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Evaluating the mechanical behaviour of aortic layers through dynamic peeling

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1. Introduction

Aortic wall is a laminate tissue in which every layer has its own mechanical behaviour. When exposed to a blunt trauma, the aortic tissue can be partially damaged. In arterial and heart tissues, post-traumatism rupture of constitutive layers and/or delamination between constitutive layers are believed to be the cause of pathologies such as aortic dissections, pseudo-aneurysms or aneurysms (Yetkin and Gurbuz 2003; Rodriguez and Ong 2005). Quantifying the intricate mechanical behaviours of the constitutive layers and their interfaces is crucial to understand the phenomena damaging the aortic wall. Using quasi-static loading, experimental characterization has been performed on different layers (Amabili et al. 2019), as well as peeling tests (Pasta et al. 2012). But dynamic peeling of the aortic layers, transcribing loading modes the aorta can undergo during a car crash, is yet to be done. The aim of this protocol is to acquire data on different aortic layers under dynamic load using a simple peeling test, and build constitutive laws for the components of the aortic tissue.

2. Methods

2.1. Aortic peeling sampling

Four samples were harvested from pig thoracic aortas from a local butchery. They are given a rectangular shape of size 85mm*12mm, oriented following the longitudinal direction of the aorta. On its proximal end, the sample is slit all along its width, as to create two separate proximal strands for the peeling procedure to drag apart from each other. The strands are called *internal strand* and *external strand* in relation to their intra-luminal or extra-luminal position on the aorta. The slit is performed at mid-thickness, with a depth of a few millimeters. The peeling is then initiated by hand to change the slit into a 13mm deep crack (Figure 1 left). While 13mm of the sample are

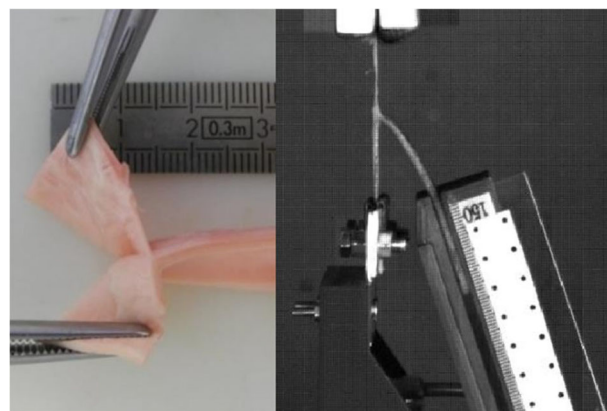


Figure 1. Left: Manual peeling during the creation of the samples – Right: Peeling test at 300mm/s speed.

pre-peeled from the proximal end, 72mm to the distal end are yet to be peeled.

2.2. Set-up

An aortic peeling sample is positioned into a dynamic tensile test machine (INSTRON 8802). Each proximal strand is fixed in a clamp of the machine, the top clamp holding the *internal strand* of the sample, and the bottom clamp holding the *external strand*. The *not-peeled strand* of the sample seats in a frictionless guide, which function is to prevent lateral movements of the sample. The guide is attached to the bottom part of the set-up, and its direction has a tilted angle to give the sample a pseudo-natural position during the peeling. The crosshead of the machine moves during the test, while the bottom part remains static (Figure 1 right).

2.3. Measurements

A load cell (S-beam, 50N scale range) and an accelerometer (1-axis, 25g) are placed on the bottom part of the setup, capturing data along the direction of peeling at 5000Hz. A camera records the peeling sideways at a 500Hz frequency. The images are processed to measure the instantaneous lengths of the *internal*, *external* and *not-peeled* strands and to calculate the speed of the crack through the aortic tissue. Using these data, the theoretical lengths of unloaded *internal* and *external strands* are computed. The stretch ratio during the peeling test is then deduced for each strand.

2.4. Loading

The crosshead moves at constant speed until the sample is completely peeled or one of the proximal strands breaks. The speed of the crosshead is 0.3m/s.

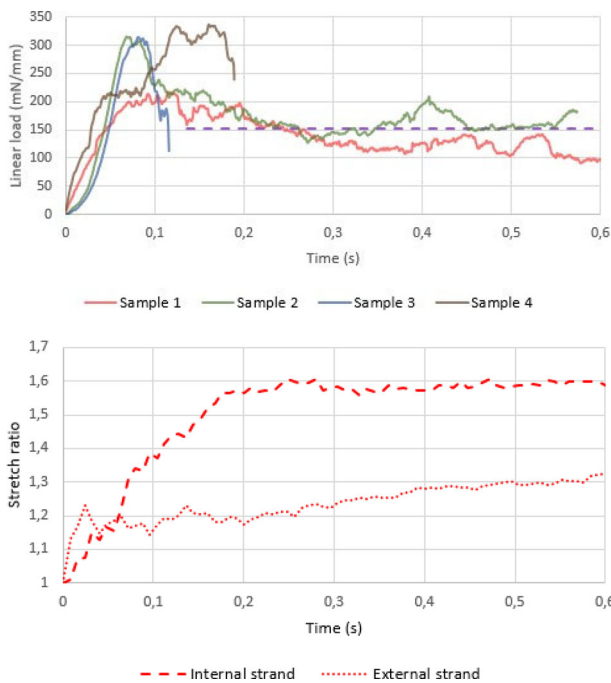


Figure 2. Top: Load per unit length during a peeling test for four samples. The dotted line represents the average of linear load during the steady state. Bottom: Global stretch ratio of *internal* and *external strands* of sample 1 during the peeling test.

3. Results and discussion

3.1. Localization of the peeling

The initial incision performed during the creation of the samples are localized at mid-thickness. During the peeling, the crack stabilizes to another thickness, indicating it reaches a weak fiber. The final thicknesses of the *internal* and *external strands* remain roughly constant, as verified by discrete thickness measurements. The *internal* and *external strands* respectively represent 27% and 73% of the total thickness of the aortic wall, probably indicating that the *internal strand* is made of the *intima* layer and a part of the *media* layer, and the external strand is made of the other part of the *media* layer and the complete *adventitia* layer. Histological observations are needed to confirm this hypothesis, that sticks to literature data (Peña et al. 2015).

3.2. Loading profile

The loading profile is split into three distinct stages: (i) a progressive loading until the activation load required to peel is reached (ascending phases on Figure 2 top), (ii) a declining stage where the sample is peeled but the load declines before stabilizing, (iii) the steady peeling stage. Out of four tested samples, two have had their *internal strand* broken during the transition between the second and the third stage.

From the remaining two, we extract the following data: peeling the sample during the last stage requires an average load of 1.82N (Figure 2 top), which corresponds to a linear load of 152mN/mm spread onto a 12mm width.

3.3. Stretch of the aortic layers

Because of the *internal* and *external strands* stretching during the peeling test, the speed of the opening crack through the not-peeled strand is lower than the speed of the machine's crosshead. While the crosshead moves at a 0.3m/s velocity, the crack propagates into the sample at 0.099m/s during the entire test. A transitory regime is observed on the stretch profile, before reaching the steady peeling stage. This transitory regime is significantly shorter for the external strand compared to the internal strain, as seen on Figure 2 bottom.

4. Conclusions

With this set-up and a simple peeling test, we can assess mechanical parameters of the aortic wall: the behaviour of the layers during a dynamic tensile test and the quantification of the peeling and delamination between two constitutive layers. This approach reveals viscoelastic phenomena that interfere with the measurements, giving us an insight at the dynamics going on in the aortic wall during a dynamic load.

Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Thoracic aorta; dynamic; peeling test; layers; delamination

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