INTRODUCTION

Knowledge of mechanical properties of living arteries is important to understand vascular function during health, disease and intervention. A mechanical model of the vascular tree would facilitate the development of (balloon-)catheters and stents.

We have developed an ex vivo model in which a porcine coronary artery can be kept at physiological circumstances; hence coronary pressure and flow, cyclic longitudinal elongation of the segment, physiological wall shear stresses, etc. are controlled, while enabling measurement of its mechanical behavior. Arterial mechanical behavior was determined for segments of the porcine left anterior descending coronary artery (LAD, fig. 1a) by simultaneous measurement of pressure (P), diameter (D) and axial force (F_{ax}) during dynamic loading at different axial strains. Also, the physiological axial strain of the LAD was determined, based on the hypothesis that: The in vivo axial strain of an artery is the strain at which the axial force is relatively insensitive to changes in pressure [1,2], as shown in figure 1b.

MATERIAL & METHODS

Ex vivo model

The complete ex vivo model consists of 4 units in parallel, one of which is schematically represented in figure 2. The coronary segment is perfused with a physiological coronary pressure and flow based on the model developed by Geven et al. [3]. The set-up is placed in an incubator ensuring a physiological environment, regarding temperature, oxygen and humidity. An extension device induces axial cyclic elongation of the segment, typical for the coronary artery.

The artery’s inner diameter is measured using an ultrasound system (ART.LAB, Esaote Europe, The Netherlands). Pressure and axial force are measured with a pressure and force transducer, resp.
Measuring arterial mechanical behaviour

Figure 3: Definition of different segment lengths for which P-D & P-F<sub>ax</sub> behavior were determined.

An approximately 4 cm proximal segment of a porcine LAD was excised and side branches were closed. The length of the segment was measured when it was still fixed to the heart (fig. 3, l<sub>heart</sub>) and when it was at its ex vivo unstrained length (fig. 3, l<sub>ev</sub>). The segment was fixed in an organ bath of the ex vivo model, immersed in a Kreb’s solution with 10<sup>-4</sup> M papaverin and kept at 38.5 °C. It was loaded with a pulsatile pressure varying from 0 to 120 mmHg max. P, D, and F<sub>ax</sub> were measured at l<sub>ev</sub> and l<sub>heart</sub>. Subsequently, the segment length was increased until the F<sub>ax</sub> change during a P cycle was minimized, which is the hypothesized physiological segment length (fig. 3, l<sub>phys</sub>). At this segment length and at l<sub>phys</sub>±0.1 l<sub>ev</sub> (fig. 3, l<sub>phys</sub>±0.1 l<sub>ev</sub>) P-D and P-F<sub>ax</sub> behavior were measured. Each measurement was performed twice.

RESULTS

Mechanical behavior was measured successfully for 8 porcine LAD segments. Successive measurements were very similar and only little hysteresis can be observed (fig. 4a&b). P-D curves show the typical arterial stiffening behavior at higher pressures (fig. 4a) and all P-F<sub>ax</sub> curves show the typical cross-over point at which the gradient of the F<sub>ax</sub>-P curve changes from negative to positive (fig. 4b). The axial stretch at this cross-over point, the hypothesized physiological axial stretch (λ<sub>phys</sub>), was 1.38±0.05 (fig. 4c). The stretch of the segment when it was still fixed to the heart (λ<sub>heart</sub>) was 1.21±0.03 (fig. 4c).

CONCLUSION

We have shown that it is feasible to perform reproducible measurements of the mechanical behavior of a porcine coronary artery in our ex vivo model. The arterial segments show the expected stiffening behavior and reveal a clear cross-over point with respect to the pressure axial force measurements. This stretch was hypothesized to correspond to the physiological stretch of the segment and was found to be 1.38±0.05 on average.

FUTURE WORK

The experiments will be fit with the model developed by Driessen and Holzapfel [4,5] to determine mechanical parameters. Moreover, the hypothesized physiological axial strain will be validated for the LAD in an isolated beating heart experiment in which a porcine heart is loaded physiologically.

REFERENCES


Figure 4: Typical example of a) P-D and b) P-F<sub>ax</sub> behavior of a porcine LAD at different axial stretches (measurement 1&2, solid & dashed line resp.). c) Average axial stretches of the porcine LAD (n=12).