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# MRI-compatible Ultrasound Heating System with Ring-shaped Phased Arrays for Breast Tumor Thermal Therapy

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*Abstract*—**Therapeutic ultrasound transducers can carry out precise and efficient power deposition for tumor thermal therapy under the guidance of magnetic resonance imaging. For a better heating, organ-specific ultrasound transducers with precision location control system should be developed for tumors located at various organs. It is feasible to perform a better heating for breast tumor thermal therapy with a ring-shaped ultrasound phased-array transducer. In this study, we developed ring-shaped phased-array ultrasound transducers with 1.0 and 2.5 MHz and a precision location control system to drive the transducers to the desired location to sonicate the designated region. Both thermo-sensitive hydrogel phantom and ex vivo fresh pork were used to evaluate the heating performance of the transducers. The results showed that the ring-shaped phased array ultrasound transducers were very promising for breast tumor heating with the variation of heating patterns and without overheating the ribs**

## I. INTRODUCTION

Therapeutic ultrasound transducers can carry out precise and efficient power deposition for tumor thermal therapy under the guidance of magnetic resonance imaging. MR signal can also be used to real-time evaluate the tissue temperature non-invasively. Different tissue responses to heating and various heating responses due to alternations in vasculature can be easily overcome using online temperature mapping with MR. This indicates that focused ultrasound combined with MRI can potentially be used in a wide variety of applications in the body. However, for a better heating, organ-specific ultrasound transducers with precision location control system should be developed for tumors located at various organs. It is feasible to perform a better heating for breast tumor thermal therapy with a ring-shaped ultrasound phased-array transducer.

## II. METHODS

Fig. 1a shows the concept of the entire transducer with the breast. The ring-shaped ultrasound transducer embraces the whole breast and the ultrasound transducer is moved by a precision location control system to the desired location with the tumor located in the focal zone.

Fig. 1b-c shows the structure of the ring-shaped phased array ultrasound transducer. The ring-shaped ultrasound transducer, with a radius of 10 cm and a height of 2 cm, was combined with four identical quarters and each quarter was made of four PZT-4 ceramic elements with a resonant frequency of 1.0 or 2.5 MHz. Acrylic material was used for housing to avoid the interference with MRI signals, and a transformer network was designed to match the impedances between elements and power amplifiers to achieve maximum power transfer.

### A. Computer simulation

First, computer simulation was employed to study the focal pattern variations when different combination of phases for each element was used. We used the linear propagation concept to calculate the pressure distribution for different focal modes. Table 1 shows some basic modes and the phase difference among the array elements.

### B. Phantom experiments

Heating performance of the ring-shaped ultrasound transducers was evaluated in both thermo-sensitive hydrogel phantom and ex vivo fresh pork. A precision location control system was also fabricated to move the transducers to suitable position in order to heat the desired region. A commercialized multi-channel power amplifier was employed to drive independently the elements of the phased array ultrasound transducers. A 1.5 T MRI system (MR 2004A, Siemens, Germany) was used for imaging guidance and temperature mapping.


(a) (b) (c)

Figure 1. (a) the concept of ring-shaped ultrasound transducer for breast tumor thermal therapy; (b-c) the structure of the proposed ring-shaped phased array transducer.

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TABLE I. THE PHASES OF THE 16 ELEMENTS FOR MODE 0, MODE 4,AND MODE 8

|  | N=0 | n=1 | n=2 | n=3 | n=4 | n=5 | n=6 | n=7 | n=8 | n=9 | n=10 | n=11 | n=12 | n=13 | n=14 | n=15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mode0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| mode4 | 0 | 90 | 180 | 270 | 0 | 90 | 180 | 270 | 0 | 90 | 180 | 270 | 0 | 90 | 180 | 270 |
| mode8 | 0 | 180 | 0 | 180 | 0 | 180 | 0 | 180 | 0 | 180 | 0 | 180 | 0 | 180 | 0 | 180 |

## III. RESULTS

**Fig. 2** displays the pressure distributions for mode 0, mode 4 and mode 8 with their phases for each element as shown in **Table I**. It can be seen that the focal pattern extends from the center point to a circular ring and becomes larger for model 8.

**Fig. 3** shows phantom experiments with transparent thermo-sensitive hydrogel and fresh pork in MR system. The transparent phantom changes to be white as the phantom temperature is higher than 43 degree. Figure 3 also shows the matching box for the power amplifier and the array elements. With the tuning of matching circuits, the reflected power was able to be controlled less than 10% for a total transmission power of 300 Watts.

**Fig. 4** displays the experimental results of hydrogel phantom indicating that the thermal lesion was formed in the planned focal zone and its pattern was changed with the phase mode for 1.0 MHz transducer; and it was able to do superficial heating for 2.5 MHz transducer with the heating region determined by the cooling water temperature and the number of the power-on PZT-4 ceramic elements (not shown).

In ex vivo fresh pork experiments, MR imaging was employed to move the phased-array to suitable position and MRI T1 image sequence was used for real-time spatial-temporal temperature measurement. Figure 5a-c shown the MR temperature mapping and the pork slice through the focal zone for mode 0, mode 4, and mode 8, respectively. The results showed that the shape and size of thermal lesions could be controlled by the power levels and the combination of phase modes. The precision location control system could move the transducer to heat the designated region. The lesion formation was also influenced by the inhomogeneity of pork tissues and the tissue shape's asymmetry.

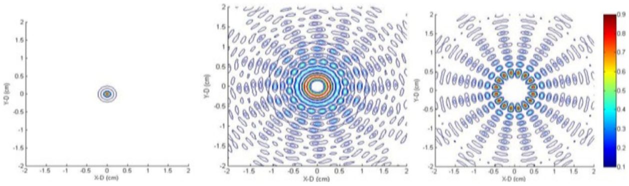

Figure 2. The pressure distributions of the ring-shaped phased array transducer with mode 0, mode 4, and mode 8 with the phases of elements as shown in Table I.

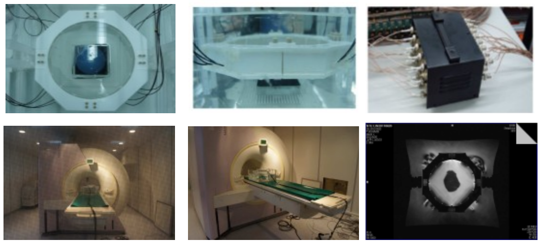

Figure 3. The arrangements of transparent phantom and fresh pork experiments, and the matching box

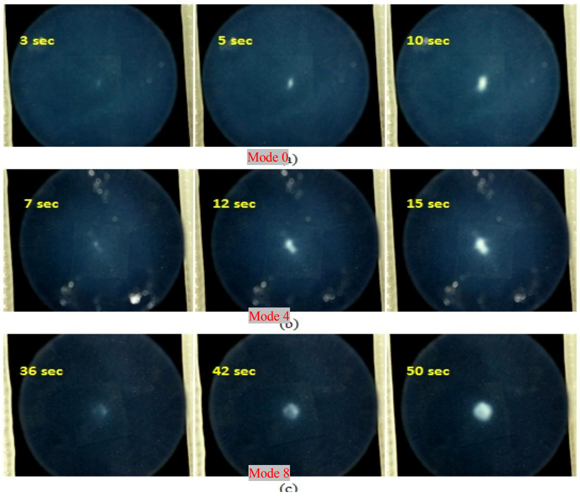

Figure 4. The lesion formation for mode 0, mode 4, and mode 8 with transparent phantoms.

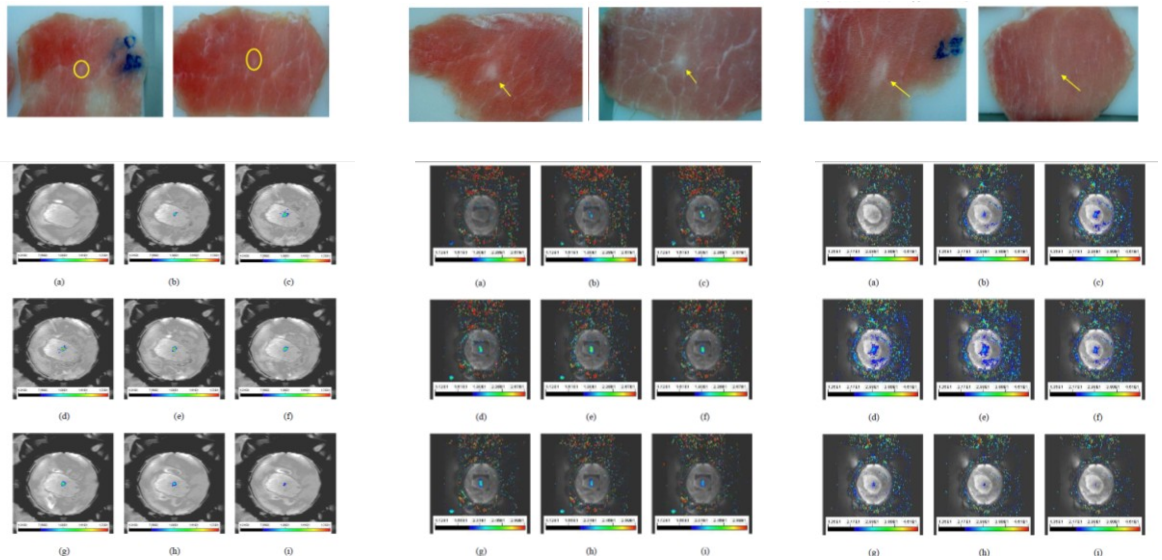

Figure 5. Shows the temperature mapping during heating and the thermal lesion slices after heating for mode 0, mode 4, and mode 8.

## IV. CONCLUSION

Ring-typed ultrasound phased array transducers with precision location control system was successfully developed and evaluated. The transducers can produce different types of lesions in the designated regions by moving the transducers with a location control system under MR imaging guidance and various settings of power heating time and focal modes.1.0 MHz phased array could be used for deep heating while 2.5 MHz one for the superficial heating.

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