In vivo non-invasive evaluation of cardiac function with strain-stiffness loops using strain echocardiography and shear wave elastography validated against PET imaging.

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Background, Motivation and Objective

Assessment of left ventricular function is critical for the evaluation of heart failure cardiomyopathy. Myocardial stiffness is known to be an important property for the evaluation of the myocardial function. Invasive pressure catheter and sonomicrometers remain the gold standard for evaluation of myocardial stiffness using strain-stress relationship. In this study, we propose to develop a non-invasive approach to assess strain-stiffness (shear wave speed) relationship in rats by using ultrasound cumulative radial strain (CRS) and shear wave elastography (SWE) during an entire cardiac cycle. Validation with PET-FDG allowed correlation with glucose consumption.

Statement of Contribution/Methods

An ultrasonic high-frequency probe (15MHz) connected to a programmable ultrasound device was positioned on top of N=3 anesthetized rats' heart in short axis view. SWE was performed using a focused ultrasound beam emitted at midwall location during 300µs. 50 compounded plane waves were used to image shear wave propagation and estimate its speed. ECG monitoring and acquisition triggering was used to assess the variation of stiffness during a cardiac cycle. Emission/reception of compounded plane waves were performed during 300ms at a repetition frequency of 15,000 Hz covering an entire cardiac cycle. CRS was performed by assessing derivative axial displacements from speckle tracking based on reconstructed B-mode images. Finally, PET-scans were acquired after intravenous administration of FDG.

Results/Discussion

SWE was performed at different moments of the cardiac cycle. It varied in average between 4.5±1 m/s during contraction and 1.5±0.5 m/s during relaxation. CRS variation at midwall gave a relative increase of strain of 25±5% during systole when setting 0% strain during diastole. Shear wave speed-strain loop relationship was assessed to evaluate the myocardial function during the cardiac cycle. The area inside the loop was assessed to quantify the amount of work provided by the myocardium and gave 48.5±8m/s.%. It was validated against PET-FDG and we found a SUV mean value of 5.85 ± 0.83 at 45min post FDG injection in the midwall of the ultrasound imaging plane. Ongoing work is focused on the assessment of the method on infarcted rats. The method has the potential to better evaluate cardiac function in heart failure and coronary diseased patient.

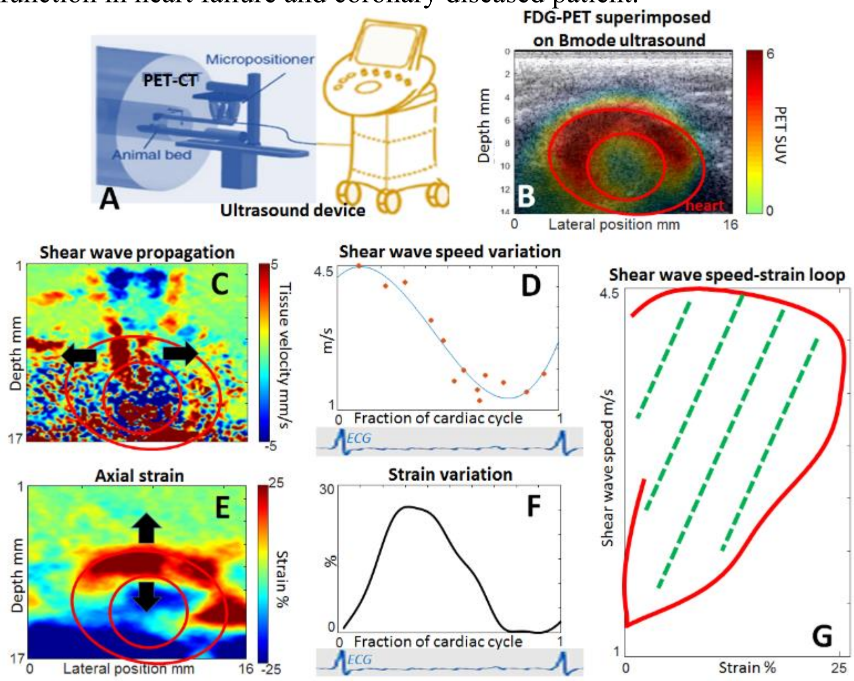

Fig 1. (A) Schematic setup representation. (B) FDG-PET assessment on a rat's heart superimposed on Bmode ultrasound image. (C) One frame of shear wave propagation on the anterior wall of the left ventricle (LV) of a rat's heart in diastole. (D) Shear wave speed variation on the LV of a rat as a fonction of time expressed as a fraction of cardiac cycle duration. (E) One frame of axial strain on the same rat's heart during contraction. (F) Strain variation against time expressed as a fraction of cardiac cycle duration. (G) Shear wave speed-strain hysteresis loop is defined as shear wave speed against strain curve.