Cyprus University of Technology
Faculty of Engineering and Technology

Doctoral Dissertation

Evaluation of a flat, rectangular MR compatible ultrasonic transducer for cardiac applications

Michalis Sotiriou

Limassol, May 2023

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING, COMPUTER

ENGINEERING AND INFORMATICS

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Approval Form

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Presented by

Michalis Sotiriou

Supervisor: Faculty of Engineering, Christakis Damianou, Professor

Signature

Member of the committee: Faculty of Engineering, Takis Kasparis, Professor

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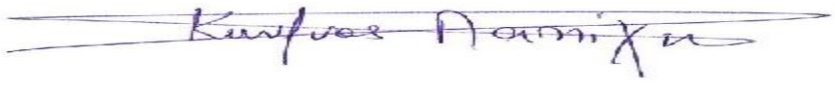
Member of the committee: Faculty of Pure and Applied Sciences, Costas Pattichis, Professor

Signature



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Approval Form of Advisory Committee

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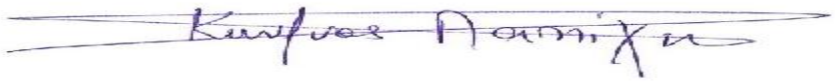

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Abstract

High Intensity Focused Ultrasound (HIFU) is a non-invasive therapeutic technique that can cause localized hyperthermia at predictable depths without injuring intervening tissues. Atherosclerosis is a condition that develops when a substance called plaque builds up in the walls of the arteries and is related with numerous problems on heart and blood vessels. HIFU can be used to ablate atherosclerotic plaque from these arteries and avoid fatal problems such as heart failure and stroke.

In this study the main objective is the design of an in vitro model to assess the thermal ablation of atherosclerotic plaque using different parameters of intravascular transducers. The experiments were initially conducted in different phantoms and in freshly excised turkey tissue phantom. A flat rectangular transducer was assessed in an arterial atherosclerotic plaque phantom which was created in the laboratory with a very low cost. The proposed phantom mimics the human atherosclerotic plaque. Atherosclerotic plaque is mainly consists of fibrous tissue, lipid core, calcium and necrotic core. Different percentages of those components would categorize different types of plaques. Agar was used for mimicking fibrous tissue, gypsum for calcium and butter for lipid core. The only limitation is that macrophages were not used for mimicking the necrotic core. The artery phantom follows the elastic properties of an artery. The amount of plaque removal was evaluated visually and using an X-Ray system. The main complications of thermal ablation were the increased artery temperature above a safe level (1 °C) and the rupture of atherosclerotic plaque during the ablation. Furthermore, different parameters of intravascular transducers were assessed with different composition percentages of atherosclerotic plaque. The frequency was 4.0 MHz and acoustical power and sonication time were between 6–15 W and 15–30 s respectively for achieving the optimum combination. Moreover, the specific flat, rectangular transducer is MR compatible and thermometry images were obtained during this evaluation. The intended application is to use it for atherosclerotic plaque ablation using a single element transducer. Finally, an evaluation of acoustic and thermal properties of plaque phantoms to test their suitability mainly for ultrasound imaging and therapy was performed. This is very important for the effective implementation of ultrasound not only in diagnosis, but especially for therapy. The evaluation included measurements of the acoustic propagation speed using the pulse-echo technique, the ultrasonic attenuation coefficient using through transmission immersion technique, and the absorption coefficient. Moreover, thermal

properties (thermal conductivity, volumetric specific heat capacity and thermal diffusivity) were measured with the transient method using a needle probe. The mean value of acoustic and thermal properties and their standard deviation of plaque phantoms were 1523±23 m/s for acoustic speed, 0.50±0.02 W/mK for thermal conductivity, 0.30±0.21 dB/cm-MHz for ultrasonic absorption coefficient and 1.63±0.46 dB/cm-MHz for ultrasonic attenuation coefficient.

Future studies should be focused on the optimum recipe of the atherosclerotic plaque phantoms that mimics the human atherosclerotic plaque (agar 4% w/v, gypsum 10% w/v and butter 10% w/v) and can be used for HIFU therapy. In future clinical trials the transducer (1-3mm wide) will be incorporated in a catheter which will be inserted intravascular, and then transferred to the heart arteries where ultrasonic ablation will take place for a minimum amount of time. This technology can be used in the future for clinical trials to treat plaques in the coronary arteries.

Keywords: HIFU, Ultrasound, Atherosclerosis, Cardiac treatment, Therapeutic Ultrasound, Atherosclerotic plaque, MRI, Attenuation; Absorption; Conductivity; Phantoms.