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Multidirectional reception of photoacoustic signal for higher resolution imaging
多方向からの光音響信号受信による高解像度イメージング

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1. Introduction

Rheumatoid arthritis (RA) is an autoimmune disease that causes inflammation in the joints throughout the body. Imaging of microvasculature of the synovial membrane is important for early detection of RA. Power Doppler ultrasound has been used for the vasculature imaging in clinical settings. However, power Doppler is not sufficient to detect slow flow and the spatial resolution is limeted to visualize small vessels [1].

Photoacoustic (PA) imaging is an imaging modality that is compatible with the advantages of high spatial resolution in optical imaging and high penetration depth in ultrasound imaging[2,3]. PA is clinically applied by combination with ultrasonic diagnostic equipment for visualization of synovial blood vessels.

Linear probes are mainly used in clinical PA imaging. In case PA imaging is implemented with a linear probe, it is usually to direct the probe to receive the signal from a specific direction. However, in that case, it is difficult to completely acquire the PA signal from the tissue generated as a point sound source because the area for receiving the signal is limited[4].

High resolution PA imaging method is proposed by receiving the PA signals from multiple directions to generate a compound PA image. In the present study, the effeciency of the method is verified by a simulation study.

2. Materials and Methods

2.1 Method of reconstruction

Fig. 1 shows a scheme of the reconstruction method in this study. Linear probes are placed at different angles θ around the imaging target, and photoacoustic signals are acquired at respective positions. Multiple data obtained from various angles are added and averaged. Then, a single PA image is acquired like compound imaging.

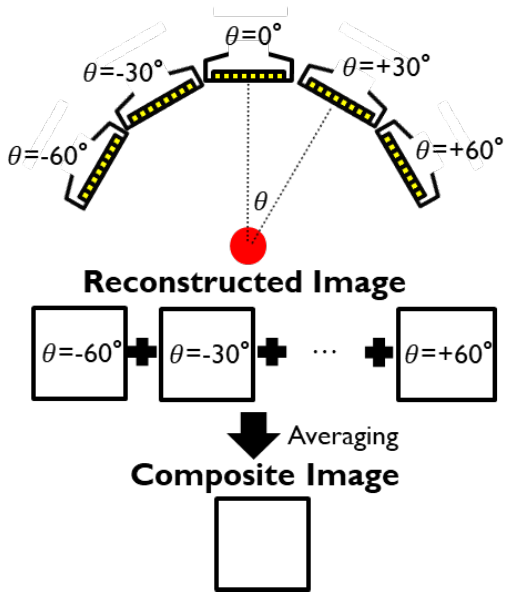

Fig. 1 Schema of reconstruction

2.2 K-Wave simulation

To verify the effectiveness, simulation was carried out using K-WAVE[5]. A scheme of the simulation model is shown in **Fig. 2** and parameters are shown in **Table 1**. The model was mimicked a finger in which muscle is surrounding a bone. The acoustic sources were placed at 0° and ± 45° with respect to y = 0. The angle θ at which the probe is placed, is set to 0°, ± 30°, ± 60°, and a compound image is generated by the proposed method using all the obtained data.

Table 1 Simulation Conditions

Parameters	Specification
Number of elements	128 ch
Element pitch	0.3 mm
Center frequency	12 MHz
Sound speed of region A	1500 m/s
Sound speed of region B	1500~1600 m/s
Sound speed of region C	3000 m/s
Size of photoacoustic source	150 μm
Pixel size	25×25 μm

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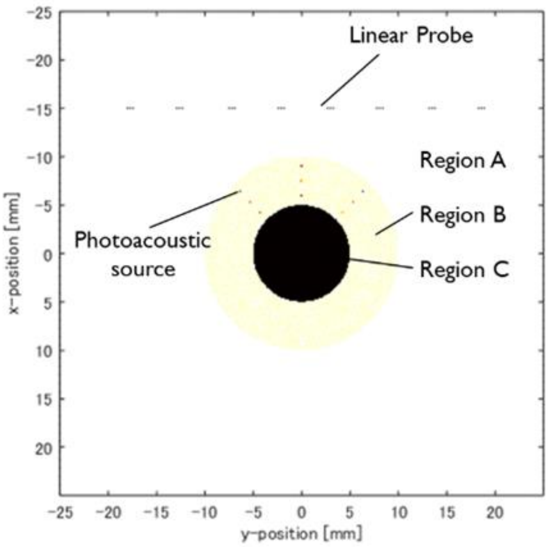

Fig. 2 Scheme of the simulation model

3. Results and discussions

Fig. 3 (a) shows a reconstructed image when a single linear probe is placed at $\theta = 0°$ and a signal is acquired from $\theta = 0°$ direction. Fig. 3 (b) shows a reconstructed image when signals are acquired at various angles (θ = 0°, ±30° and ±60°) and generated by the proposed method.

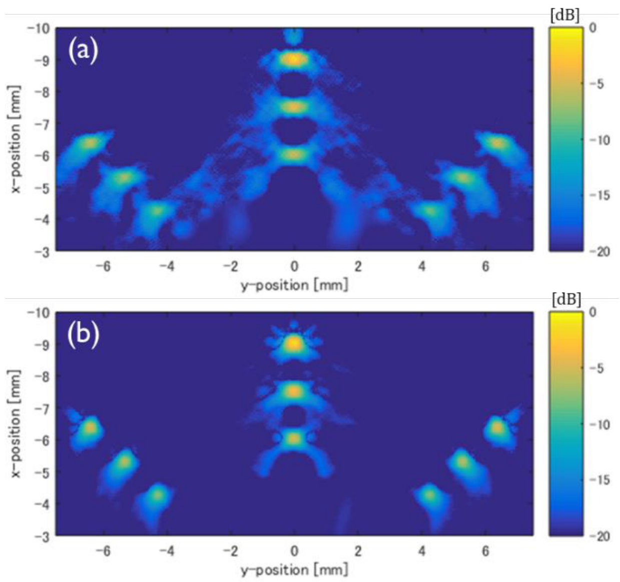

Fig. 3 Reconstructed image. (a) Probe is placed at $\theta = 0°$. (b) Probe is placed at $\theta = 0°$, ±30° and ±60°.

As shown in Fig. 3 (a), when the signal was received and reconstructed in only one direction, the reconstructed shape of the acoustic source was blur. Also, the contrast was reduced due to the influence of side lobes. However, in the reconstructed image using the proposed method (Fig. 3 (b)), the shape of the point sound source becomes clear, and side lobes are suppressed.

The resolution was precisely compared in the magnified image around a single point sound source. **Fig. 4** (a) and (b) show the enlarged reconstructed image of a point sound source in Fig. 3 (a) and (b), respectively.

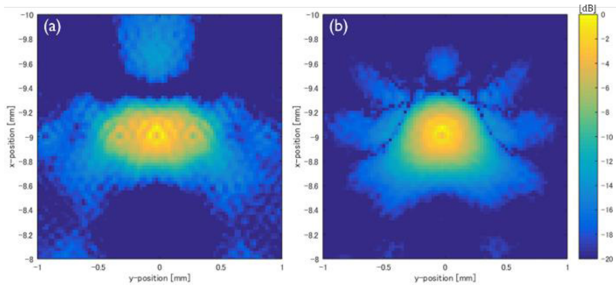

Fig. 4 Reconstructed point sound source in (a) Fig. 3(a) and (b) Fig. 3(b)

When the linear probes were placed at one direction ($\theta = 0°$), the lateral resolution was 650 μm, but in the proposed method it was improved to 450 μm. This shows that point spreading can be suppressed by receiving signals from multiple directions.

4. Conclusion

In the present study, simulation study in which a linear probe was placed around the target to receive PA signal from multiple directions. The generated compound image was compared with a PA image acquired from one direction. The results showed that the resolution, contrast and shape of the sound source were improved by the proposed method. The results also indicate the possibility to obtain high resolution PA image of micro vasculature of a synovial membrane for early diagnosis of RA.

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