In vivo deformation analysis of aortic walls by time resolved 3D ultrasound

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ABSTRACT

The biomechanical properties of vascular wall tissue are important for the physiological function of the cardiovascular system as well as for the progression of cardiovascular diseases. The currently available clinical information on arterial wall properties is limited by the employed measurement / imaging techniques. Pulse wave velocity (PWV) or vascular compliance / distensibility are available as averaged values for larger sections of arteries (PWV) or for single cross sections (compliance), only. Understanding disease progression and improving treatment options, like endovascular stent graft design, would benefit from a more detailed analysis of the in vivo deformation of arteries. We have used a dynamic 3D imaging modality (time resolved 3D ultrasound with speckle tracking) to investigate the 3D deformation of ascending and abdominal sections of the healthy and aneurysmal human aorta.

Temporally (20-25 Hz) and spatially (2x2 mm) resolved displacement fields of aortic segments were collected by 3D ultrasound imaging and subsequent speckle tracking analysis [1]. Time resolved displacement fields were used to compute longitudinal, circumferential and in plane shear strain components, respectively. The resulting strain distributions showed a heterogeneous deformation of the aortic segments under pulsatile loading. In the abdominal aorta the predominant deformation occurred in circumferential direction, whereas longitudinal strain was found to be very low. In the ascending aorta, circumferential and longitudinal strain amplitudes were approximately equal, while maximum circumferential strain preceded maximum longitudinal strain by approximately 10% of the cardiac cycle. In AAA the observed strain amplitudes are much lower, whereas the strain distributions are more heterogeneous.

The analysis of the complex 3D deformation of aortic walls under physiological loading can be used to characterize the mechanical state of the aorta with a high spatial resolution in vivo. Diseased areas can be analyzed specifically to characterize their mechanical state. In addition, the differential information on deformation can be used to identify the relevant qualitative and quantitative deformation parameters for the design of medical devices like, e.g. stent grafts. The detailed information on the cyclic deformation of the aortic wall can be used to better specify the mechanical environment of vascular cells and to investigate the impact on the mechanobiology of these cells.

Fig.: Maps (left) and plot over time (right) of strain distributions of a 4 cm segment of an abdominal aorta.

References