Volumetric Thermal HIFU Therapy Using Continuous Phase Modulation

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Background, Motivation and Objective

HIFU is used to ablate tissue through thermal effects. Phased array techniques or acoustic lenses are used to achieve a high focal gain, and the heating volume is determined by the f-number of the transducer. To increase lesion size, the exposure time and/or intensity must be increased. Relatively high temperatures at the focal centre could increase the likelihood of cavitation, and could result in overtreatment, reducing the efficacy of the procedure. Alternatively, the transducer may be steered, either electronically or mechanically, to form several discrete lesions. However, this can be time consuming as tissue must cool between exposures. The objective of this work was to control the size of the focal region to treat a large volume.

Statement of Contribution/Methods

A ten-strip bowl-focused array HIFU transducer was driven using in-house hardware. A tissue-mimicking agar phantom was exposed for 2s using continuous wave excitation. The focus was positioned at the far surface of the phantom to allow a thermal camera to measure the temperature rise during exposures. Each element of the transducer was excited using continuous phase modulation (CPM): $A_n = \sin\left[2\pi f_c + \varphi\left(n - \frac{N+1}{2}\right)\sin(\omega_p t)\right]$ where n is the element number, N is the total elements, f_c is the centre frequency, ω_p is the angular speed of the modulation and φ was the modulation magnitude. The sine function ensured that the focus was continuously and rapidly swept with a shift of $\frac{3\pi}{2\omega_p}$, without interrupting the power to the transducer. Data from the camera was processed to find the area where the thermal dose exceeded 240 CEM43. Further testing will be conducted in BSA tissue-mimicking phantoms where the full thermal effects can be characterized.

Results/Discussion

Figure 1(a) shows two intensity beamplots generated by regular and CPM excitation. Figure 1(b&c) show data acquired from the thermal camera showing the respective heating of the phantom material. The peak excitation voltage and exposure time were maintained between tests. The area where CEM43 > 240 was 5mm^2 when regular excitation was used, and 22mm^2 when CPM was used. CPM resulted in four times the area experiencing enough thermal dose for potential tissue denaturation compared with regular excitation, for equivalent electrical drive conditions.

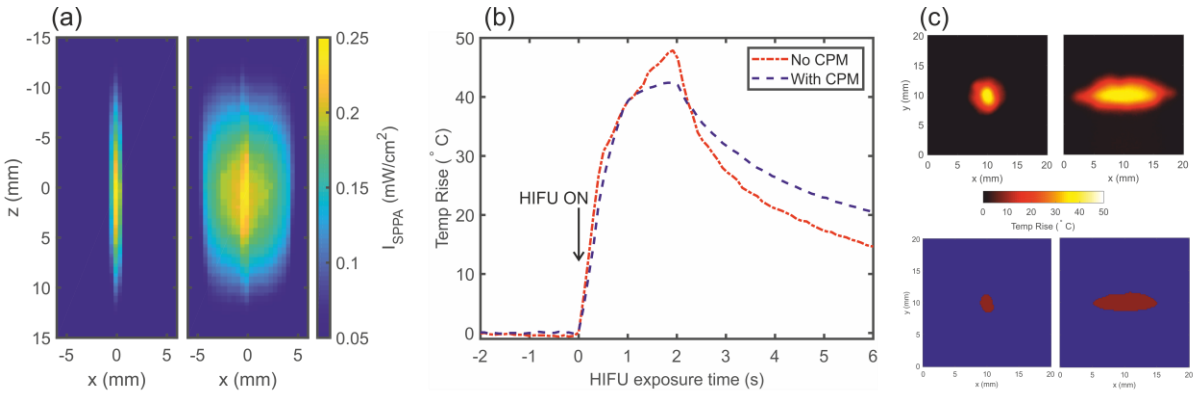

Figure 1. (a) A intensity beamplot of the HIFU fields generated without and with CPM. (b) Peak temperature rise measured by thermal camera. (c) Top, temperature distribution in the radial plan for both field generation modalities. Bottom, a binary image showing (in red) where 240 CEM43 has been exceeded.