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Minghua Xu, Xueding Wang, Lihong V. Wang, "High-resolution thermoacoustic tomography of biological tissue," Proc. SPIE 4618, Biomedical Optoacoustics III, (10 June 2002); doi: 10.1117/12.469852

SPIE.

Event: International Symposium on Biomedical Optics, 2002, San Jose, CA, United States

High-resolution thermoacoustic tomography of biological tissue

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ABSTRACT

A study of pulsed-microwave-induced thermoacoustic tomography in biological tissues is presented. A backprojection algorithm based on rigorous theory is used to reconstruct the cross-sectional image from the thermoacoustic measurement in a circular configuration that encloses the sample under study. The results demonstrate the possibility of application in detecting small tumors buried in biological tissues using microwave absorption contrast and ultrasound spatial resolution. Finally, the method is compared with laser-induced thermoacoustic tomography.
Keywords: Thermoacoustic imaging, Tomography

1. INTRODUCTION

Pulsed microwave-induced thermoacoustic tomography combines the advantages of both ultrasound spatial resolution and microwave absorption contrast [1]–[4]. With this technique, a very short microwave pulse (<1 microsecond) heats a sample; the sample then absorbs the microwave energy in a confined time and simultaneously generates temporal thermoacoustic waves, which are strongly related to the locally absorbed microwave energy. The thermoacoustic signals have a wide frequency range up to ~ MHz and carry the information about microwave absorption distribution with millimeter spatial resolution. In practice, microwaves at 300 MHz ~ 3 GHz with 0.1 ~ 1 μs pulse are often adopted, which provide several centimeters penetration depths in biological tissues. Due to the bounded water and salt that exist in cancer cells, a tumor absorbs more microwave energy and generates more intense thermoacoustic waves than the surrounding tissues [5], [6]. The wide range of absorption values among various tissues makes it possible to achieve a high image contrast. In addition, the long penetration depth allows this technique to detect interior tumors.

In this paper, we present our study of pulsed-microwave-induced thermoacoustic tomography under a circular measurement configuration in biological tissues. A wide beam of short-pulse microwave energy is used to illuminate a sample from the bottom. An unfocused ultrasonic transducer with a small aperture is used to record the thermoacoustic signals. A backprojection method based on rigorous theory is used to reconstruct the cross-sectional image from the measured data. A phantom sample is investigated. The reconstructed image agrees with the original sample very well. Finally, the method is compared with laser-induced thermoacoustic tomography.

2. METHOD

A schematic view of the circular measurement system for our study is shown in Fig. 1. 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, which is made of thin plastic material that is transparent to the microwave. 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 0.5μs. A function generator (Protek, B-180) is used to trigger the microwave generator, control its pulse repetition frequency, and synchronize the oscilloscope sampling. Microwave energy is delivered to the sample by a rectangular waveguide with a cross section of 72 mm × 34 mm. A personal computer is used to control the step. The signal from the transducer is first amplified through a pulse amplifier, then

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Biomedical Optoacoustics III, Alexander A. Oraevsky, Editor,
Proceedings of SPIE Vol. 4618 (2002) © 2002 SPIE · 1605-7422/02/$15.00

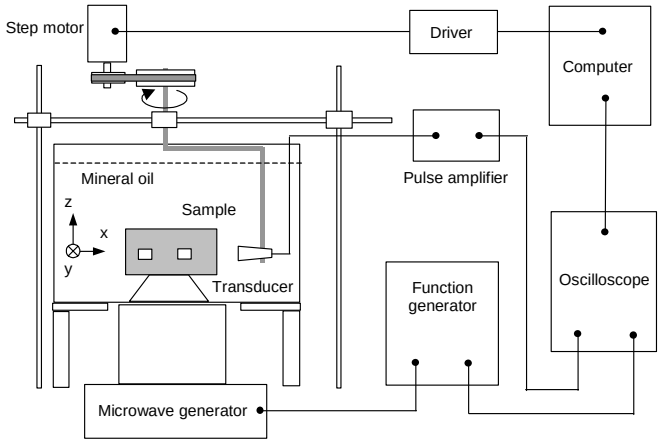

Fig. 1 Schematic of the circular measurement system

recorded and averaged 500 times by an oscilloscope (TDS640A, Tektronix), and finally transferred to a personal computer for imaging.

We assume the tissue to have inhomogeneous microwave absorption and a relatively homogeneous acoustic property. When the microwave pulse duration is < 1 μs, the heat diffusion's effect on the thermoacoustic wave in the tissue can be ignored. The speed of sound c in most soft tissue is relatively constant at ~1.5 mm/μs. Suppose a delta illuminating function $I_0\delta(t)$ and a detected acoustic pressure $p(\mathbf{r}_0,t)$ on the circular surface $\mathbf{r}=\mathbf{r}_0=(\rho_0,\varphi_0,z_0)$ and time *t*. If challenged to detect small size tumors, we can safely remove the low-frequency component. In addition, the wavelengths of the high-frequency thermoacoustic waves are much smaller than the detecting distances between the thermoacoustic sources and the transducers. Under the above conditions, the spatial absorption function $A(\mathbf{r})$ can be calculated by the following 2D surface integral in the cylindrical configuration

$$A(\rho,\varphi,z)=-\frac{C_p}{2\pi c^4\beta I_0}\int\int_{S_0}\rho_0 d\varphi_0 dz_0\sqrt{1-\frac{(z_0-z)^2}{|\mathbf{r}-\mathbf{r}_0|^2}}\frac{1}{t}\frac{\partial p(\mathbf{r}_0,t)}{\partial t}\bigg|_{t=\frac{|\mathbf{r}-\mathbf{r}_0|}{c}}, \qquad (1)$$

where β is the isobaric volume expansion coefficient and C_p is the heat capacity. The above reconstruction formula indicates that the cross-sectional image of any *z* plane is determined mainly by the data measured on the circle of the same *z* plane. In other words, if small absorption sources are located on a *z* plane, a set of circular measurement data on the same plane can be sufficient to yield a good cross-sectional image.

3. RESULTS AND DISCUSSION

A phantom sample was imaged by our microwave-induced thermoacoustic tomography system. The measurement diagram and its cross-sectional photograph are shown in Fig. 2 (a) and (b), respectively. Three small absorbers, which were made of gelatin, salt and water, were buried inside a large fat base. The transducer rotationally scanned the sample from 0 to 360 degrees with a step size of 2.25 degree. The reconstructed image produced by our backprojection method is shown in Fig. 2 (c), which agrees with the original sample very well. The relative locations and sizes of those thermoacoustic sources perfectly match the buried objects in the original sample.

For comparison, as Fig. 3 shows, an example of two black dots with a gap distance 40 μm was imaged by traditional photoacoustic tomography, in which short laser pulses were used to illuminate the sample. A 10 MHz transducer was used to detect photoacoustic signal. Because the laser duration is only 4.7 ns, a higher frequency thermoacoustic signal was generated and a higher spatial resolution was obtained. However, the laser was not able to penetrate very deeply inside of the tissue.

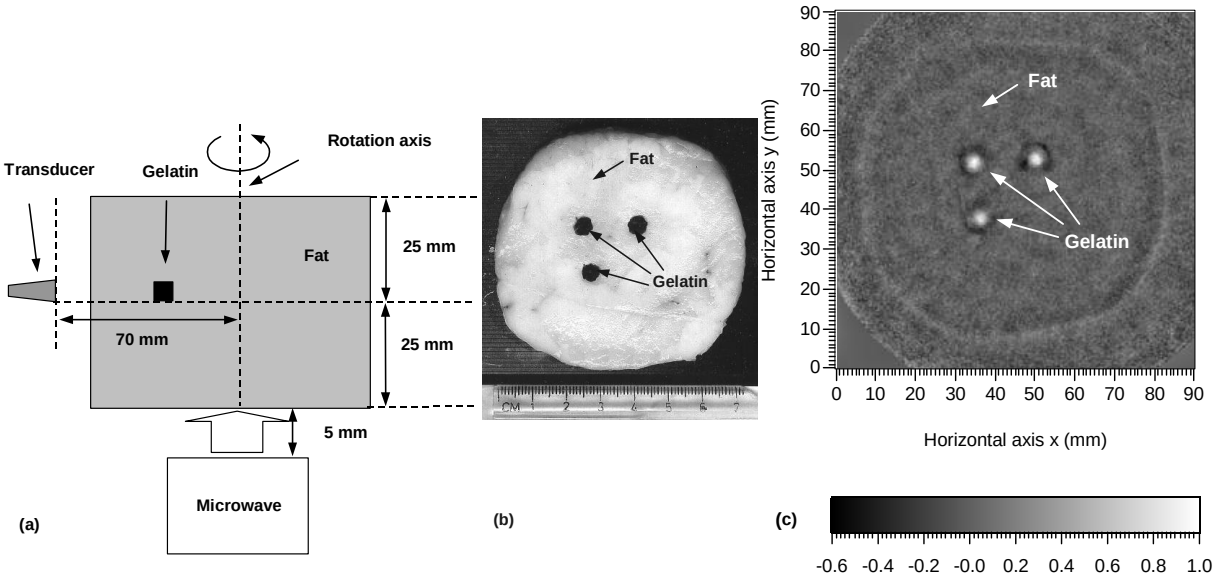

Fig. 2 (a) Diagram of the measurement scheme. (b) Photograph of the sample. (c) Reconstructed image.

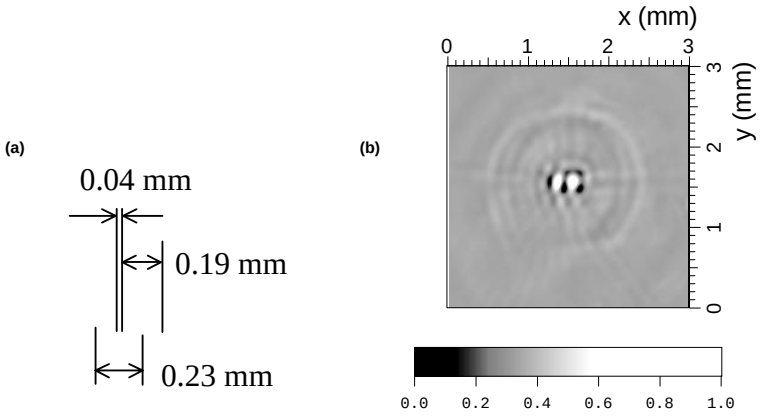

Fig. 3 (a) The schematic of two adjacent dots. (b) The reconstructed image.

4. CONCLUSION

We have presented our study on pulsed-microwave-induced thermoacoustic tomography by a circular measurement configuration in biological tissues. A backprojection algorithm is used to reconstruct the cross-sectional images. The reconstructed image of a phantom sample agrees with the original values very well. The result demonstrates that the circular measurement configuration combined with the backprojection method is a promising technique for use in detecting small tumors buried in biological tissues with microwave absorption contrast and ultrasound spatial resolution (~ mm). Alternatively, a pulsed-laser technique, which provides laser absorption contrast as well as high spatial resolution (~ 50 μm), can be employed as an illumination source to detect small tumors that are not very deeply buried.

ACKNOWLEDGMENTS

This project was sponsored in part by the U.S. Army Medical Research and Materiel Command Grant No. DAMD17-00-1-0455, the National Institutes of Health Grant No. R01 CA71980, the National Science Foudation Grant No. BES-9734491, and Texas Higher Education Coordinating Board Grant No. ARP 000512-0123-1999.

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