In the past decades multiple techniques have focused in the characterization of the vasculature elasticity in a clinical setting. In their development in vitro testing and validation is mandatory. Unfortunately, this is done on arterial phantoms that are isotropic, linearly elastic, and that do not match the real mechanical and morphological properties of the vessels. In this work, we developed a series of phantoms made from clinical images and compared them to ex vivo pig aortas.

Statement of Contribution/Methods

MRI images from a healthy volunteer were used to create a mould and contermould of the descending aorta. PVA at 10% bwt was injected between the mould and contermould. Before injection, the contermould was wrapped in a reinforcing fabric (elastic along the circumferential direction and rigid in the longitudinal). The PVA was polymerized by 7 cycles (12 hours) of freezing and thawing. The mechanical properties of the models were assessed using ultrasound elastography and tensile testing. The models were connected to a circulating loop and tested under static and physiological pressure conditions (0 to 200 mmHg). Ten shear wave elastography measurements were performed over one cardiac cycle using a sequence consisting of a 100 µs push and an ultrafast imaging at 6 kHz. To recover the Young's modulus, a thin plate Lamb wave model was fitted to the dispersions curves of the propagating shear waves.

For the tensile testing, the models and pig aortas were open longitudinally and samples (1 X 4 cm2) taken in the longitudinal and circumferential directions. Using an Instron machine a strain rate of 50 mm/s was applied. The strain-stress curves were analyzed and the incremental Young's modulus calculated.

Results/Discussion

The aortic models displayed a nonlinear and anisotropic elastic behavior. The static pressure studies showed significant increases of the Young's modulus from 0.165 MPa at P = 0 mmHg to 1.02 MPa at P = 200 mmHg. The dynamic studies also displayed a significant variation of 56% between systole and diastole (1.33 and 0.58 MPa, respectively) for a mean P = 100 mmHg. The tensile testing for the models and healthy aortas presented a good agreement. Both materials showed a similar increase in Young's modulus as a function of strain in the circumferential direction. Increasing from 200 kPa at low strain (< 10%) to 1 MPa at 40% strain. In the longitudinal direction, the aortic model displayed higher mechanic properties with a Young's modulus of 8MPa at 20% strain. This result is expected due to orientation of the reinforcing fabric. Therefore, it is possible to customize the mechanical properties of these models by changing the orientation and the material of the reinforcement. Finally, this work presents a new type of arterial models that mimic the arterial tissue (anisotropy and nonlinear behavior) which can be used to study the role of arterial elasticity in pathological processes as well as in the development of new imaging methodologies.

5J-5

2:30 pm Guided Wave Elastography of Press-Stressed Thin-Walled Soft Tissues

Guo-Yang Li[1], Qiong He[1], Robert Mangan[2], Guo-Qiang Xu[1], Jianwen Luo[1], Michel Destrade[2], **Yanping Cao[1]**; *[1]Tsinghua University, China, People's Republic of, [2]National University of Ireland Galway, China, People's Republic of*

Background, Motivation and Objective

In vivo measurement of the mechanical properties of thin-walled soft tissues (e.g., mitral valve, artery and bladder) and in situ mechanical characterization of thin-walled artificial soft biomaterials in service are of great challenge. Those thin-walled structures are usually pre-stressed to achieve and/or improve their functional performance, which further complicate the inverse analysis to identify the mechanical properties. In this study, we investigate the properties of guided waves generated by focused acoustic radiation force in immersed pre-stressed plates and tubes, and show that they can address this challenge.

Statement of Contribution/Methods

To obtain the dispersion relation and establish an inverse approach for guided wave elastography (GWE) (Li and Cao, 2017) of the pre-stressed plate and tube, we carried out (i) theoretical analysis, (ii) finite element analysis(FEA), and (iii) phantom experiments. The dispersion equation was firstly derived by incremental theory (Ogden, 2007) and solved to study the effect of the pre-stress. Then frequency-domain finite element model was established to validate the theoretical analysis. Results given by FEA accurately match the theoretical dispersion relation. Experiments were conducted on a polyvinyl alcohol (PVA) cryogel phantom (as shown in the figure). The dispersion relation of the phantom in stress-free and two pre-stressed (stretch ratios were 1.08 and 1.18) states were measured by GWE method, and results shown the theoretical solution can well predict the variation of the dispersion relations.

Results/Discussion

It has been reported the arterial wall stiffness varies with the blood pressure (Couade et al, 2010). However, yet no theoretical solution can address the effect of the blood pressure. By conducting FEA we found in the low frequency range (0-2000 Hz), the curvature of the arterial wall can be ignored and the present theoretical analysis can predict the dispersion relations of both guided axial and circumferential waves. Besides, we also found the variation of the dispersion relation almost only relies on the stretch ratio along the wave propagation direction, instead of the other two stretch ratios along the directions perpendicular the wave propagation direction, which provides convenience in practical used because the accurate deformation state is not necessary.