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Cao, Rui; Le, Nhan; Nabi, Ghulam; Huang, Zhihong

Published in:
Proceedings from the 13th International Symposium on Therapeutic Ultrasound

DOI:
10.1063/1.4976592

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

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Cite as: AIP Conference Proceedings **1816**, 020002 (2017); https://doi.org/10.1063/1.4976592
Published Online: 03 March 2017

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Full Acoustic and Thermal Characterization of HIFU Field in the Presence of a Ribcage Model

Rui Cao[1], Nhan Le[1], Ghulam Nabi[2], Zhihong Huang[1, a)]

[1]*School of Engineering, Physics and Mathematics, University of Dundee, UK*
[2]*Department of Urology, Ninewells hospital, Dundee, UK*
[a)] Corresponding author: z.y.huang@dundee.ac.uk

Abstract:
In the treatment of abdominal organs using high intensity focused ultrasound (HIFU), the patient's ribs are in the pathway of the HIFU beams which could result in acoustic distortion, occasional skin burns and insufficient energy delivered to the target organs. To provide full characterization of HIFU field with the influence of ribcage, the ribcage phantom reconstructed from a patient's CT images was created by tissue mimicking materials and its effect on acoustic field was characterized. The effect of the ribcage on acoustic field has been provided in acoustic pressure distribution, acoustic power and focal temperature. Measurement result shows focus splitting with one main focus and two secondary intensity maxima. With the presence of ribcage phantom, the acoustic pressure was reduced by 48.3% and another two peak values were observed near the main focus, reduced by 65.0% and 71.7% respectively. The acoustic power was decreased by 47.5% to 52.5%. With these characterization results, the form of the focus, the acoustic power, acoustic pressure and temperature rise are provided before the transcostal HIFU treatment, which are significant to determine the energy delivery dose. In conclusion, this ribcage model and characterization technique will be useful for the further study in the abdominal HIFU treatment.

INTRODUCTION

High intensity focused ultrasound (HIFU) has been developed in the treatment of liver cancer, prostate cancer, breast cancer and et al. [1-4]. It has the ability of destroying the target tissue without damaging the overlying structures within the ultrasound beam path. However, the ribs can absorb and reflect the ultrasound wave toward the target, which result in skin burns. Moreover, reduction of the deposition of ultrasound energy at target tissue affects the efficacy of HIFU treatment. Thereby, to investigate the behaviours of ribs as obstacle in the HIFU treatment was proposed. Characterization of acoustic filed based on a 3D reconstructed model of the ribcage was also required for helping select the accurate dose of HIFU energy in treatment planning. The aim of this study was to fully characterize the HIFU field with the presence of a ribcage model.

METHODS

Ribcage Model Reconstruction

The computer reconstructed model was designed based on a patient's CT images using Simpleware software (Simpleware Ltd, Exeter, UK), which has been reported in our previous work [5]. This model was then used to create the physical ribcage model using uPrint SE (Stratasys Ltd., Minnesota, USA). Four ribs at lower position (Fig. 1) were selected for the investigation of transcostal HIFU treatment.

Proceedings from the 13th International Symposium on Therapeutic Ultrasound
AIP Conf. Proc. 1816, 020002-1–020002-4; doi: 10.1063/1.4976592
Published by AIP Publishing. 978-0-7354-1484-6/$30.00

FIGURE 1. Ribcage model

Effect of Ribcage Model on HIFU Field

The HIFU field was fully characterized with and without the ribcage model to investigate the impact of this model on HIFU treatment.

The acoustic pressure field can provide a visualized profile of the ultrasound beam. Needle hydrophone (Precision Acoustics, Dorset, UK) was mounted onto a 3D motor to measure the acoustic pressure field of 20mm by 20mm area. The radiation force balance (Precision Acoustics, Dorset, UK) was applied to measure the acoustic power. The input electric power ranged from 10W to 50W during the acoustic power measurement. The temperature characterization was applied on ExAblate 2000 system (InSightec Ltd., Haifa, Israel), which can work with MRI scanner compatibly. Focal temperature was monitored by MRI thermometry. DQA gel phantom (ATS Laboratories, Connecticut, USA) was applied as the target phantom. Sonications were performed with and without the ribcage model using different acoustic power and duration time. A set of sonications used 25W to 100W acoustic power for constant 20s. The other set applied constant acoustic power 30W for different duration time 10s to 60s.

RESULTS

Effect on Acoustic Pressure

Low power was used to drive the HIFU transducer in the pressure field mapping. The maximum pressure at focus reduced by 48.3% due to the effect of ribcage model. And there were another two smaller peak pressure values (reduced by 65.0% and 71.7%) located near the main focus, as shown in Fig. 2.

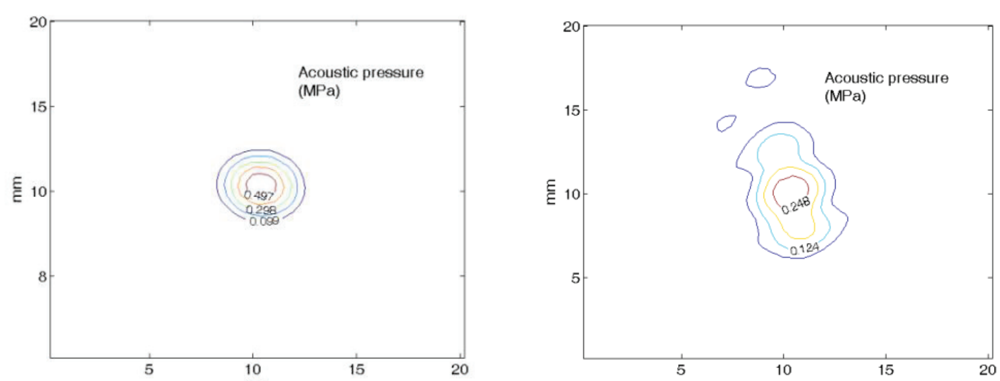

FIGURE 2. Acoustic pressure at focus in the transverse plane in free field (left) and with the ribcage model in the beam path of ultrasound wave (right)

Impact on Acoustic Power

The acoustic power of a HIFU transducer driven by 10W to 50W input electric power was measured. The ribcage in the pathway of the ultrasound wave significantly affected the acoustic power measured by the force balance. The acoustic power reduction due to the ribcage model effect ranged from 47.5% (using 45W electric power) to 52.5% (using 25W electric power).

Influence on Temperature at Focus

The focal temperature in the sonications with and without the ribcage was summarized in Fig. 3 and 4. Temperature induced by different acoustic power for 20s duration time was shown in Fig. 3. Focal temperature with the ribcage effect (red line in Fig. 3) shows apparent decrease compared to the result without the ribcage (blue line in Fig. 3). Different sonication time leading to different temperature at focus using the same input power 30W was shown in Fig. 4. Obvious influence of temperature decrease was observed due to the presence of ribcage model.

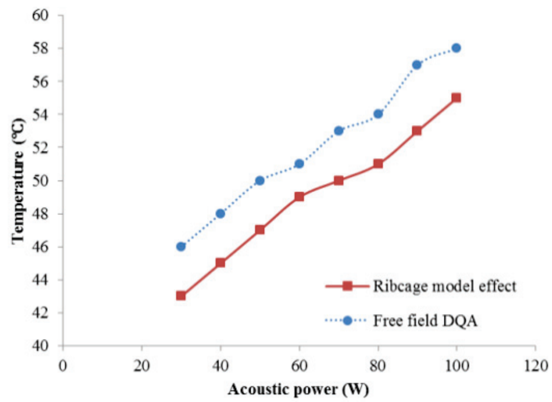

FIGURE 3. Temperature at focus using different acoustic power for 20s duration time

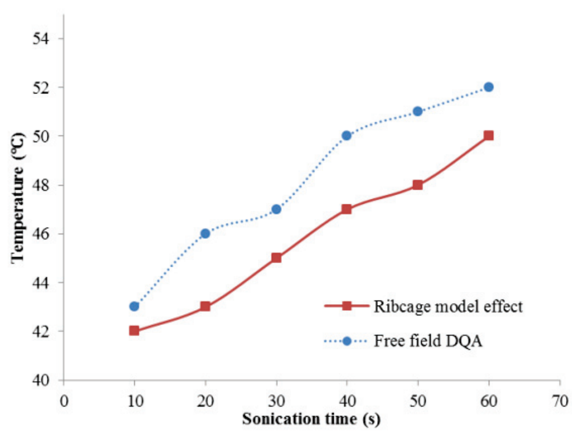

FIGURE 4. Temperature at focus using 30W acoustic power for different sonication duration time

DISCUSSION AND CONCLUSIONS

The work presented in this paper provides a 3D model and tissue mimicking phantom to investigate the effect of ribcage on the delivery of HIFU energy. Estimation of ultrasound field generated by HIFU devices is important in the development of pre-treatment planning. With the impact of the ribcage model, 51.7% acoustic pressure was dropped off, 47.5% to 52.5% acoustic power was decreased and focus was split into three main parts. Focus splitting affects the position accuracy of the focus and may lead to ablation on normal tissue. The splitting happened when the ribcage was in the ultrasound beam path and the ribcage only allowed the wave propagating through the gap of the ribs due to the absorption and scattering by the ribcage. This model and the characterization data can help to optimise the HIFU treatment parameters and to further develop the pre-treatment planning to predict the lesion at focus combined with simulation. The future work would be the study of differences between inter-costal and trans-costal effect on the HIFU field.

ACKNOWLEDGMENTS

This work is supported in part by Chinese Scholarship Council (CSC), China.

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