MR-guided focused ultrasound ablation through the ribcage

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Introduction  In recent years, MR-guided focused ultrasound (FUS) ablation has shown promise as a non-invasive alternative for the treatment of various diseases. For FUS applications in the upper abdomen and chest, a major limitation is the restricted acoustic window for FUS delivery, due to the higher acoustic impedance of thoracic bone and cartilage compared to soft tissues. Here, we investigate if a human size ribcage provides enough acoustic window to ablate tissue in the heart.

Methods  Experiments were performed with the InSightec ExAblate 2000 system installed in a 3T GE MRI system. The system has a FUS phased array transducer (120 diameter, 208 elements, 160 mm radius of curvature, 1.1 MHz fundamental frequency) built into a modified patient table. A plastic ribcage from a classroom skeleton was placed in a water bath above the transducer. The ribcage was positioned at a slight angle such that the FUS beam path went through the cartilage and ribs next to the sternum, to mimic a clinical parasternal approach (see Fig. 1, left). A polyacrylamide gel phantom was placed inside the ribcage at the position of the heart. In a coronal plane 8 cm from the transducer surface, 25 sonications spots were selected on a 5×5 grid (10 mm spacing). All spots were sonicated with 153 W acoustical power for 20 s without tilting the transducer. During the sonications, temperature measurements were performed with PRF-thermometry (gradient echo, TE = 12 ms, TR = 25 ms, FOV = 32 cm, slice thickness = 3mm, matrix = 256x128, BW = 7 kHz).

Results and Discussion  The results showed that the maximum ablation temperature varied with the amount of rib obstruction. For comparison, no rib obstruction resulted in a temperature of 45°C. Figure 1, right, demonstrates that areas with less than approximately 40% rib obstruction reached temperature rises of more than 30°C. A temperature rise of this magnitude would be sufficient to create tissue necrosis in living tissue (final temperature > 55°C). However, temperature elevations as low as 5°C were measured in areas with more than 80% beam path obstruction by the ribs. Figure 2 shows the maximum temperatures reached in each sonication as a function of rib obstruction is approximately linear. An additional result is that the selected sonication location and the location of the maximum measured temperature rise was offset on average by 5 mm in the imaging plane (the accuracy of the InSightec system using the gel phantom without rib obstruction is better than 1 mm). This suggests that the ribs not only attenuate the heating spot but also influence its position and shape. We believe that shift of the focal spot along the direction of sound (the slice direction of the MR temperature image), which was not measured in this experiment, contributes to the data variability in Fig. 2, as it will cause underestimation of the maximum temperature if the imaging slice is not centered on the focus of the sonication [1]. Our results are in agreement with hydrophone and thermocouple measurements of Aubry et al. [2] who reported shifting of the focus, decreased maximum temperatures, and more energy deposition of the secondary lobes when sonicating through a sheep ribcage. Surface heating of the ribcage was observed, which highlights the need for adaptive mechanisms such as turning off individual transducer elements with beam paths obstructed by ribs.

Conclusions  Our results show that sonications through the ribcage can achieve ablative temperatures with the acoustic windows provided through a human-size rib-cage.


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