest achievable minimum.

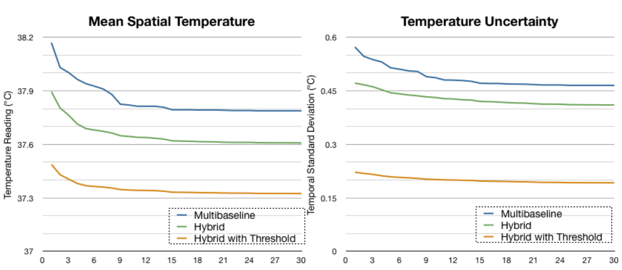

Fig 3. Average magnitude temperature (left) and temporal uncertainty (right) measurements over three volunteers. Measurements are collected across the entire brain using various temperature imaging techniques.

Discussion We have shown an overall decrease in temperature error with increasing library size across the entire brain. In three datasets, a library size of 13 provides 90% of the improvement in temperature uncertainty; however, analyses over sub-regions of the brain may not always produce the same results. In some cases, absolute mean temperature and uncertainty information gathered from 6x6 pixel ROIs (frontal lobe, parietal lobes, cerebellum) show an optimum temperature improvement at library sizes lower than 13, and may even show slight increases by adding additional baseline images (frontal lobe). These trends suggest that some regions of the brain improve more than others, primarily due to the hybrid algorithm's method of calculating a weighted average of baseline coefficients optimized over the entire brain, as opposed to a localized region. Nonetheless, in all cases, the temperature uncertainty is significantly improved using the hybrid algorithm over single baseline subtraction or multi-baseline alone.

Conclusion Our results show that the hybrid method produces better overall temperature information by adding pre-procedural baseline images. While these trends may vary within small regions, we observe a reduction in motion artifacts with increasing library size across the entire brain. Recognizing a tradeoff between minimizing motion artifacts and scan time, we found an optimal number of approximately 13 baseline images is necessary to achieve error reductions of up to 90% in volunteers without a stereotactic frame. Such improvements are promising for MRgFUS ablation treatments within the brain, offering more accurate and reliable temperature monitoring.

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