SonoKnife

Surgery using Focused Ultrasound

Graduate

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Introduction: In medicine, ultrasound (US) is a well-established modality for numerous diagnostic applications and has recently also been employed for non-invasive (no incision wound) surgical applications. Here, its wave nature is used to focus ultrasound energy from numerous, separately controllable emitters (phased array transducers) at the desired target point by means of controlled interference. This focused ultrasound (FUS) allows pinpoint heating with resulting local destruction (thermal ablation) of tissue (e.g. tumor, cyst) deep inside the body due to internal friction at the focal point. However, secondary damage to surrounding tissue caused by thermal conduction must be considered in the surgical planning. This work pursues the goal of calculating the phase-coupled control of the ultrasound system in such a way that tissue ablation by focused ultrasound is performed as precisely as possible in the target area despite locally varying tissue parameters. Moreover, the treatment of extensive regions by means of using multiple adjacent target points was considered.

Approach: For this purpose, a simulation environment was created to investigate the accuracy of tissue ablation by FUS. Therein, the propagation of ultrasound waves in heterogeneous tissue, the local US energy deposition and the resulting heat propagation in tissue had to be modeled in a coupled manner. The model can be used to simulate various surgical procedures using FUS. A suitable platform for this is the MATLAB-based toolbox k-Wave, which allows the simulation of 2- and 3-dimensional heterogeneous structures by exploiting the computational power of GPUs. Arc-shaped ultrasonic transducers were excited with signals of different phasing to investigate the focusing of ultrasonic waves at different target points outside the geometric focus. Determination of the phase setting of the transducer elements for optimal focusing in a given target point is done using a preceding time-reversal simulation. Here, the hypothetical propagation of the ultrasound signal backwards in time from the focal point to the transducer is simulated and the phase registered at the position of the ultrasound element is used for the excitation signal. Furthermore, the tissue heating by the focused ultrasound is modeled by calculating the temperature based on the heat input in the tissue over time. The locally varying thermal properties of the heterogeneous tissue structure (Fig. 1) and thermal diffusion are also taken into account. Local tissue damage is assessed by calculating the cumulative thermal dose CEM43 over time (Fig. 2). Once an individual CEM43 threshold, known for each tissue type, is exceeded, the thermal damage is sufficient to destroy the affected tissue (Fig. 3).

Conclusion: The developed simulation environment allows simulations of local heating and resulting tissue ablation by focused ultrasound in heterogeneous tissue structures. Correct beam focusing using time-reversal simulation could be demonstrated in geometrically complex structures. The use of the GPU capability of Matlab k-Wave enabled short computation times and allowed the extension to a 3D simulation domain.

Figure 1: Structure of the treatment area
Own presentment

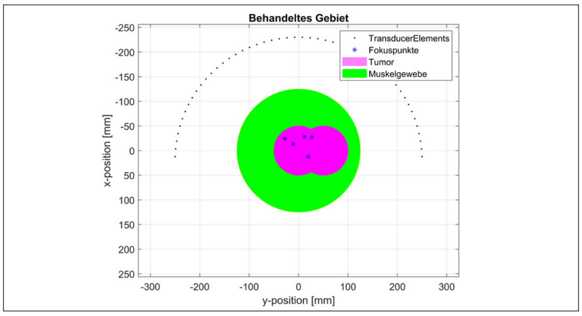


Figure 2: Thermal dose CEM43
Own presentment

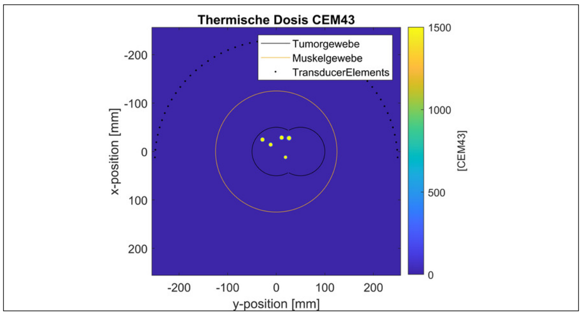
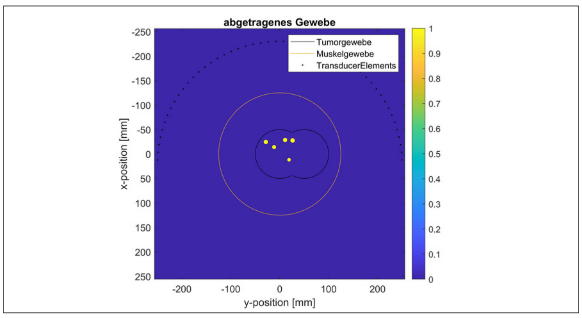


Figure 3: Ablated tissue
Own presentment



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