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Basic study on USCT for brain imaging
頭蓋内超音波 CT の基礎的検討

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1. Introduction

Currently, echo is widely used as a ultrasound tomography method. Another tomography method, USCT (Ultrasound Computed Tomography) uses reflected wave as well as transmitted wave, which can construct the map of medium sound speed distribution. Greenleaf *et al*.[1] showed sound speed and attenuation index could be used to distinguish benign masses from cancer by measuring the sound property of breast. However, this method did not result in clinical test due to the limited performance of CPU in those days. Duric *et al*.[2] developed the Computed Ultrasound Risk Evaluation (CURE) system with the clinical goals of whole breast. In this system, the ring-shaped transducer (**Fig.1**) surrounding the breast moves vertically to construct tomographic images. USCT can construct three different images, reflection image, sound speed image and attenuation image with each data collection.

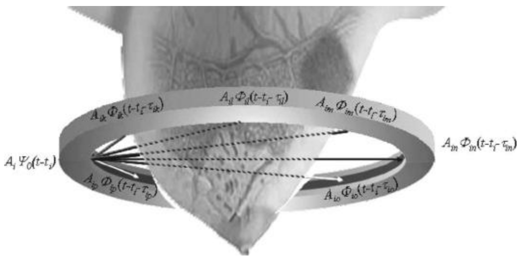

Fig.1　Ring-Shaped Transducer[2]

We are considering diagnosing inside the skull with USCT. Generally, emergency patients with cerebral infraction or cerebral hemorrhage are carried to hospital, then examined and treated. Since every minute counts in such situations, we intend to examine during the conveyance and reduce the time until the treatment starts by introducing USCT into ambulances. When we try to construct tomographic images inside the skull with USCT, the skull would have some influence unlike the case of the breast. The purpose of this study is to clarify the skull's influence on acoustic properties and establish the method of reconstructing images for the diagnosis inside the skull.

2. Experiment

To construct tomographic images, the sound speed distribution of the skull should be acquired in advance. Owing to this, we fabricated objects in the shape of the skull with various materials and measured their sound speed.

We designed and fabricated the prototype of ring-shaped transducer as shown in **Fig.2**. The ring consists of 1024 elements and its diameter is 100 mm. Each element can transmit and receive US signals independently. This transducer is operated by Verasonics ultrasound system (**Fig.3**), which is capable of controling the behaviors of elements freely with MATLAB program. We placed objects simulating the skull inside the ring and collected the data.

The preliminary result of this experiment will be discussed on the day of the symposium.

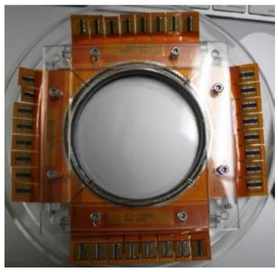

Fig.2　Prototype of Ring-Shaped Transducer

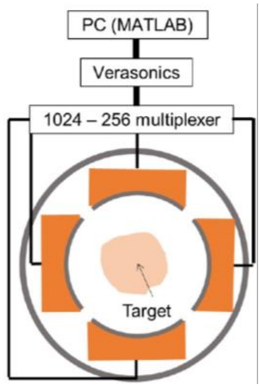

Fig.3　Verasonics ultrasound system

3. Simulation

3.1 Method

Consider the diagram in **Fig.4(a)** in which 1024 elements are equally spaced. Assuming that the transmitter is located at $\vec{r_t}$, the receiver at $\vec{r_r}$, the scatter at $\vec{r_p}$ and the velocity of ultrasound is v, the arrival time from any transmitter to any receiver via the scatter is obtained as below.

$$\tau = \frac{l_T + l_R}{v} = \frac{1}{v}\{|\vec{r}_p - \vec{r}_t| + |\vec{r}_p - \vec{r}_r|\} \qquad (1)$$

Calculating the total sum of signal values that exist along the locas represented by Eq.(1) from the plot of the arrival time and the receiver number (**Fig.4(b)**), the resulting sum represents the reflection intensity at that point. Repeating this process with the scatter located at each grid point, reconstruction images are obtained by fitting the resulting reflection intensity to each grid point. We acquired the reconstruction image with the simulation in which the ring-shaped area simulating the skull was set by using k-Wave, MATLAB toolbox for acoustic wave simulation. The simulation condition is shown in **Table I**.

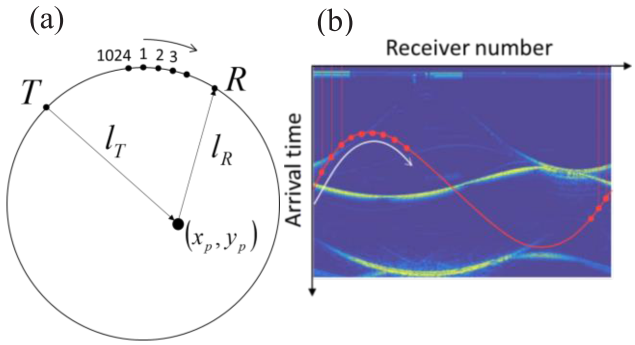

Fig.4 Method of calculating transmit times

Table I Simulation condition

Sound speed of water [m/s]	1500
Sound speed of the skull [m/s]	3265
Grid size [mm]	0.215×0.215
Thickness of the skull [mm]	2.15

3.2 Result

The results are shown in **Fig.5**, in which the vertical/horizontal axes represent arrival time and receiver number respectively. Fig.5(a) of the case without the skull shows a sinusoid representing the wave reflected by the scatter in addition to signal of waves which traveled from the transmitter to the receiver directly. Although the sinusoid did not change in shape remarkably, some noise appeared in Fig.5(b) of the case with the skull. It is assumed that this noise was caused by reflected wave by the skull and multiple reflection(**Fig.6**). Moreover, **Table II** shows comparison of typical signal intensity at enclosed area 1, 2 (receiver numbers are 35, 896 repectively) in Fig.5. At area 1, dB value difference is 7.4, which corresponds to 57.3% reduction in original signal value. This reduction probably arised from reflective energy loss. Similarly, dB value difference is 24.9 at area 2, which corresponds to 94.4% reduction in original value. We speculate that reflected wave by the scatter couldn't arrive at the receiver due to total reflection.

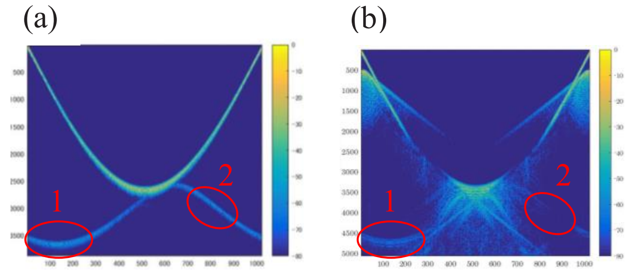

Fig.5 Plot of the arrival time and the receiver number

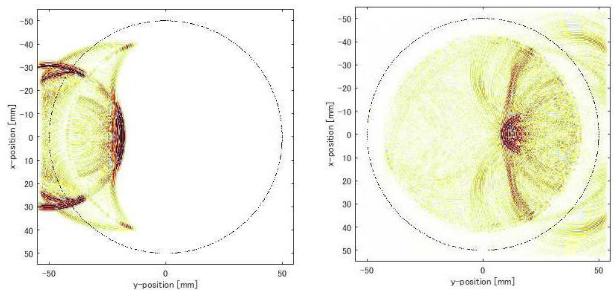

Fig.6 Transmitting wave through the skull

Table II Comparison of signal intensity with/without the skull

	1 (35 ch)	2 (896 ch)
(a) [dB]	-33.9	-37.2
(b) [dB]	-41.3	-62.1

4. Summary

In this paper, we discussed the influence of the skull on brain imaging. Future studies will focus on image reconstruction method from echo data obtained by ring array. Although we simulated with homogeneous medium, actual skull, which consists of cortical bone, cancellous bone and any other, is inhomogeneous. Additionally, its thickness is also not uniform unlike ring-shaped model. Thus, the simulation in which such a complicated medium is set should be done. For validation of these simulations, the experiments using the prototype system are required. Furthermore, it is anticipated that conventional reconstruction method doesn't work for clinically realistic model. We will improve reconstruction method that can be applied to clinilcal data.

References

1. Greenleaf JF, Johnson SA, Bahn RC:Ultrasonics Symposium. (1977) 989-95

2. Duric N, Littrup P, Poulo L,et al:Medical Physics. **34** (2007) 773-85