Real-time photoacoustic tomography of cortical hemodynamics in small animals

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Abstract. For the first time, the hemodynamics within the entire cerebral cortex of a mouse were studied by using photoacoustic tomography (PAT) in real time. The PAT system, based on a 512-element full-ring ultrasound array, received photoacoustic signals primarily from a slice of 2-mm thickness. This system can provide high-resolution brain vasculature images. We also monitored the fast wash-in process of a photoacoustic contrast agent in the mouse brain. Our results demonstrated that PAT is a powerful imaging modality that can be potentially used to study small animal neurofunctional activities.

Keywords: photoacoustic tomography; real time; noninvasive.

Fig. 1 Full-ring array PAT system. (a) Top view of the full-ring array and the animal head. (b) Side view of the array system and the position of the animal.

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chose this dye because its absorption spectrum has a peak around 620 nm (Ref. 14), where the blood absorption is relatively low. Moreover, the fast uptake of the Evans blue makes it a good model to demonstrate the in vivo imaging speed advantage of the system.

The cerebral cortex of a Swiss Webster mouse (Harlan Sprague Dawley, Inc., Indianapolis, ~23 g) was imaged in vivo. Before the experiment, the hair on the mouse head was gently depilated by using a hair removal lotion, as shown in Fig. 1(a) and a layer of ultrasound gelatin was applied. Then the mouse was fixed in a homemade animal holder, with its head covered by a thin transparent plastic membrane, and protruding into the imaging plane. To keep the animal motionless, oxygen was supplied with 1% isoflurane via a homemade breathing mask during the experiment. All experimental animal procedures conformed to the National Institutes of Health (NIH) guidelines and were in compliance with the Washington University Institutional Animal Care and Use Committee (IACUC).

Before the administration of the contrast agent, the cortical vascular structure was imaged noninvasively at 532-nm wavelength, as shown in Fig. 2(a). For comparison, an open-scap anatomical photograph of the cortex vasculature was taken [Fig. 2(b)] after the experiment and mouse euthanasia. Since blood has strong absorption at this wavelength, the blood vessels in the reconstructed image have a high contrast. Cortical vascular structures in mice are not anatomically identical. For instance, Figs. 2(c) and 2(d) present the PA image of another mouse (weight 19.7 g) and the anatomical photograph.

To monitor the wash-in process of the contrast dye, about 0.1 ml of Evans blue dye at 3% concentration was administered through tail vein injection. The entire cortical region was continuously imaged at a fixed position at 620-nm wave-
due to breathing motion and motion stimulated by the injection, as both can alter the mouse’s position and thus affect the reconstructed images. Although only several sample PA images were provided, the images were continuously acquired at 1.6 s/frame.

The image reconstruction is based on the solid-angle-weighted reconstruction algorithm. Due to the limited-view scanning geometry and the finite bandwidth of the system response, some of the reconstructed image pixels have nonphysical negative values, which were removed in the image processing. The changes in the PA value, as in Figs. 3(c)–3(e), denote the relative variances in the initial PA pressure, which are proportional to the changes in the optical absorption.

For the first time, we obtained real-time PA functional imaging of the hemodynamics of the entire mouse cortex in vivo. We imaged the wash-in process of Evans blue contrast dye in the cortex vasculature. The temporal resolution of 1.6 s can be further improved to about 1 s by using a laser source with a more appropriate repetition rate. Substantial improvement in the imaging speed could be achieved by adding more parallel data acquisition channels or using an iterative reconstruction algorithm with fewer required data acquisitions, such as the compressed-sensing method. Our results demonstrated that array-based PAT can be a powerful candidate for studying various neurofunctional activities, such as epilepsy, which induce changes in the vasculature system.

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References