Anatomical-based model for simulation of HIFU induced lesions within atherosclerotic plaques

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Atherosclerosis is a chronic vascular disease affecting large and medium sized arteries. Several treatment options are already available for treatment of this disease. Targeting atherosclerotic plaques by high intensity focused ultrasound (HIFU) using dual mode ultrasound arrays (DMUA) was recently introduced.

We simulated a case of targeting atherosclerotic plaque within the posterior wall of the external femoral artery of Familial Hypercholesterolemic (FH) swine. The targeting was conducted in the form of seven adjacent HIFU shots that were placed across the circumference of the posterior wall of the artery, with 1 mm spacing circumferentially. Steering the beam from the geometric focus was achieved without the need to mechanical scanning. We propose a numerical simulation model which helps to understand and predict the outcome of lesion formation procedures. This model simulates transient bioheat equation (tBHTE) with a convective term accounting for blood flow in the target vessel. A finite difference time domain (FDTD) heterogeneous model is used for both acoustic field and tBHTE computations. Ultrasound images of the treatment region were used together with a segmentation algorithm to identify five tissue layers within the HIFU field. The acoustic field simulation accounted for the concave geometry of a 3.5-MHz 32-element array used to target the femoral artery of the adult swine through a water bolus. In addition we considered the vessel geometry (e.g. wall thickness) into the field and temperature calculation. The results of our simulation correlated well with the histology data of the targeted plaque which has revealed thermal injury within the plaque tissue consistent with the applied HIFU shots. Therefore, the results provide an early validation for the feasibility of using image-based modelling of the acoustic and thermal field in heterogeneous tissues. Our simulation model also correctly predicted the protection of the intima by the heat sink effect due to blood flow in the targeted vessel. This could be significant when noninvasive HIFU is used in the treatment of vulnerable plaques. In conclusion, image-based modelling could play a critical role in treatment planning when HIFU is used in precision lesion formation noninvasively.