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Development of a novel ultrasound vascular imaging system

Chuck Peng and Jun Tang, Cloudstream Medical Imaging Inc., Houston, Texas
Chengwu Huang and Shigao Chen, Mayo Clinic, Rochester, Minnesota

Objectives:
The integration of ultrafast ultrasound imaging with advanced tissue clutter filtering has led to superior sensitivity of ultrasound Doppler to small blood vessels, enabling imaging of the microvascular bed, traditionally undetectable by conventional ultrasound Doppler. Despite its potential, current clinical implementation of microvascular imaging (MVI) is hindered by inadequate signal-to-noise ratio and artifacts like reverberation and phase aberration. In this paper we will present an improved solution for MVI applications in hepatic and renal vascular network.

Methods:
We developed an advanced beamforming method on ultrasound radio frequency data that retains high spatial resolution and high frame rate. Unique features include generation of partial image gathers for post processing and special compounding. Color Doppler and power Doppler processing and analysis were added. For the beamformed data, a Huygens-Fresnel coherence cube is used in the Doppler estimation. The subsequent processing removes the residual noise of the conventional clutter filtering and corrects the aliasing effect in the Doppler phase estimation. Image processing techniques are then applied to enhance the contrast and resolution of the power Doppler image to visualize the detailed structure of the microvascular network. Both the beamforming and the Doppler analysis are programed to run on Nvidia graphic processing units (GPU). Real time performance was achieved.

Results:
Ultrasound MVI from the liver of a healthy volunteer is shown in Figure 1. Verasonics Vantage ultrasound system (Verasonics Inc., Kirkland, WA, USA) equipped with a linear array transducer (5.2 MHz GE 9L, GE Healthcare, Wauwatosa, WI, USA) was used. A total of 31 plane wave beams (angles from -30º to 30º) are used in the data acquisition. Tissue clutter filtering was performed on a packet of data (100 frames, frame rate = 300 Hz) to extract blood flow signal for generation of microvascular Doppler imaging. Hepatic vasculature, i.e., arteries, arterioles, veins, and venules, was imaged at high spatial resolution (~200 microns) throughout three centimeters under the liver capsule scanned from right rib intercostal view (Fig 1a). The display intensity varied with size of the imaged vessel, indicating that blood flow velocity positively correlated to vascular diameter. This was also shown by color Doppler imaging (see Fig 1b). The same equipment was used to image the renal microvasculature from the same healthy volunteer (Figure 2). Despite the high vascular density of the renal circulation, clear resolution of the renal cortical microvascular network was obtained (~200 microns).

Conclusions:

We describe the development of a novel imaging system for the hepatic and renal vascular network with high resolution. High resolution imaging of vascular beds of different organs may offer the potential for novel assessment and insights into both physiological and pathological states. Larger validation studies are needed.

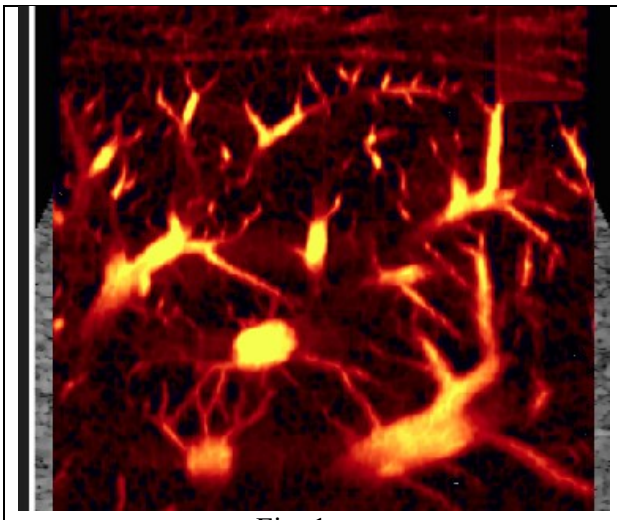

Fig. 1a

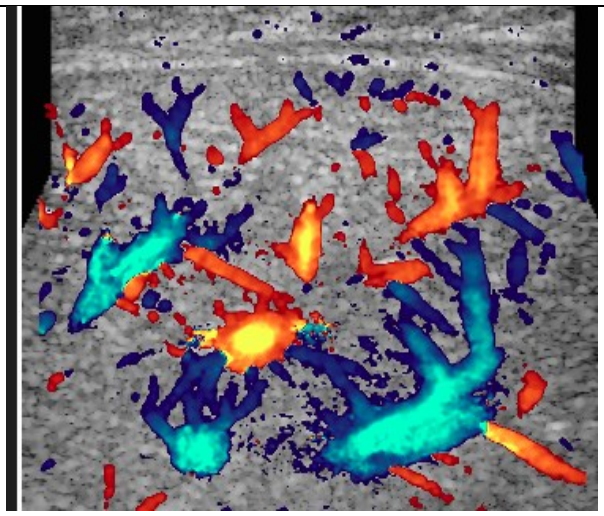

Fig. 1b

Figure 1. Power Doppler (left: 1a) and color Doppler image (right: 1b) of the superficial 3 cm below the hepatic capsule of the liver of a healthy volunteer. The resolution of the smallest vessel is approximately 200 microns on the left and 500 microns on the right. Color Doppler (1b) displays the magnitude of blood flow velocity along the up direction (red) and down direction (blue) of the vascular network.

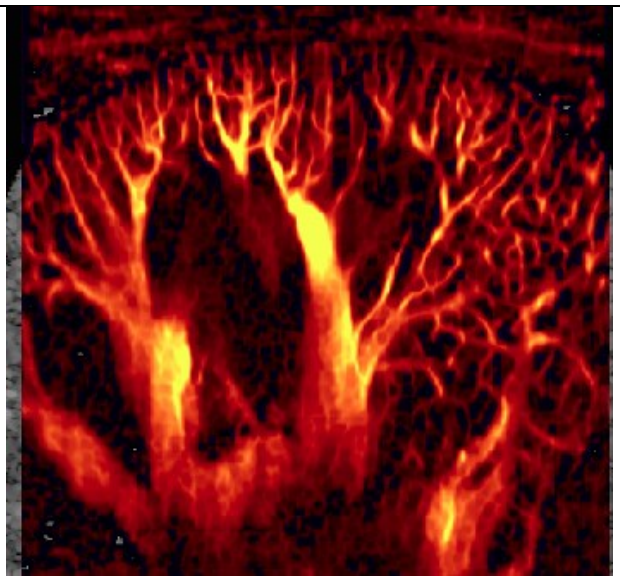
Fig 2

Figure 2. Power Doppler image of the renal circulation from a healthy volunteer. The resolution of the smallest vessel is approximately 200 microns.

Chuck Peng received a Ph.D. degree in applied physics from Massachusetts Institute of Technology in 1994. He is currently Chief Technology Officer at Cloudstream Medical Imaging Inc. His research interests include ultrasound beamforming, ultrasound guided intervention, vector blood flow quantification, microvessel imaging, and echocardiography.

Jun Tang was a Software Development Engineer at CSMI. Before CSMI, Jun had over 10 years' experience in software development for seismic imaging and medical imaging. He has a master's degree in electrical and computer engineering from Rice University and a bachelor's degree in physics from Peking University.

Chengwu Huang received his Ph.D. degree from the Department of Biomedical Engineering, Tsinghua University in 2017. He is currently an Assistant Professor with the Department of Radiology, Mayo Clinic College of Medicine, Rochester, MN, USA. His current research interests include ultrasound microvessel imaging, ultrasound elastography and their clinical translations.

Shigao Chen received a Ph.D. degree in biomedical imaging from the Mayo Graduate School, Rochester, MN, USA, in 2002. He is currently a professor of radiology at the Mayo Clinic College of Medicine, Rochester. His current research interests include ultrasound beamforming, shear wave elastography, liver steatosis quantification, and microvessel imaging.