

## Delamination Strength of an Arterial Wall

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**Abstract.** Aortic dissection is a life-threatening disease. It is manifested by a separation of the layers of an artery wall, and may end with total rupture and internal haemorrhaging. The exact conditions under which the dissection is initiated remain largely unexplored. In this study, we would like to contribute to the elucidation of these conditions. It is generally accepted that the dissection propagates by a delamination mechanism. The main objective is to collect a set of experimental data to be able to describe age-related changes in the delamination strength of the human aorta. Preliminary results of the peeling tests show that a strong correlation between age and delamination strength exists. This is in accordance with clinical observations which reveal that elderly people are more susceptible to the dissection than young individuals.

### Introduction

Aortic dissection is a life-threatening disease manifested by a separation of the layers of an artery wall [1–3]. Although one could consider aortic dissection to be a relatively rare disease, the incidence is typically reported ranging from 3 to 6 cases per 100 000 per year, however the lethality of the dissection is rather high. According to [4], 37% of patients who reach the hospital alive die in next 30 days, and approximately 20% patients die before they receive medical intervention [5].

During the dissection, blood enters the wall and causes the delamination of its layers and consequently flows in a false lumen. A rupture of the weakened aorta may occur. The exact tear initiation mechanism is unknown and mechanical events underlying dissection have not been definitively established so far. In this study, we would like to contribute to elucidation of conditions under which the dissection appears by means of experimental research, focused on delamination properties of the human aorta. Our research is planned as a three-year study and this is only a preliminary report. The main objective is to collect a set of experimental data to be able to describe age-related changes in the delamination strength of the human aorta in detail.

### Methods

A method adopted to characterize delamination properties of the aorta is the so-called peeling test. This experimental protocol was, in the context of biomechanics of the aortic dissection, introduced by Sommer in 2008 [1] and adopted in further studies focused on delamination properties of arteries [6–9]. It resembles the mode I crack opening that is widely used in fracture mechanics, see Fig. 1. The main advantage of this experimental technique consists in the controllable crack propagation which allows for the quantification of fracture energy.

As indicated in Fig. 1, when the clamps move apart, forces induced by them open the crack front and delamination takes place. The intact portion of the sample shortens as the clamps continue in their movement. In the final stage of the experiment, the tested sample falls apart into two separate parts.

The experiments were carried out with the help of the multipurpose tensile testing machine Zwick/Roell (Messphysik). Both the delamination force  $F$  (the force that is necessary to increase a tear length), and the tear lengths were recorded on PC. Subsequently, the delamination strength was computed as a ratio of the force to a width of the sample. During the experiment, clamps moved with the velocity  $0.1 \text{ mm} \cdot \text{s}^{-1}$ , and HBM U9C  $\pm 25 \text{ N}$  force transducers were used.

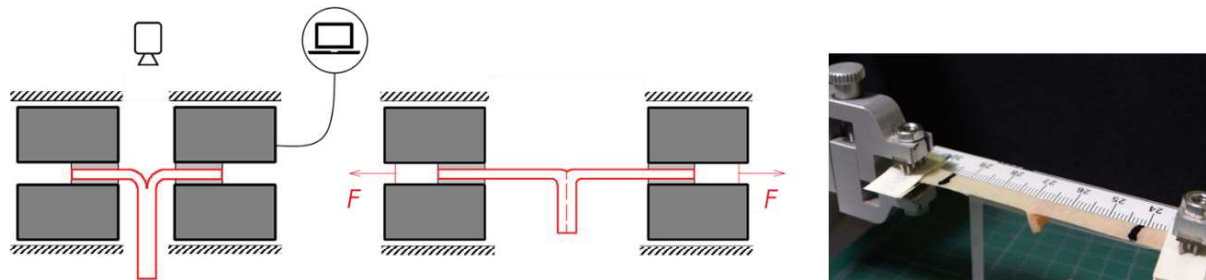


Fig. 1: Peeling test.

## Materials

Samples of the human descendent thoracic aorta were obtained in regular autopsies carried out in the Department of Forensic Medicine and Toxicology at the Regional Hospital Liberec. The usage of the post-mortem tissue has been approved by the Ethical Committee of the Regional Hospital Liberec.

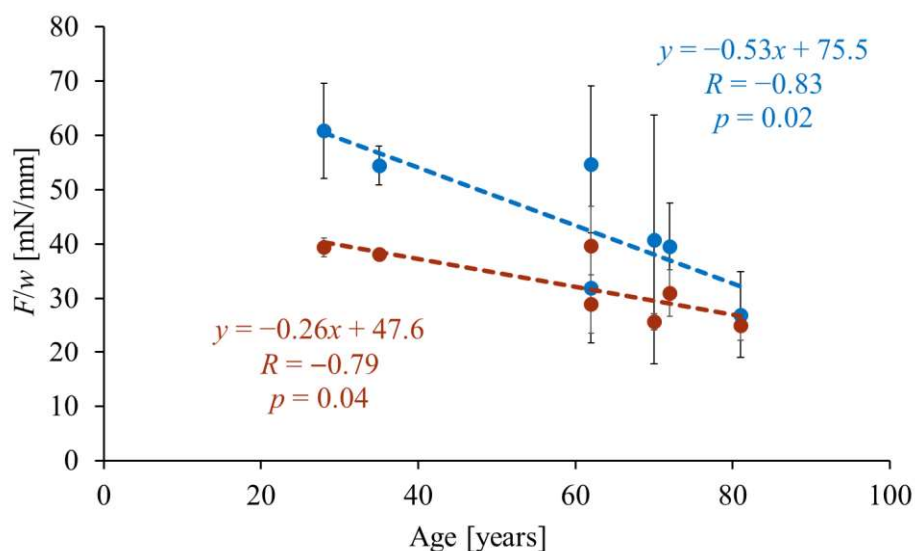


Fig. 2: Age-related changes in the delamination strength (mean delamination force per mean width of the sample). The brown line corresponds to circumferentially oriented samples, and the blue line was obtained in the linear regression of observations collected in experiments with samples aligned in the longitudinal direction.

The total number of donors was 7. Donors' age ranged from 28 to 81 years (an average  $\pm$  sample standard deviation was  $59 \pm 20$  years). Post mortem interval between death and experiment ranged from 2 to 6.5 days (an average  $\pm$  sample standard deviation was  $3.6 \pm 1.7$  days).

day). Until the experiment, the samples were stored in refrigerators at 5°C. No putrefaction changes were observed. Three strips of the aorta aligned in the circumferential direction and three strips in the longitudinal direction were cut from each donor.

## Results and Conclusions

Results of preliminary experiments are shown in Fig 2. It is a graph of the force per width of the sample necessary to propagate a crack front along the strip obtained at a given donor's age. Each point expresses the mean computed from three strips. Error bars indicate sample standard deviation. The regression lines, which were created separately for longitudinal and circumferential samples, clearly show that the delamination strength correlates negatively with age. Pearson correlation coefficient is  $R = -0.83$ , and  $R = -0.79$ , for longitudinal and circumferential direction, respectively, and in both cases reached statistical significance. It is in accordance with our working hypothesis that gradual deterioration of the crack resistance accompanies ageing of our arteries.

However, further experiments will be necessary to confirm it definitively, because the hypothesis as such may not be accepted at an initial reading. One could argue that we rather should expect age-related stiffening because of overall crosslinking and calcification which are well-known consequences of the ageing of human arteries. On the other hand, this contradiction between crack propagation properties and elastic properties of bulk material, is for example well-known for brittle materials which typically are stiff but at the same time very fragile.

Collected data also indicates that the delamination properties of the human thoracic aorta are anisotropic. It is because the delamination strength of the longitudinally oriented samples was always higher than the strength observed for the samples aligned in the circumferential direction. This is in accordance with results available in the literature [1,6,9] which also suggest that delamination resistance is a direction-dependent property.

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## References

- [1] G. Sommer, T.C. Gasser, P. Regitnig, M. Auer, G.A. Holzapfel, Dissection properties of the human aortic media: An experimental study, *J. Biomech. Eng.*, 130 (2008) art. no. 021007.
- [2] C.A. Nienaber, R.E. Clough, Management of acute aortic dissection, *The Lancet*, 385 (2015) 800–811.
- [3] T.-Y. Yeh, C.-Y. Chen, J.-W. Huang, C.-C. Chiu, W.-T. Lai, Y.-B. Huang, Epidemiology and medication utilization pattern of aortic dissection in Taiwan: A population-based study, *Medicine*, 94 (2015) art. no. e1522.
- [4] C. Olsson, S. Thelin, E. Ståhle, A. Ekbom, F. Granath, Thoracic aortic aneurysm and dissection: Increasing prevalence and improved outcomes reported in a nationwide population-based study of more than 14 000 cases from 1987 to 2002, *Circulation*, 114 (2006) 2611–2618.
- [5] I. Mészáros, J. Mórocz, J. Szlávi, J. Schmidt, L. Tornóci, L. Nagy, L. Szép, Epidemiology and clinicopathology of aortic dissection: A population- based longitudinal study over 27 years, *Chest*, 117 (2000) 1271–1278.

- [6] J. Tong, T. Cohnert, P. Regitnig, J. Kohlbacher, R. Birner-Gruenberger, A.J. Schriebl, G. Sommer, G.A. Holzapfel, Variations of dissection properties and mass fractions with thrombus age in human abdominal aortic aneurysms, *J. Biomech.*, 47 (2014) 14–23.
- [7] Y. Wang, J. A. Johnson, F. G. Spinale, M. A. Sutton & S. M. Lessner, Quantitative Measurement of Dissection Resistance in Intimal and Medial Layers of Human Coronary Arteries, *Exp. Mech.*, 54 (2014) 677–683.
- [8] M. Kozuń, M. Kobielarz, A. Chwiłkowska, C. Pezowicz, The impact of development of atherosclerosis on delamination resistance of the thoracic aortic wall, *J. Mechan. Behav. Biomed. Mater.*, 79 (2018) 292–300.
- [9] M. Kozuń, Delamination properties of the human thoracic arterial wall with early stage of atherosclerosis lesions, *J. Theor. App. Mech.*, 54 (2016) 229–238.