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Preliminary Study of Skin Microvasculature Visualization by High Frequency Ultrasound Plane Wave Imaging

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1. Introduction

Cutaneous microvascular imaging plays a pivotal role in the diagnosis of various skin diseases.[1)] Many studies have been conducted to visualize the micro scale structures in skin. For example, high-frequency ultraosund was used to visualize layered structures of skin with good spatial resolution and penetration depth.[2)]

While B-mode images cannot clearly visualize the microvasculature, it has been reported that Doppler techniques can be used to map and visualize those precise structure.[3)] However, Doppler sensitivity to the slow blood flow in the microvasculature is not sufficient on conventional ultrasound imaging systems because of the line-by-line focused imaged formation scheme. A solution is use of ultrafast ultrasound imaging (i.e. plane wave imaging) that can increase number of Doppler ensembles and the Doppler sensitivity. In addition, by using coherent compounding processing, high resolution both in space and time can be achieved.[4)]

In this study, we develop an ultrafast ultrasound imaging system in order to achieve high-resolution and high-sensitive images of cutaneous microvasculature. As a preliminary study, the system properties such as spatial resolution, SNR and CNR were evaluated using wire and tissue mimic phantoms.

2. Materials and Methods:

2.1 Imaging System

An ultrafast high-frequency ultrasound imaging system was devised using a research ultrasound platform (Vantage 256 high-frequency configuration; Verasonics Inc., Kirkland, WA, USA) equipped with a L38-22v CMUT linear array transducer (KOLO silicon, USA) as shown in **Fig. 1**. Plane wave pulses (128 ch, f_c = 30 MHz) were emitted at pulse repetition frequency of 250 Hz and a hundred frames of 256 channel-domain RF signals from up to 9 mm in depth were received and recorded. Note that the Vantage system has a limited sampling rate of 62.5 MHz that is insufficient for acquiring high-frequency signals. Instead, we used the approach of bandwidth

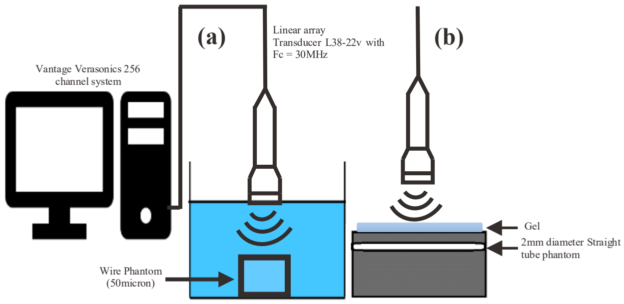

Fig. 1 Schematic diagram of ultrafast high frequency ultrasound setup to test its imaging characteristics.
(a) 20 μm wire phantom to evaluate the spatial resolution, (b) Straight tube phantom of 2 mm diameter and 40 mm length to evaluate the B-mode image quality

sampling[5)] with a controlled sampling rate of 41.6 MHz.

2.2 Experiment

In this preliminary study, we built up a setup to validate the quality of B-mode images and optimize the system parameters by using two phantoms: 1. A 20 μm wire-phantom to evaluate the spatial resolution of the system; and 2. A straight tube phantom made of poly-vinyl alcohol (PVA) to evaluate image contrast.

2.2.1 Wire Phantom

A 20 μm wire was submerged in the water bath and the probe was adjusted with the probe stand to acquire noise-free images. Based on the acquired B-mode images, axial resolution of the imaging system was calculated by full width half maximum (FWHM) of the point spread function of the wire target.

2.2.2 PVA Straight Tube Phantom

A PVA phantom was designed to contain a straight tube of 2 mm in diameter and 40 mm in length and fabricated by the following published protocol.[6)] The material for the phantom consisted of 10 wt% of PVA powder and 3 wt% of graphite particles.

Fig. 2 shows the step-wise procedure of PVA phantom fabrication. To evaluate the system properties (spatial resolution, SNR and CNR) using ultrafast high frequency ultrasound. B-mode imaging of the phantom will provide sufficient information about the system performance.

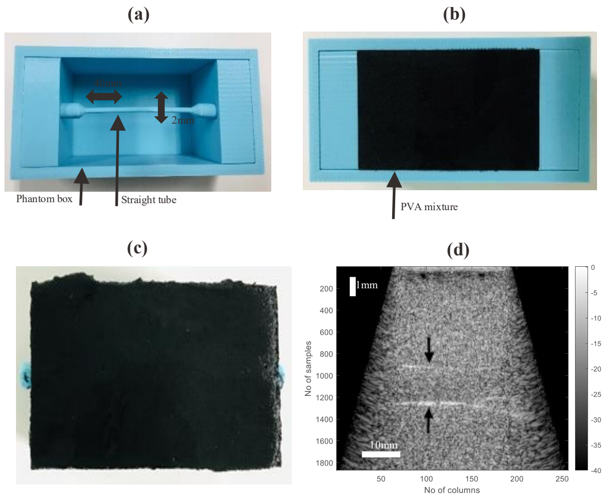

Fig. 2 Design and imaging result of the PVA phantom (a) the mold for the phantom, (b) casting of PVA phantom, (c) PVA phantom after a freeze-thaw cycle, and (d) a B-mode image (arrows indicate upper and lower wall of the straight tube)

3. Results

Fig. 3 shows the measurement results of axial resolution at 30 MHz frequency. The experimental axial resolution obtained from FWHM of PSF was calculated to be 82.0 μm at 1 cycle in pulse in relation to the theoretical value of 77.0 μm. From this result, it can be said that the obtained resolution is sufficient to visualize skin microvasculature, which diameter is a range of 80 - 160 μm.[2)]

On the other hand, a straight tube in the PVA phantom was also successfully visualized (Fig.2(d)). The distance between the upper and lower wall of the straight tube in the image was found to be 1.70 mm, which was reasonably same as the designed diameter of the tube.

4. Conclusion:

In this study, we devised an ultrafast high-frequency ultrasound imaging system and validated its fundamental imaging performance. Measurements from wire and straight tube PVA phantoms, indicate that the developed system will be useful for visualizing skin microvasculature, although further investigation of system parameters is needed to achieve optimal spatial and temporal resolvability.

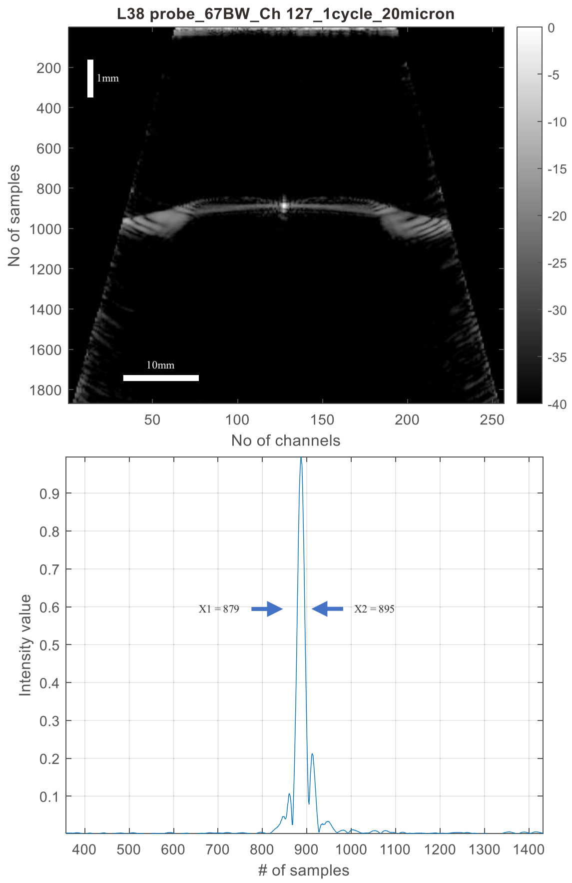

Fig: 3 Experimental Axial Resolution

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