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Breast cancer imaging by microwave-induced thermoacoustic tomography

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ABSTRACT

We report a preliminary study of breast cancer imaging by microwave-induced thermoacoustic tomography. In this study, we built a prototype of breast cancer imager based on a circular scan mode. A 3-GHz 0.3~0.5-μs microwave is used as the excitation energy source. A 2.25-MHz ultrasound transducer scans the thermoacoustic signals. All the measured data is transferred to a personal computer for imaging based on our proposed back-projection reconstruction algorithms. We quantified the line spread function of the imaging system. It shows the spatial resolution of our experimental system reaches 0.5 mm. After phantom experiments demonstrated the principle of this technique, we moved the imaging system to the University of Texas MD Anderson Cancer Center to image the excised breast cancer specimens. After the surgery performed by the physicians at the Cancer Center, the excised breast specimen was placed in a plastic cylindrical container with a diameter of 10 cm; and it was then imaged by three imaging modalities: radiograph, ultrasound and thermoacoustic imaging. Four excised breast specimens have been tested. The tumor regions have been clearly located. This preliminary study demonstrated the potential of microwave-induced thermoacoustic tomography for applications in breast cancer imaging.

Keywords: Breast cancer, imaging, microwave, thermoacoustic tomography

1. INTRODUCTION

Breast cancer is the most common cancer among women, accounting for one out of every three cancer diagnoses. The incidence of breast cancer increases with age: approximately 3 out of 4 women with a new diagnosis of breast cancer each year are older than 50. Although breast cancer remains a leading cause of cancer deaths among women, the cure rate is much improved by early detection. X-ray mammography and ultrasonography are the current clinical tools for breast-cancer screening and detection. Mammography is the "gold standard"; however, it uses ionizing radiation and has difficulty in imaging pre-menopausal breasts, which are radiographically dense. Currently, ultrasonography is used only as an adjunct tool to x-ray mammography and tends to miss non-palpable tumors.

The contrast in the microwave or radiofrequency (RF) regime is very sensitive to tissue physiological states—molecular constituents, ion concentration and mobility, free- and bound-water concentrations, and temperature. Cancerous breast tissues absorb microwave or RF 2–5 times more strongly than surrounding normal breast tissues [1–3]. However, pure-microwave or RF imaging is limited to poor resolution because of the long wavelengths utilized. Ultrasonic imaging has good resolution but has poor contrast for early-stage tumors. Microwave-induced thermoacoustic imaging combines the contrast advantage of pure-microwave imaging and the resolution advantage of pure-ultrasonic imaging, and therefore, has greater potential to detect early breast cancers and to assess and monitor treatments as well.

In this paper, we present a preliminary study of breast cancer imaging by microwave-induced thermoacoustic tomography. The reconstruction is conducted by our proposed back-projection algorithm. We quantified the line spread

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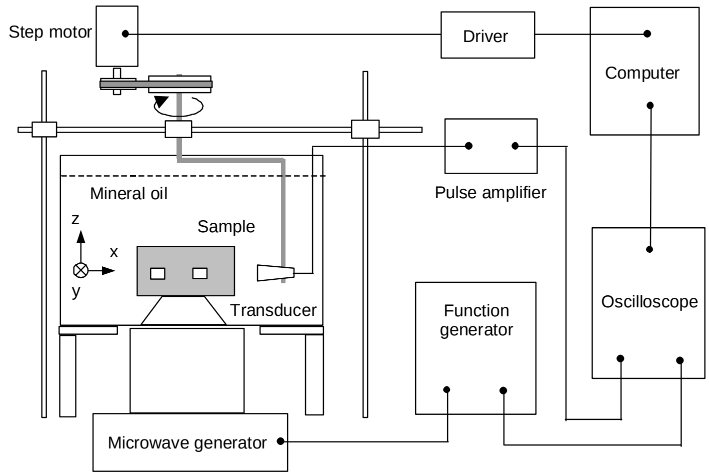


Figure 1: Diagram of experimental setup

function of the imaging system. Then, we moved the imaging system to the University of Texas MD Anderson Cancer Center and imaged four excised breast cancer specimens.

2. METHOD

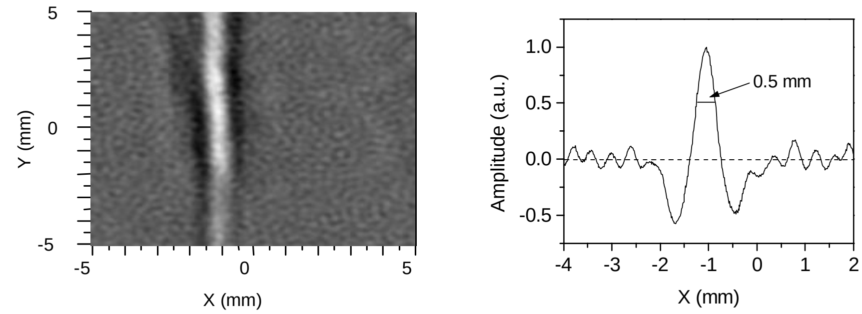
In the initial study, we use 2-D circular measurement geometry. Figure 1 shows the experimental setup. A plexiglass container is filled with mineral oil. An unfocused transducer is immersed inside it and fixed on a rotation device. A step motor drives the rotation device and then moves the transducer scan around the sample on a horizontal *x*-*y* plane, where the transducer horizontally points to the rotation center. A sample is immersed inside the container and placed on a holder: it is made of a thin plastic material, which is transparent to microwaves. The transducer (V323, Panametrics) has a central frequency of 2.25 MHz and a diameter of 6mm.

The microwave pulses transmitted from a 3-GHz microwave generator have a pulse energy of 10 mJ and a pulse width of 0.3 or 0.5 μs. A function generator (Protek, B-180) is used to trigger the microwave generator, control its pulse repetition frequency, and synchronize the oscilloscope sampling.

In our experiments, the pulse repetition frequency is 50 Hz and the sampling frequency of the oscilloscope is 20 or 50 MHz. Microwave energy is delivered to the sample by a rectangular waveguide with a cross section of 72 mm $\times$ 34 mm. A personal computer is used to control the steps. The signal from the transducer is first amplified through a pulse amplifier, then recorded and averaged 100~500 times by an oscilloscope (TDS640A, Tektronix), and finally transferred to a personal computer for imaging based on our proposed back-projection algorithms [4,5].

3. SPATIAL RESOLUTION

We quantified the line spread function (LSF) of the imaging system with pulse duration. A metal wire with a diameter of 0.2 mm was buried in pork fat and then imaged by our imaging system with a scan radius of 75 mm. The photoacoustic image of the embedded wire is shown in Fig. 2(a). Fig. 2(b) shows the profile of the LSF across the wire, where the ringing is caused primarily by the bandwidth of the imaging system. Its full width at half maximum (FWHM) is about 0.5 mm. We can, therefore, claim the spatial resolution of our experimental system reaches 0.5 mm, which agrees with the theoretical spatial-resolution limit for 3 MHz photoacoustic signals whose half wavelength is <0.5 mm in soft biological tissues. It is worth noting that the claimed 0.5-mm resolution is a worst-case estimation of the true resolution because of the finite thickness of the wire (0.2 mm diameter). Of course, the detecting transducer has a finite physical size. If it is close to the thermoacoustic sources, it cannot be approximated as a point detector. Its size will blur the images and decrease the spatial resolution. Therefore, in experiments, the transducer must be placed some distance away from the tissue samples.



(a) (b)

Figure 2: (a) Thermoacoustic image of a thin wire; (b) Profile across the wire.

4. BREAST CANCER IMAGING

We took the prototype of thermoacoustic imaging system to the University of Texas M.D. Anderson Cancer Center and conducted a preliminary study of breast imaging. In our initial study, we investigated tumors in breast mastectomy specimens. Four excised breast specimens were imaged. The tumor regions in these specimens can be located in the thermoacoustic images as expected.

In experiments, we followed the following procedure:

(a) First, a mammogram before the mastectomy of the breast was taken at the Cancer Center as a part of the clinical procedure. Fig. 3(a) shows the mammogram of the specimen in one of the four samples we investigated. A mammogram reflects the different attenuations of the x-ray beam within a patient's breast. Therefore, the image contrast produced by an object depends on its attenuation of the x-ray beam relative to the attenuation of the background tissue. To improve the contrast, the breast is often taken with standard compression.

(b) After the mastectomy, the excised specimen was placed in a plastic cylindrical container with a diameter of 10 cm [Fig. 3(b)]. The nipple of the specimen faced the bottom of the container. For the specimen shown in Fig. 3, its thickness in the container was ~6 cm; but the thickness varied for different specimens. The container had a minimal effect on the transmission of microwave, ultrasound, and x-ray.

(c) Then, a conventional B-mode gray-scale sonogram of the specimen [Fig. 3(c)] was taken using a real-time scanner (HDI 5000, Philips-ATL, Bothell, WA) equipped with a 5–12 MHz broadband linear array electronic transducer. The tumor region was marked by two lines. In a sonogram, the contrast is based on the tissues' mechanical properties.

(d) Next, the specimen was imaged using our thermoacoustic imaging system. A circular scan was carried out by a cylindrically focused ultrasound with a step size of 2-1/4 degrees. The scan radius was 7.5 cm. The reconstructed image [Fig. 3(d)] was computed by the back-projection method. We adjusted the image contrast and set a threshold level to suppress the background. The tumor region clearly shows up (marked by a circle), the location of which agrees with the original sample's. Of course, the normal breast tissues also have certain microwave absorption. In principle, based on the pathological characteristics, the tumor region can be differentiated from the normal tissues.

(e) Finally, another radiograph of the specimen was taken from the top of the cylindrical container [Fig. 3(e)]. In this case, the tumor region is not clearly imaged.

(f) After these imaging experiments, the specimen was rendered to the Department of Pathology for histopathological diagnosis. This lesion shown in Fig. 3 was diagnosed as invasive lobular carcinoma with a size of ~1.5 cm.

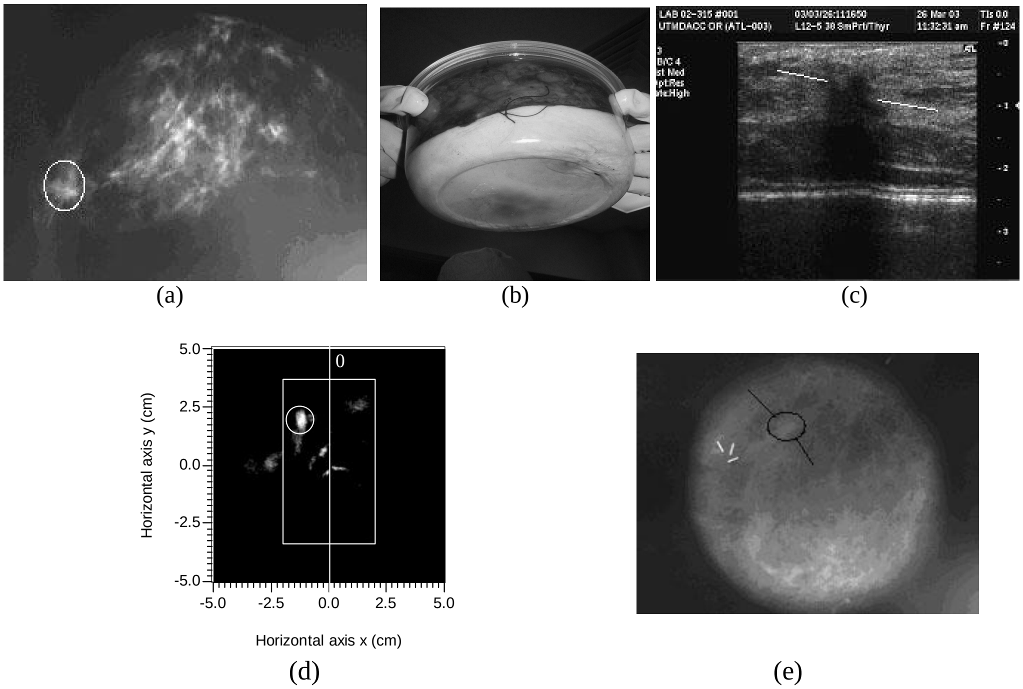


Figure 3: (a) Pre-operative mammogram showing suspicious density in the breast, which was taken with standard compression. (b) The mastectomy specimen placed in a plastic cylindrical container with a diameter of 10 cm (c) Sonogram of the specimen in the container. (d) Thermoacoustic image of the specimen in the container. The rectangle marks the wave-guide aperture. (e) Radiograph of the mastectomy specimen in the container. The tumor is marked by a circle in (a), (d) and (e) and by two white lines in (c).

The rectangle in Fig. 3(d) marks the wave-guide aperture. The wave-guide for this experiment was not large enough to cover the entire specimen. Since then, we have upgraded our system with a larger wave-guide to overcome this problem.

5. SUMMARY

We built a prototype of microwave-induced thermoacoustic imaging system with circular measurement geometry. We also quantified the spatial resolution of the imaging system. Then, we conducted a preliminary study of breast cancer imaging. Four excised breast specimens have been tested. The tumor regions have been clearly located. This initial study shows that the microwave-induced thermoacoustic tomography has great potential in the application of breast cancer imaging.

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