Modeling of thermal lesions induced by high intensity focused ultrasound (HIFU) in mobile and elastic organs

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Background, Motivation and Objective

Numerical modeling is performed to optimize therapies that use HIFU. Nowadays, these therapy strategies are clinically applied in the treatment of various pathologies. However, cardiac procedures are particularly challenging due to heart movements and deformations. This study aims to demonstrate with a new numerical model of thermal ablations that accurate modeling of temperature and thermal dose in elastic and mobile organs requires considering deformations and motions.

Statement of Contribution/Methods

In the model, ultrasound pressure field is calculated using the Rayleigh integral method and a point-by-point estimation of the attenuation in the tissues. Temperature map is obtained by the discretization with finite volume method of the Bio Heat Transfer Equation (BHTE) on a collocated, smooth and non-orthogonal tridimensional mesh with hexahedral cells. The equation is solved on a curvilinear coordinate system fitting the grid. Pressure field and BHTE algorithms are respectively parallelized on GPU and CPU to speed up the computation. Simulated HIFU beam is generated by a 3-cm^2 truncated spherical transducer with 40-mm natural focus and operating at 3 MHz. Tests are performed on two configurations with 6s-long sonication at an acoustic power of 32 W: 1) on a homogeneous matrix affected by compression, dilatation, rotation or translation movements and 2) on the atrioventricular (AV) node of a healthy beating heart model reconstructed from 4D CT-scan.

Results/Discussion

In homogeneous volume (1), for static configuration, the maximum temperature reaches 66°C and the thermal lesion volume is 2.81 mm^3. Depending on applied deformations, the maximum temperature varies from 59 to 69°C, and the lesion volume fluctuates from 2.67 to 4.24 mm^3. No lesion is visible with dilatation. In AV node (2), the maximum temperature reaches 75°C in non-moving heart simulation and the lesion volume is 9 mm^3. Considering heart deformations and motions, temperature only reaches 47°C and no lesion is visible. Movements and deformations affect significantly simulation results in simple and more complex models. Simulations in static organ overestimate the treatment efficacy. Thus, considering deformations and movements in modeling studies is required to provide accurate treatment strategies.

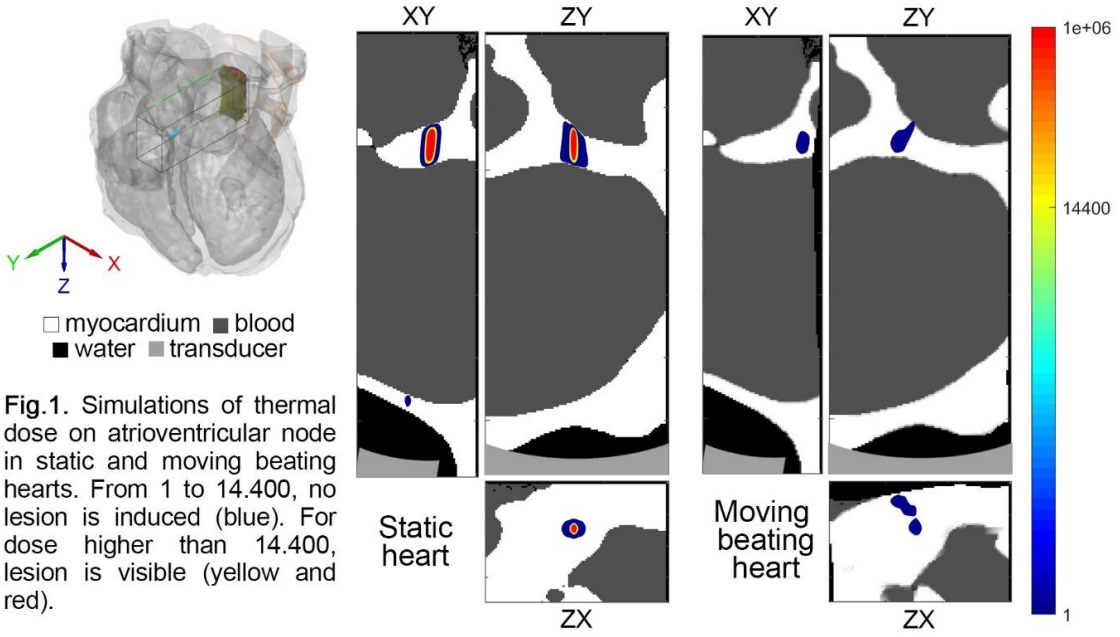

Fig.1. Simulations of thermal dose on atrioventricular node in static and moving beating hearts. From 1 to 14.400, no lesion is induced (blue). For dose higher than 14.400, lesion is visible (yellow and red).