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Effect of Coherence Factor Weighting for Improving the Image Quality of an Annular Array Photoacoustic Microscope

アニュラアレイ光音響顕微鏡の画質向上に資するコヒーレンスファクタの検討

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1. Introduction

Morphological observation of the peripheral microvascular network is known as a promising diagnostic method for detecting subtle changes in systemic hemodynamics and evaluating inflammation in skin and joints[1, 2)]. Microvessels in the dermis have a diameter of several tens of micrometers, and in order to visualize these superficial microvessels, it is necessary to establish imaging techniques with high spatial resolution and selective extraction of blood vessels. On this topic, photoacoustic (PA) imaging has gathered much attention as it is capable of selectively visualizing those micro-scale blood vessels[3)].

Our research group has developed a novel photoacoustic imaging system equipped with a four channels annular array transducer to achieve visualization of superficial microvascular networks with an increased depth-of-field (DoF). The annular array transducer consists of four ring-shaped concentric concave elements so that it can improve the DoF by applying the Delay-and-Sum (DAS) method. Nevertheless, the DAS method sometimes results in blurred images when signals from off-axis cause the phase shift of the received signals[4)].

As a solution, the coherence factor (CF) weighting may be used in addition to the DAS method as it has effectively suppressed such off-axis signals in the adaptive beamforming in the signal processing of ultrasound imaging systems[4)]. In this paper, we applied the CF weighing to the PA data acquired with the annular array transducer and evaluated the efficacy of the method for improving the image quality.

2. Material and Methods

2.1 Experiment setup and data acquisition

A PA imaging system (Hadatomo™ Z WEL5200 prototype developed in a joint effort by Tohoku University and Advantest Corporation) was utilized in this study. The system can emit pulsed laser beams (wavelength: 532 nm) and acquire PA signals from the superficial vessels with the 4-ch annular array transducer (center frequency: 60 MHz). In this study, the laser fiber and the transducer were set to be mechanically moved to scan an area of 9 x 9 mm at a scan step of 30 x 60 μm.

Cutaneous microvessels in the inner side of the forearm of a healthy male in his 20s were measured with the system. In order to avoid artifacts from the melanin in the epidermis, only the PA signals that came from the dermis layer (approximately 1.2–1.8 mm) were acquired at a sampling frequency of 500 MHz.

2.2 Processing of the received PA signals

For the photoacoustic signals received by the four elements, the DAS algorithm was applied by correcting the difference in the arrival time of the signals to each element and summing those corrected signals together[5)]. Furthermore, the CF weighting coefficients were calculated and multiplied to the signals after the DAS processing[5)]. The range of CF was from 0 to 1 depending on the phase coherency of the signals among the channels. It is noted that raw RF data was generated as a control by adding the received signals without any phase corrections.

2.3 Visualization of skin microvessels

To visualize the processed PA data, the maximum amplitude projection (MAP) method was applied and three C-mode images (Raw, DAS and DAS+CF) were generated. Each image was normalized by its maximum amplitude value. To evaluate the image quality of each condition, the full width at half maximum (FWHM) and peak signal to noise ratio (PSNR) were calculated. All signal and image processing and data analysis were carried out in MATLAB software (MATLAB 2020b, Mathworks).

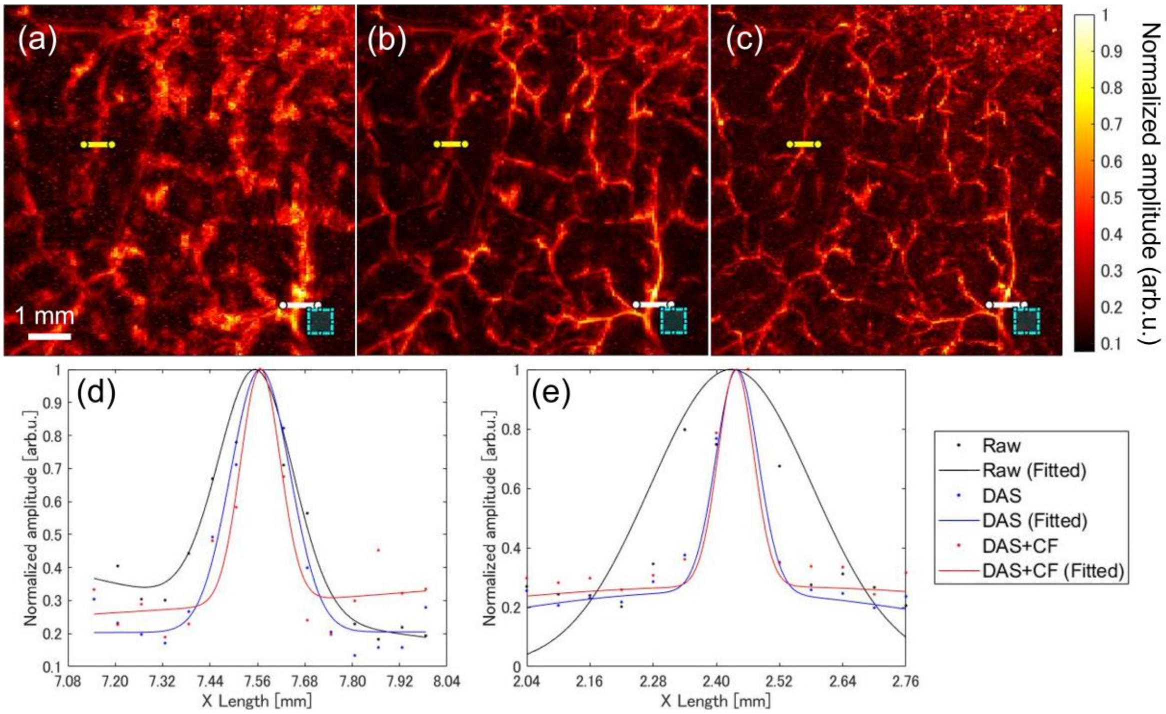

Fig. 1. The microvessels C-mode images: (a) Raw image, (b) Image with the DAS method, and (c) Image with the DAS and CF weighting. Profiles in white and yellow line correspond to curves in (d) and (e), respectively.

Table 1. Values of full width at half maximum and PSNR for each data.

	Raw	DAS	DAS+CF
FWHM of Fig.1 (d) (μm)	288.09	211.78	157.93
FWHM of Fig.1 (e) (μm)	362.98	118.57	103.66
PSNR (dB)	16.47	17.32	15.88

3. Results and discussion

The micro-scale blood vessels were successfully visualized with our PA imaging system (**Fig. 1**). The image generated using the raw PA signals (Fig. 1(a)) was blurred and the vascular structure was not clear. On the other hand, the image generated applying the DAS and CF methods (Fig. 1(b, c)) showed that those methods could effectively sharpen the microvascular structure.

The sharpness of the vessels was evaluated at a large and a small blood vessels marked by respectively white and yellow lines in Fig. 1(a–c). Each profile of the amplitude under the lines and its fitted curve using a gaussian mixture model were shown in Fig. 1(d, e) and their FWHM values were shown in **Table 1**. The FWHM of DAS+CF was found to be the smallest among the conditions, and the visualized diameter of the vessels was sharpened by 45–71 % compared to the raw image.

In addition, we calculated PSNR using a noise region marked as blue boxes in Fig. 1(a–c). As shown in Table 1, PSNR was decreased in DAS+CF method because it suppressed signal intensity in the noise region as well as those in the vessel regions.

4. Conclusion

In this paper, we assessed the effect of the CF weighting method, in addition to the DAS method, for the annular array PA imaging system by evaluating the imaging quality of the cutaneous microvasculature. The experiment showed that the CF weighting was effective to sharpen microvessels, while it might excessively suppress the entire signal intensity. To overcome the drawback, we will further study the appropriate way to utilize the CF weighting method by considering the effect of the imaging depth for the CF coefficients.

References

1. L. I. Manneschi, A. D. Rosso, A. F. Milia, A. Tani, D. Nosi, A. Pignone, S. Generini, R. Giacomelli and M. M. Cerinic: Rheumatology **44** (2005) 607.
2. I. B. McInnes and G. Schett: Nature Immunol. **7** (2007) 429.
3. J. Yao and L. V. Wang: Laser Photonics Rev. **7(5)** (2013)758.
4. J. Zhao, Y. Wang, W. Guo and J. Yu: J. Acoust. Soc. Am. **141** (2017) 2177.
5. P. V. Chitnis, O. Aristizábal, E. Filoux, A. Sampathkumar, J. Mamou and J. A. Ketterling: Ultrasonic Imaging **38(1)** (2016) 32.

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