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Noninvasive Coronary Angiography with Ultrafast Cascaded-wave Ultrasound

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Background, Motivation and Objective

Signal-to-noise ratio (SNR) is a key to noninvasively mapping vasculature in soft tissues (e.g., coronary artery) by ultrasound. However, SNR of current pulsed-wave ultrasound imaging even with the prevalent coherent plane wave compounding (CPWC) method remains limited due to short-pulse transmission and low backscattering of blood. We have recently developed ultrafast cascaded-wave ultrasound (uCUS) and demonstrated its superior anatomic imaging of tissues with a significant SNR increase. This study aims to further adopt uCUS to achieve high-SNR noninvasive ultrasound coronary angiography for blood flow detection.

Statement of Contribution/Methods

This study employs cascaded-waves to increase SNR of coronary angiography while overcoming the tradeoff between spatial resolution and pulse length. On transmission, each transmitted signal is a long pulse containing N ($N = 2^k$, k = 0, 1, 2,…) cascaded plane-waves with designed polarity coefficients. On reception, high-SNR backscattered signals (Gain in SNR = $10 \cdot \log10(N)$) for each steered plane-wave are recovered by a linear decoding design and then beamformed and filtered to obtain high-quality angiography images.

An *in vivo* human heart in a transthoracic parasternal view and a homemade vessel phantom were scanned using a Verasonics Vantage system with an L11-4v probe (6.25 MHz). Interleaved CPWC and uCUS sequences (16 cascaded-waves) were performed, each with four steered plane waves from -8° to 8° at 1000 compounded fps. The same human heart was further scanned by the uCUS sequence only, with doubled (eight) steered plane waves at the same fps. Coronary angiography images were obtained using power Doppler with singular value decomposition filtering of 60 frames during early diastole of the heart.

Results/Discussion

Our proposed uCUS method greatly enhanced delineation of fluid channels in the homemade phantom (Fig.1A_2) and the coronary artery in human myocardium (Fig.1B_2), compared with the current CPWC method (Fig.1 A_1, B_1). The improvement of contrast ratios (black boxes in Fig.1 A_1, B_1) were +5.3 dB for vessel phantom and +6.7 dB for coronary angiography. Moreover, coronary vasculature images (1st acquisition: Fig.1 C_1, C_2; 2nd acquisition: Fig. 1 D_1, D_2) with only the uCUS sequence show much clearer vasculature in the myocardium than those with the interleaved sequence because of doubled steered plane waves.

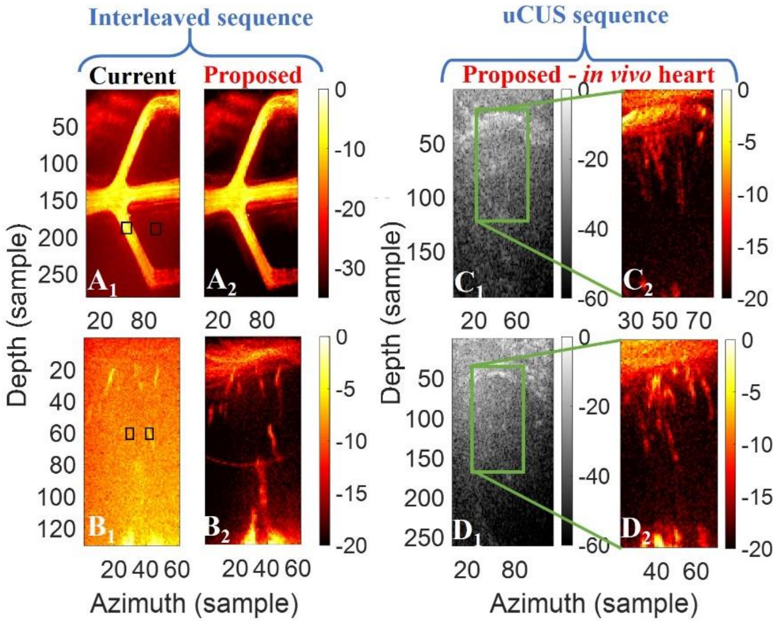

Fig.1. Contrast-agent-free power Doppler images of the homemade vessel phantom and *in vivo* human heart muscle at early diastole. A_1, A_2: Power Doppler images of homemade vessel phantom (Fluid velocity 2 mL/s) with interleaved CPWC and uCUS, B_1, B_2: Coronary angiography images with interleaved CPWC and uCUS , C_1, C_2: B-mode and angiography images of the myocardium with uCUS in acquisition #1, D_1, D_2: B-mode and angiography images of the myocardium with uCUS in acquisition #2. Note that CPWC denotes Coherent Plane Wave Compounding, and uCUS denotes ultrafast Cascaded-wave Ultrasound.