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Accuracy Verification of Visceral Fat Area Measurement Using Ultrasound Tomography
超音波トモグラフィ法による内臓脂肪面積測定の精度検証

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1. Introduction

With the escalation of the public medical expenses, importance of the preventive medical care of adult deceases was recognized. Under the circumstances, Japanese government introduced the metabolic syndrome examination as the health diagnosis from Apr. 2008. For this purpose, we have been studying the ultrasound tomographic reconstruction of the abdominal sound speed image aiming to measure the visceral fat area[1,2]. Although the fundamental feasibility of the technique had been demonstrated, more elaborate examinations were required in order to put the technique into practical use. In this paper, further examinations were made to verify the validity of the present method through the experiment using a phantom specimen of human abdomen.

2. Method of the acoustic tomography

We consider the problem to obtain the abdominal cross sectional sound speed $c(x,y)$ by collecting travel time data along the various paths between the tranmitter and receiver points on the abdminal surface. We denote the travel time along m-th path as T_m (m=1,･･,M) and the inverse sound speed of n-th pixel of the medium f_n (=($1/c_n$-$1/c_0$)) (n=1,･･,N), where c_0 is the constant background sound speed. We also denote m-th path's length l_m, travel time difference τ_m (=T_m-l_m/c_0), and intersecting length over the n-pixel w_{mn}. They are symbolized with matrix notations as $\mathbf{f}=[f_1,\cdot\cdot,f_N]^t$ (Nx1), $\boldsymbol{\tau}=[\tau_1,\cdot\cdot,\tau_M]^t$ (Mx1) and $\mathbf{W}=[w_{mn}]$ (MxN). Based on the straight ray propagation assumption, they are related by the following matrix equation:

$$\boldsymbol{\tau} = \mathbf{W}\mathbf{f} \qquad (1)$$

As tomographic solution of eq.(1), unknown inverse sound speed **f** can be calculated by knowing observation $\boldsymbol{\tau}$ and path matrix **W**. We note that the highy distorted waves, including those transmitting through the spinal cord are excluded from the tomographic calculation, since they does not satisfy the straight ray propagation assumption of eq.(1).
The abdominal sound speed of the fat region, which is around 1450m/s, is much lower than the average value of the soft tissues of 1540m/s. On the other hand, the sound speed of protein regions including muscle, intestine and kidney, which is above 1550m/s, is higher than the average value. The fact enables us to estimate the fat areas from the reconstructed abdominal cross sectional sound speed image. Here, in order to serve the technique to the metabolic syndrome diagnosis, visceral fat regions should be discriminated from the subcutaneous fat region. To this end, border between the subcutaneous and visceral region is estimated using the marked points obtained along the high sound speed abdominal muscle regions in the reconstructed image. Using the border information thus obtained, visceral fat regions are separated from the subcutaneous ones and visceral fat area can be finally measured.

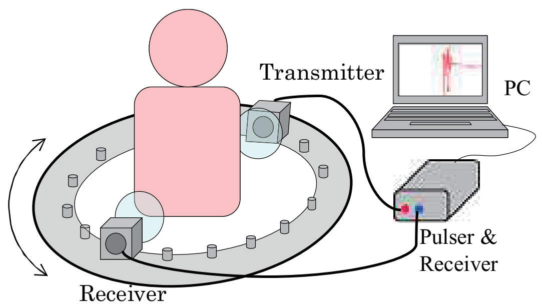

Fig.1 Abdominal travel time observation system.

3. Evaluation experiment

3.1 Experimental setup

As shown in Fig.1, a facing pair of ultrasound transmitter and receiver (with frequency band 10-500 kHz and aperture diameter 40 mm) are moved along the abdominal peripheral circular boundaries with diameter D=380 mm. The transmitter is moved at 32 equiangular points and the receiver is moved along 16 equiangular points along the circular boundaries. With the combination of these transmitter and receiver points, measurements are made along M = 96 paths.

3.2 Phantom

An abdominal mimicking phantom was prepared as shown in Fig.2. A urethane wall

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ultrasound abdominal phantom (275x200 mm) having a plastic spinal cord pillar was used as a container. At the circumference region, high speed polyethylene glycol objects were embedded as abdominal muscle regions, where 8% concentration glycerin was added to adjust the sound speed with c_2=1575 m/s. In the interior part, food oil objects with sound speed c_3=1450 m/s were embedded as visceral fat regions. Between the objects, ultrasound gel with sound speed c_1=1500 m/s was filled. By changing the areas of the visceral fat region (whose sound speed being c_3), examination experiment were made for the precision verification of the visceral fat area measurement.

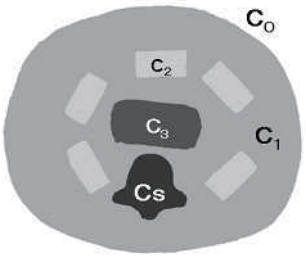

Fig.2 Abdominal phantom used in the experiment.

3.3 Result and discussion

The travel time data were measured for the abdominal phantom described above. Using the measured data, the sound speed image was reconstructed as shown in Fig.3(a). In addition, the images using the simulation data were compared based on the ideal straight ray propagation calculation and the rigorous finite difference methods as shown in Fig.3(b) and (c), respectively. The experimental result in Fig.3(a) is close to the theoretical ones in (b) and (c). The resolution and fidelity of the image are somewhat degraded. This is due to the lack of the data and can be improved if the much number of path data are incorporated. On the whole, however, it was demonstrated that the reproducibility of the image was almost satisfactory, especially for the purpose of the visceral fat area measurement. Finally, similar examinations were made using the phantom having different visceral fat areas. The experimentally obtained visceral fat area as a function of predetermined value are shown with solid line in Fig.4. Its correlation coefficient was estimated as R^2=0.95. For comparison, results using the simulation data based on the ideal straight ray propagation model is shown with dotted line in Fig.4 (R^2=0.98). It is confirmed that correlativity is good enough in both experiment and simulation results. The results demonstrate the validity of the present method for the abdominal visceral fat area measurement.

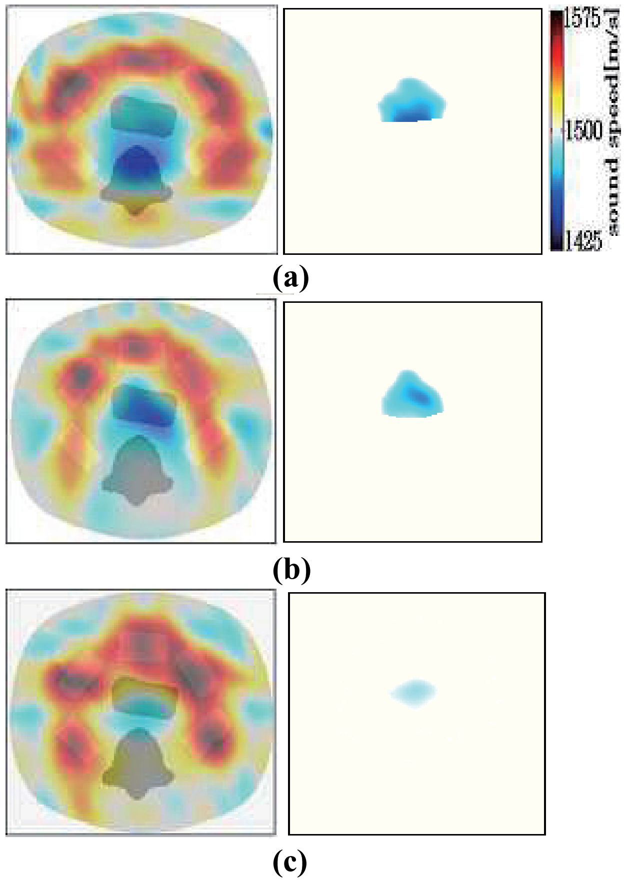

Fig.3 Reconstructed sound speed image (left hand) and extracted visceral fat region (right hand): (a) experimented image, (b)simulated image based on the straight ray path model, (c) simulated image based on the finite difference calculation.

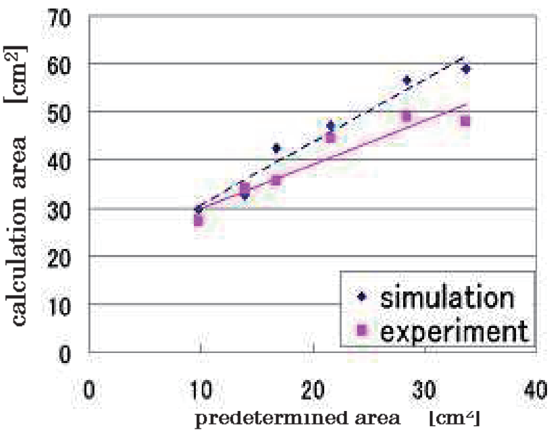

Fig.4 Relationship between measured and predetermined visceral fat area.

References

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