Transcutaneous ultrasound super-resolution imaging of vasa vasorum in rabbit atherosclerotic plaques

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Background, Motivation, and Objective:

Acute coronary syndromes and strokes are mainly caused by atherosclerotic plaque (AP) rupture. Abnormal proliferation of adventitial vasa vasorum (VV) and their penetration into AP is a key evidence of AP progression and vulnerability. However, due to their tiny size, it is challenging to identify VV near the major vessels. Ultrasound super-resolution (USR) technique that provides high spatial resolution beyond acoustic diffraction limit can be a promising imaging tool. In this study, by integrating a deconvolution-based USR for short scan time with a spatio-temporal-interframe-correlation (STIC) algorithm for cardiac motion compensation, VV in rabbit AP were identified and evidenced by μCT morphologically and histology pathologically.

Statement of Contribution/Methods

Two rabbits were treated with the balloon injury in the right femoral artery and high-fat diet for following 4 weeks under an approved animal protocol. At 8 weeks post injury, a bolus of 0.2mL MBs (Definity) was intravenously injected via ear vein. Thirty seconds after injection, 3000 frames (500 frames/s) image data of both injured and uninjured femoral arteries were acquired in vivo by multi-angle plane wave imaging using L22-14v probe (15.6MHz) connected to Verasonics Vantage system. The raw data were processed through beamforming, SVD filter, Richardson-Lucy deconvolution, and STIC based frame summation to reconstruct the final USR images. Upon completing USR imaging, one rabbit was prepared for μCT imaging (Scanco μCT 50) using Microfil agent. The other was prepared for H&E and CD31 stain for plaque and vessel identification.

Results/Discussion

VV was identified with spatial resolution of 32 μm. Development of plaque (e, m) and increased VV population on injured sides (f, n) was observed. The abnormally populated VV was directly evidenced by the corresponding μCT images (c, d, g, h). The plaque development (k, o, H&E) and VV proliferation and penetration into AP (l, p, CD31) were also verified by histology. The VV density estimated by USR on the injured side was 3 times higher than the uninjured side, which closely matches the estimation from CD31 stain. Overall, the effectiveness of USR for in vivo VV detection was validated visually and pathologically using a limited number of rabbits.

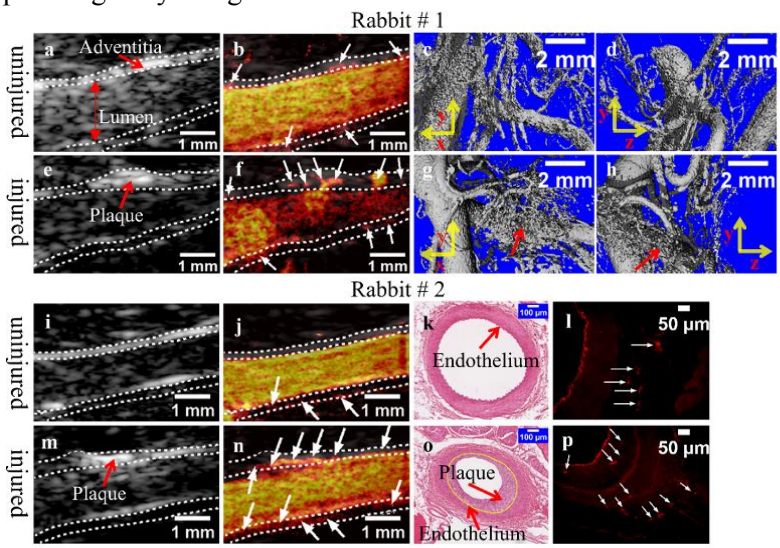

Fig. B-mode (a, e) and USR (b, f) images, and corresponding 3D μCT images in 0° (c, g) and 270° (d, h) view of uninjured and injured arteries from rabbit #1. B-mode (i, m) and USR (j, n) images, and corresponding H&E stain (k, o) and CD31 stain (l, p) from rabbit #2. Plaque development was shown in B-mode (e, m) and H&E stain (o). Significant increase of vasa vasorum, marked by arrows in USR images (b, f, j, n), 3D μCT images (c, d, g, h) and CD31 stain (l, p), was indicated in injured side compared to uninjured.