Real-time Photoacoustic & Ultrasound imaging of human vasculature

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ABSTRACT

A real-time photoacoustic imaging system was designed and built. This system is based on a commercially available ultrasound imaging system. It can achieve a frame rate of 8 frames/sec. This system has been characterized in phantom experiments. In addition, vasculature in the hand of a human volunteer was imaged.

Keywords: photoacoustic, optoacoustic, imaging, blood vessels

1. INTRODUCTION

Blood vessels play a key role in homeostasis, growth and repair of tissue. Knowledge on the presence of blood vessels, the content of hemoglobin and its degree of oxygenation, yield crucial information regarding the ability of tissue to heal or of the tumor to sustain itself and grow. The effect of therapies based on blood vessel targeting drugs can primarily be judged from the response of the vascular bed.

A promising new technique to obtain both anatomical and functional information about the vascular bed is photoacoustic imaging. Photoacoustic imaging is a hybrid imaging tool that is based on the generation of acoustic waves by optical absorption of pulsed light. Here the main absorber will be hemoglobin in the red blood cells. The absorption of short (nanosecond) light pulses causes a small local rise in temperature. This results in restricted dilatation of the red blood cells and an elevation of the local pressure, thereby generating ultrasonic waves. From the time of flight of this ultrasonic wave to reach the tissue surface (detector position), the distance of the photoacoustic source can be calculated using knowledge about the speed of sound in tissue. The positions of blood concentrations can be reconstructed in three dimensions when the ultrasonic waves are measured in a sufficient number of locations on the skin. In this way PAI exploits the high intrinsic optical contrast of blood and provides high contrast images.

Due to its intrinsic optical absorption contrast and its quantitative nature, PAI has successfully been applied to in vivo imaging of blood vessel-structures in small animals [1]-[5] and humans[6]-[10]. Furthermore, the application of PAI in

Photons Plus Ultrasound: Imaging and Sensing 2009, edited by Alexander A. Oraevsky, Lihong V. Wang, Proc. of SPIE Vol. 7177, 717704 · © 2009 SPIE · CCC code: 1605-7422/09/$18 · doi: 10.1117/12.807266

mammography is being investigated[11]-[13]. However, clinical application of photoacoustic imaging is currently limited by its long imaging time. In this paper we will present the development of a clinically applicable real-time photoacoustic imaging system.

2. REAL-TIME PHOTOACOUSTIC IMAGING SYSTEM

A commercially available ultrasound imaging system (Picus, ESAOTE Europe BV, Maastricht the Netherlands) was modified to be used for photoacoustic imaging. To this system a linear array (L10-5, 40 mm, 7.5 MHz central frequency, 128 elements, ESAOTE Europe BV) was connected to generate and detect the ultrasound. In case of photoacoustic imaging the entire detection system as well as image reconstruction of this ultrasound system are employed.

The necessary changes to this system include synchronization of the data-acquisition with the firing of the laser and an option to switch-off the emission of ultrasound.

To generate the laser-induced ultrasound, an optical system was developed which was connected to the ultrasound detection array. This optical system deflects the beam towards the tissue below the ultrasound array (Figure 1). By changing the distance between the ultrasound probe and the tissue, the position of incidence of the light can be tuned. In this way it allows for direct illumination (illumination of the tissue within the detection plane) or dark field illumination (illumination of the skin just outside the detection plane).

By this optical system the tissue was illuminated with light pulses from an Nd:YAG laser (Diny pQ, IB laser, Berlin, Germany) with an energy of about 2 mJ/pulse, a pulse repetition frequency of 1000/s and a pulse duration of 8 ns.

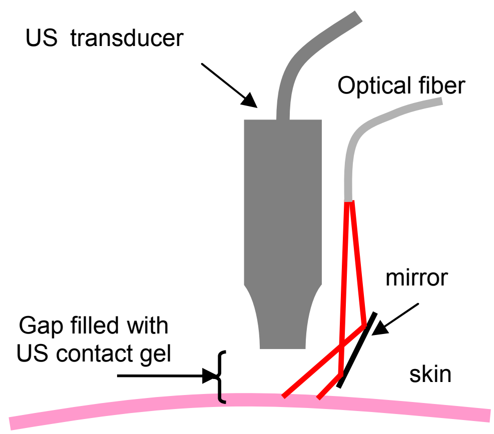

Figure 1: Schematic overview of optical system attached to ultrasound probe.

The modified ultrasound imaging system is able to acquire a single A-line of the image for each laser-pulse. For a full B-scan 128 laser pulses are required. With a laser operating at 1000 pulses/s this results in a frame-rate of 8 frames/s, which is an enormous improvement in temporal resolution compared to reported *in vivo* photoacoustic imaging times in the order of 2 minutes for a single B-scan [10]. A photograph of the system and the probe are shown in Figure 2.

Compared to the systems reported in literature [8],[14] the combined photoacoustic and ultrasound imaging system described in this letter has the advantage that it is based on a conventional ultrasound system, not requiring a 128-channel high speed digitizer in combination with a personal computer to capture the data or reconstruct the images.

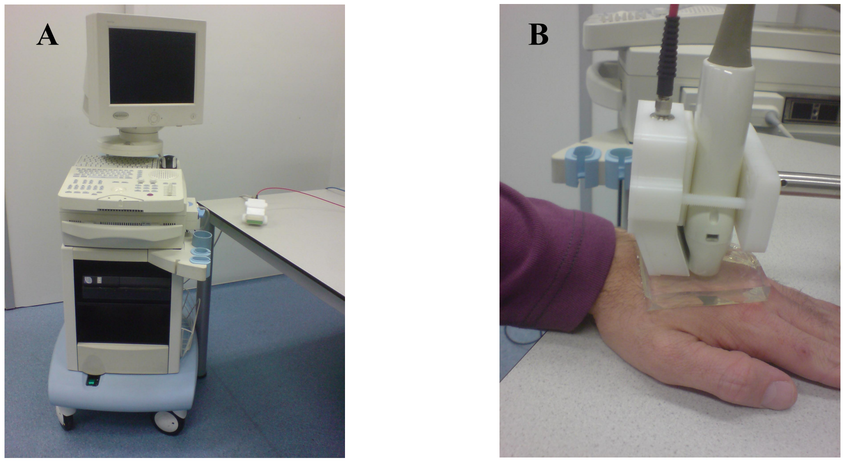

Figure 2: Photograph of the photoacoustic imaging system (A) and the ultrasound probe positioned on the hand on a volunteer (B)

3. RESULTS

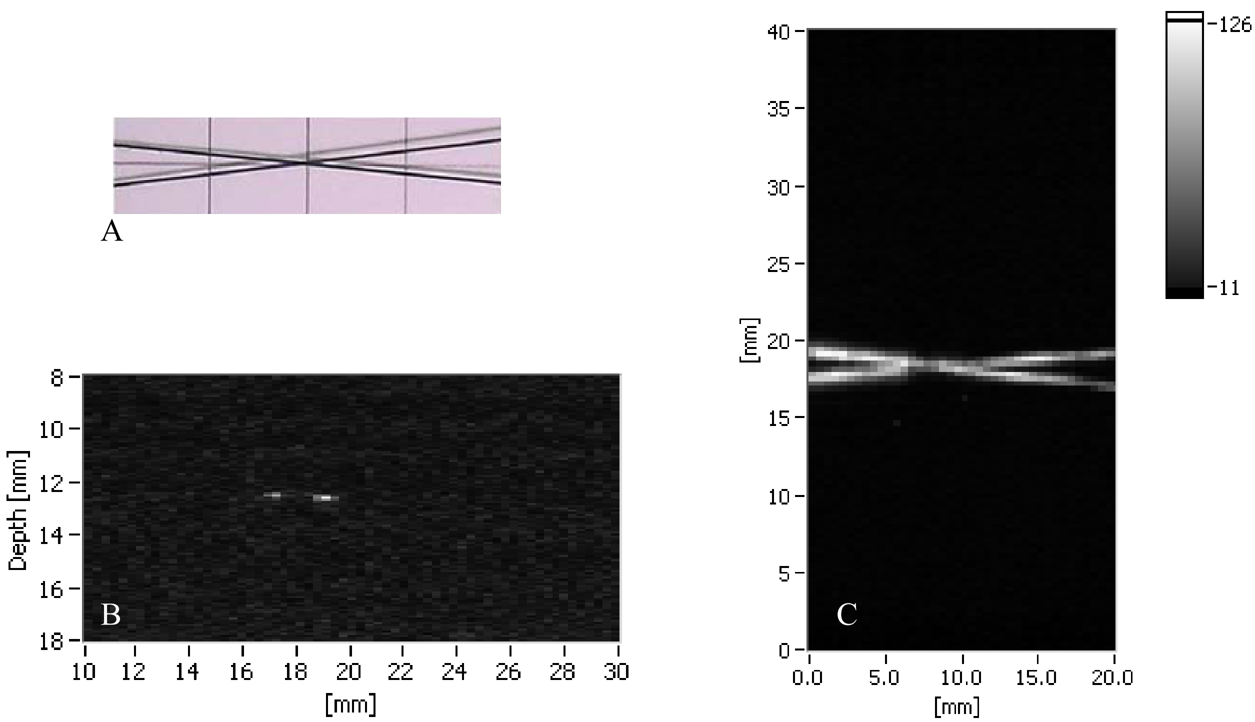

Figure 3: A – photograph of crossed sutures; B – B-scan of crossed black sutures embedded in water; C – Photoacoustic image of the top view (Maximum Intensity projection) of the black sutures.

The resolution of the system was estimated by imaging two crossed black sutures (diameter 200 µm) embedded in water. A photograph, a single slice as well as the top view (Maximum Intensity Projection) of this suture are shown in Figure 3.

The lateral resolution was estimated from the intensity profiles of the top-view image. A Gaussian distribution was fitted to the intensity profiles (Figure 4) and from the Full Width at Half Maximum the resolution was estimated to be 270 μm.

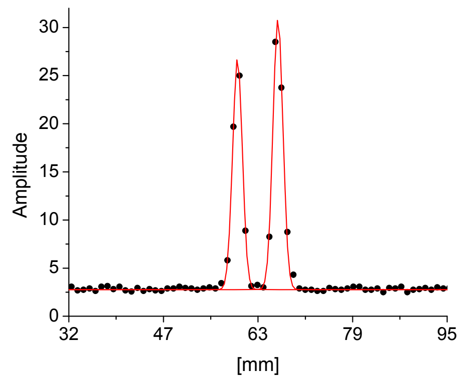

Figure 4: Fit of Gaussian distributions to intensity profile of crossed sutures.

The system has been applied to imaging of human vasculature in the dorsal side of the hand of a human volunteer. An energy of 1.9 mJ/pulse was applied to an area of the skin of 5 x 20 mm^2. The pulse repetition of the laser was set to 1000 pulses/s. The gap of about 11 mm between the ultrasound transducer and the skin was filled with water.

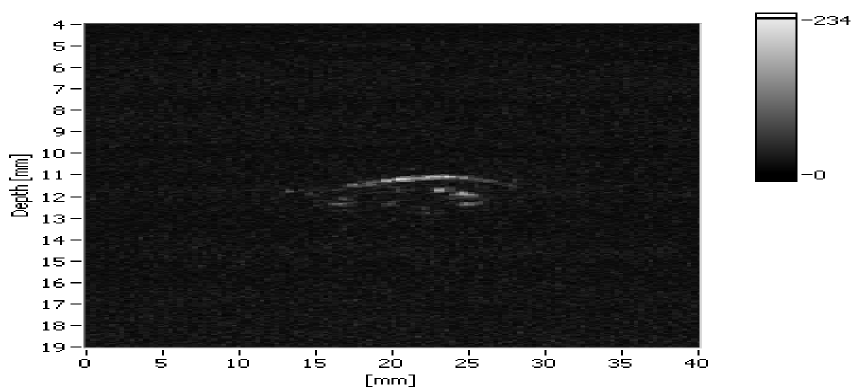

Figure 5: Photoacoustic image of vasculature in the hand of a human volunteer.

In Figure 5 a photoacoustic image is shown of vasculature in the dorsal side of the hand of a human volunteer. In this image the absolute value of the RF-data is plotted in a 2D imaging plane. In this way the contour of the lumen of the blood vessels is visualized[15]. The contour of the skin is visualized in this image at a continuous line at a depth of about 11 mm with respect to the transducer. Due to the limited beam size of 5 x 20 mm^2, only a part of the skin was illuminated and thus only this part of the skin is visualized in the photoacoustic image. Underneath the contour of the skin several blood vessels are visualized.

CONCLUSIONS

A real-time photoacoustic imaging system based on a commercial available ultrasound imaging system has been developed. This system is able to perform photoacoustic imaging at a frame rate of 8 frames/sec. Applications of this system can be found in imaging of superficial vascular malformations such as port-wine stains and imaging and monitoring of tumor growth.

ACKNOWLEDGEMENT

This work was funded by the Institute for BioMedical Technology (BMTI) of the University of Twente and by a Casimir grant from the Netherlands Organisation for Scientific Research (NWO). The authors thank Jan Schellingerhout, Dolf Rothbauer, Michael Hoffmann and John Lutgens from ESAOTE Europe BV for making the necessary changes to the ultrasound system.

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