Mechanical and structural properties of porcine coronary arteries

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INTRODUCTION

Knowledge of the arteries mechanical and structural characteristics can improve understanding of their behavior and functions, and help to develop or improve vascular devices, such as intracoronary stents. Even though there are many studies concerning global [1], layer-specific [2] or age-specific [3] mechanical properties of coronary arteries, there is still a need to further investigate mechanics and structure of arteries from different parts of the arterial tree. The aim of the study was to determine mechanical and structural properties of left and right porcine coronary artery, dimensions and changes in structure depending on its location were also evaluated.

MATERIALS AND METHODS

The hearts of twenty three, about six months old domestic pigs were taken immediately after the slaughter of the latter. The vessel was longitudinally cut and 5x25 mm longitudinal, rectangular specimens and circumferential, ring-shaped specimens were excised. The specimens were subjected to uniaxial tension at a rate of 2 mm/min until rupture using an MTS Synergie 100 testing machine (Fig.1). Each test was preceded by conditioning consisting in repeated loading and unloading to a deformation corresponding to 10% of the measuring length.

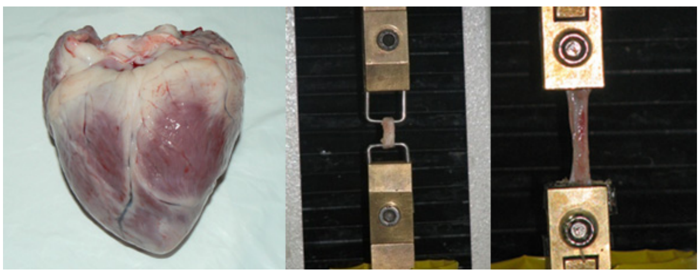


Figure 1: Heart with marked coronary artery; samples mounted in strength machine grips.

Samples from proximal and distal parts of left and right coronary artery branches were stained with Van Gieson's tissue elastin stain or Hematoxylin and Eosin to obtain general structure of the artery as well as elastin and collagen fibers distribution. Based on the images obtained using Nikon Eclipse 80i microscope, morphometric analysis of the investigated arteries were performed. Analysis included differences in diameter, thickness of individual layers and number of muscular layers in proximal and distal parts of coronary artery.

RESULTS

Typical stress-strain curve consist of first initial nonlinear stress growth region, second quasi-linear elastic phase ended with yield point and the final periods of tissue destruction and plastic deformations can be distinguish (Fig. 2). Based on obtained characteristics Young modules $E_{1,2}$ and stiffness coefficients $k_{1,2}$ for first and second curve regions were determined, according to Holzapfel's procedure [4]. Tensile strength, corresponding strain and maximum force were also obtained (Tab. 1). Circumferential samples have higher Young's modulus, tensile strength, are able to carry higher loads and deform in greater range than longitudinal samples. Their tearing process is also more sudden than for samples with longitudinal orientation which characteristics are gently-sloping.

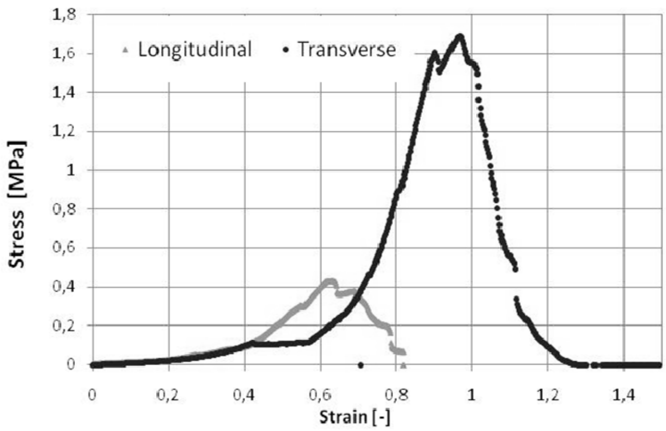


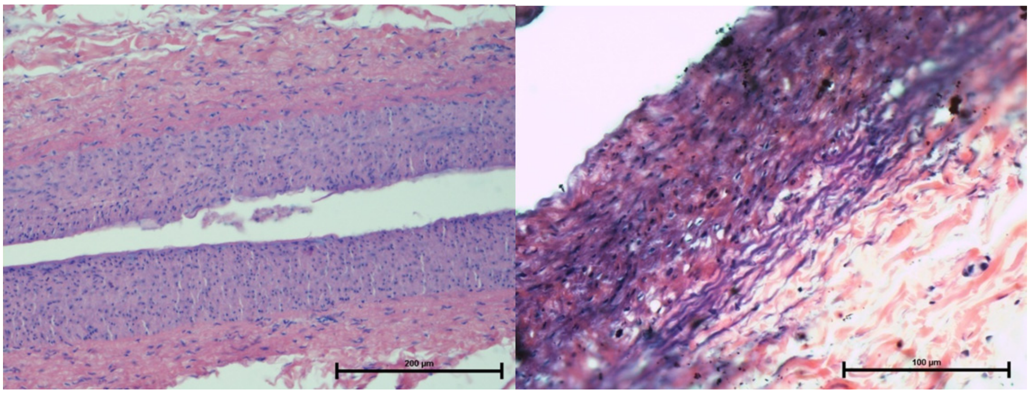
Figure 2: Typical stress-strain curves obtained for pig coronary arteries, longitudinal and transverse direction.

Sample orientation	Longitudinal	Transverse
E_1 [MPa]	0.369±0.410	0.170±0.079
E_2 [MPa]	2.164±0.956	5.735±2.808
k_1	0.166±0.185	0.253±0.110
k_2	0.813±0.373	6.230±3.401
σ [MPa]	0.588±0.307	1.710±1.070
ε [-]	0.567±0.192	0.907±0.402

Table 1: Values of obtained parameter for pig coronary artery.

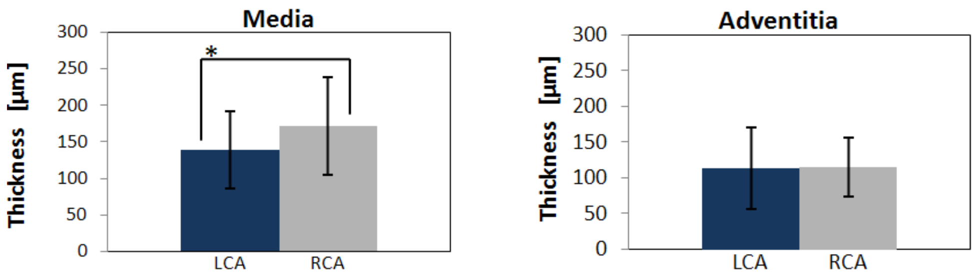
Structure of all investigated arteries was physiological, three layers: intima, media and adventitia were distinguished (Fig.3a) with no evidence of discontinuities, atrophy or distortion. External layer (adventitia) consists mainly of connective tissue, elastic and collagen fibers. Media layer (media) is composed of circumferentially-oriented muscular layers, elastic fibers and few only collagen fibers (Fig.4). Internal layer (intima), wavy in contour, consists of internal elastic lamina and endothelium (Fig.3b).

Due to easily distinguishable layers it was possible to measure thickness of media and adventitia. There were differences between left and right artery wall thickness, resulting from different dimensions of particular layers. Differences between thickness of media layer measured for left and right coronary artery are statistically important, whilst the thickness of adventitia layers are similar (Fig. 4). For left coronary artery wall, analyses of thickness of individual layers for proximal and distal parts were conducted. It was shown, that both adventitia and media layer thickness is lower for distal part of the artery, and higher at the aortic outlet region (Fig. 5).



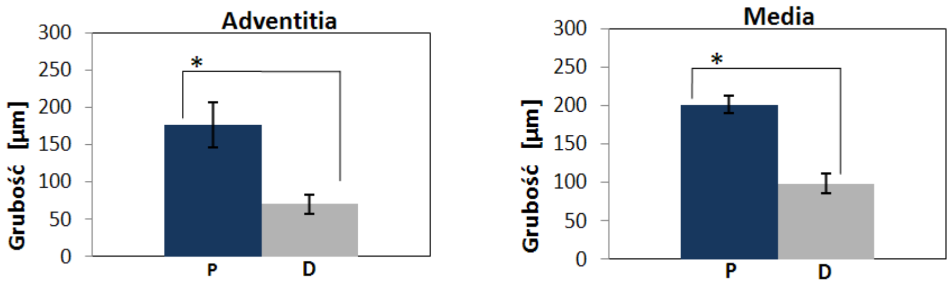
(a) (b)

Figure 3: Longitudinal section of a) left coronary artery (hematoxylin and eosin staining Mag 200x) b) right coronary artery (van Gieson's staining Mag 400x).



(a) (b)

Figure 4: Thickness of a) media b) adventitia layer of left (LCA) and right (RCA) coronary artery (* statistically important).



(a) (b)

Figure 5: Thickness of proximal(P) and distal(D) part of a) adventitia b) media layer of left (LCA) coronary artery (* statistically important).

Both for media and adventitia there were rises and falls of their thickness, which are related with distance from aortic outlet. Character of changes was approximated by decreasing linear function (Fig. 6)

The number of media muscular layers is different for proximal and distal part, both for right and left coronary artery (Tab. 2). Maximum number of layers can be observed for proximal part of right coronary artery, which is simultaneously the thickest area.

CONCLUSION

Higher values of mechanical parameters of tissues tested in the transverse direction are consistent with the biomechanical function of the vessel which in physiological work conditions is subject to much greater forces and circumferential strains. Thanks to its greater stiffness, tensile strength and deformability the tissue can carry loads connected with the pulse wave, the action of the external muscles and the internal blood pressure.

Thickness of coronary artery wall is different for left and right coronary artery, as well as for proximal and distal part of the vessel and is the highest near aortic outlet. Taking into account similar thickness of adventitia layer for proximal and distal parts of the artery, it can be concluded that decrease of wall thickness is caused by the decrease of muscular layers in the media.

It is still necessary to improve methodology of testing mechanical and structural properties of the arteries, to better explore mechanisms of destructive pathological changes. Knowledge of directional mechanical properties and different structure of the artery depending on its location is also essential to develop implant adapted to the particular artery's characteristics.

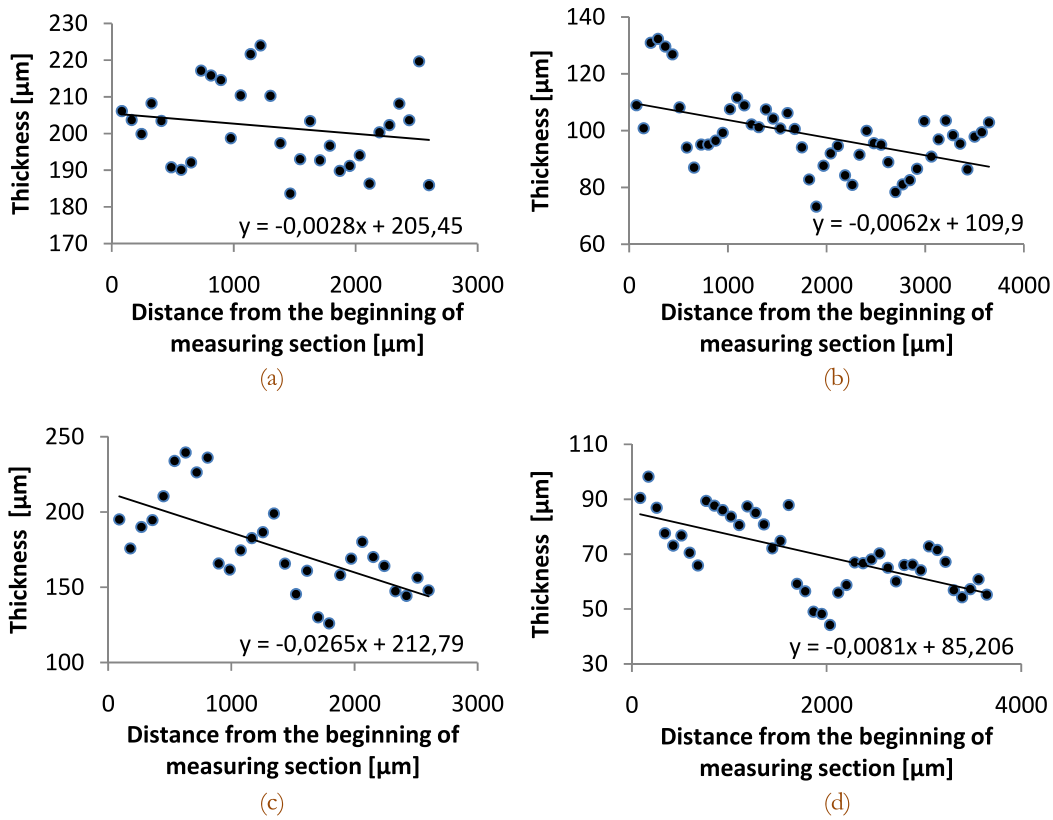


Figure 6: Changes in thickness of media layer (a) proximal (b) distal, external layer (c) proximal, (d) distal.

		Left coronary artery		Right coronary artery	
		Number of layers	SD [µm]	Number of layers	SD [µm]
Muscular layers	Proximal	16.333	1.632	19.000	1.632
	Distal	11.000	0.816	14.250	0.957

Table 2: Number of muscular layers for proximal and distal part of left and right coronary artery.

ACKNOWLEDMENTS

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