Wroclaw University of Science and Technology
Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms

THE EFFECT OF SMOOTH MUSCLE CELLS RELAXATION ON MECHANICAL PROPERTIES OF ABDOMINAL AORTIC ANEURYSM WALL

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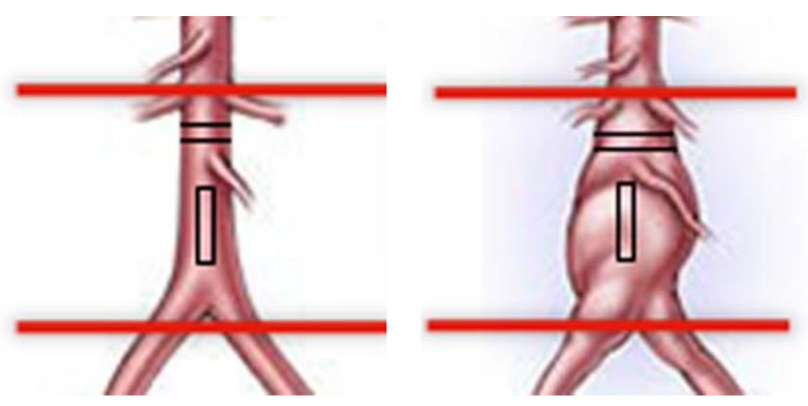
INTRODUCTION

The main structural components of the abdominal aorta are collagen fibers (40%), elastin fibers (25%) and smooth muscle cells (20%). Collagen and elastin fibers are the main load bearing components and determinant of passive mechanical properties of soft tissues in general. Smooth muscle cells (SMC) thanks to contraction and relaxation have strong influence of the mechanical function of the artery wall. Interaction between smooth muscle cells and fibers forming extracellular matrix is critical for the further evolution of mechanical properties investigations, especially for abdominal aortic aneurysms development issue.

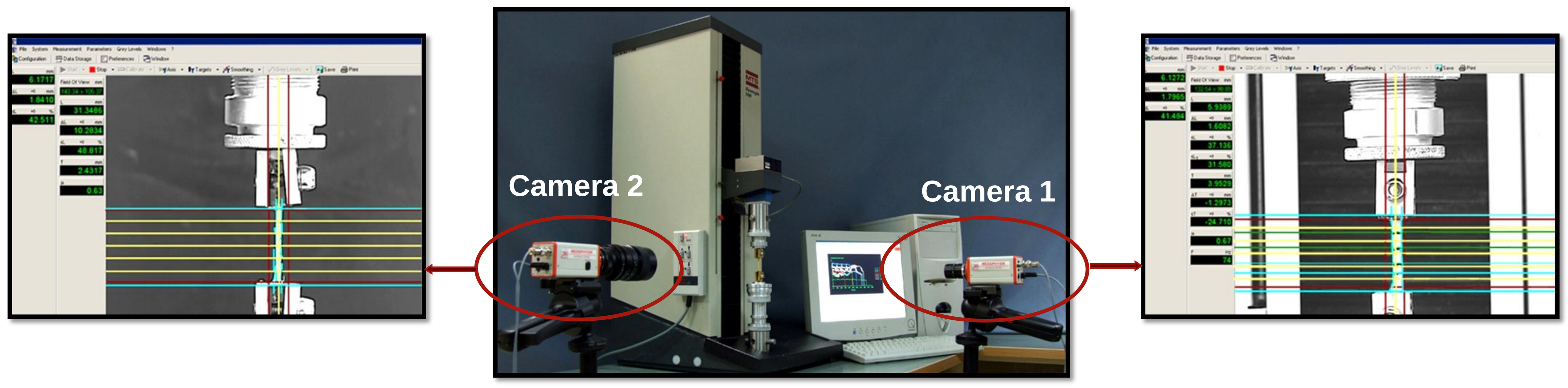
COLLAGEN FIBERS, ELASTIN FIBERS AND SMOOTH MUSCLE CELLS RELATIONSHIP

MATERIAL AND METHODS

Aortic and aneurysmal samples were harvested during cardiac surgery and directly were kept in cardioplegic solution in order to protect the smooth muscle cells from death. The uniaxial tensile test (2mm/min) were performed on system consisting of testing machine Synergie 100 (MTS) and videoexstensometer ME 46-350 (Messphysik). During the mechanical test specimens were kept in cardioplegic solution (group A) and in physiologic solution of saline (group B).



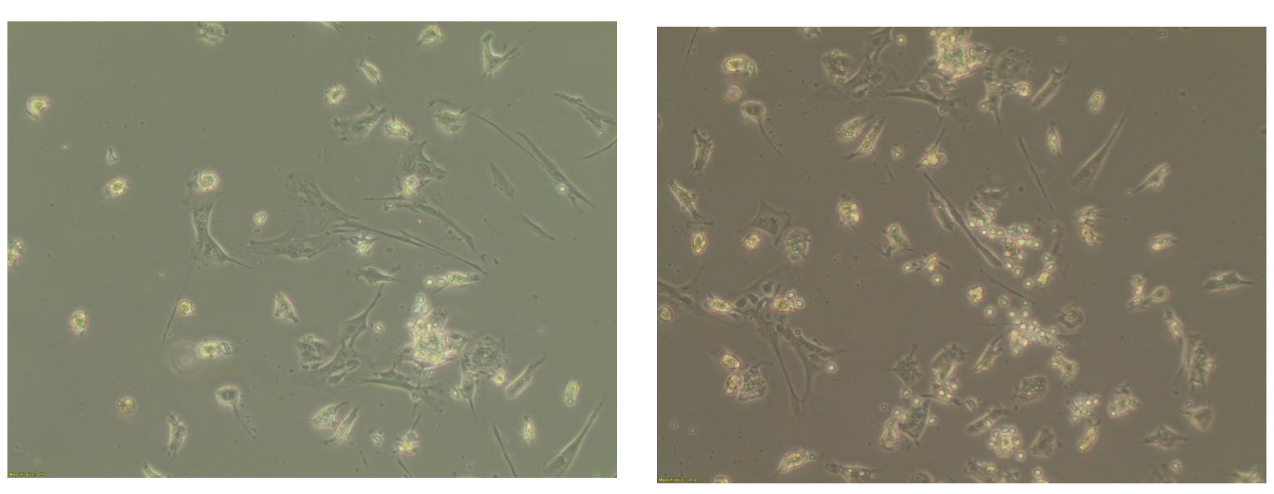
The cubic (25 mm length; 2 mm width) specimens were cut out from aortic walls in two perpendicular directions.



Videoekstensometer system was consisted from two CCD cameras and all geometrical dimensions were measured during mechanical test in real-time.

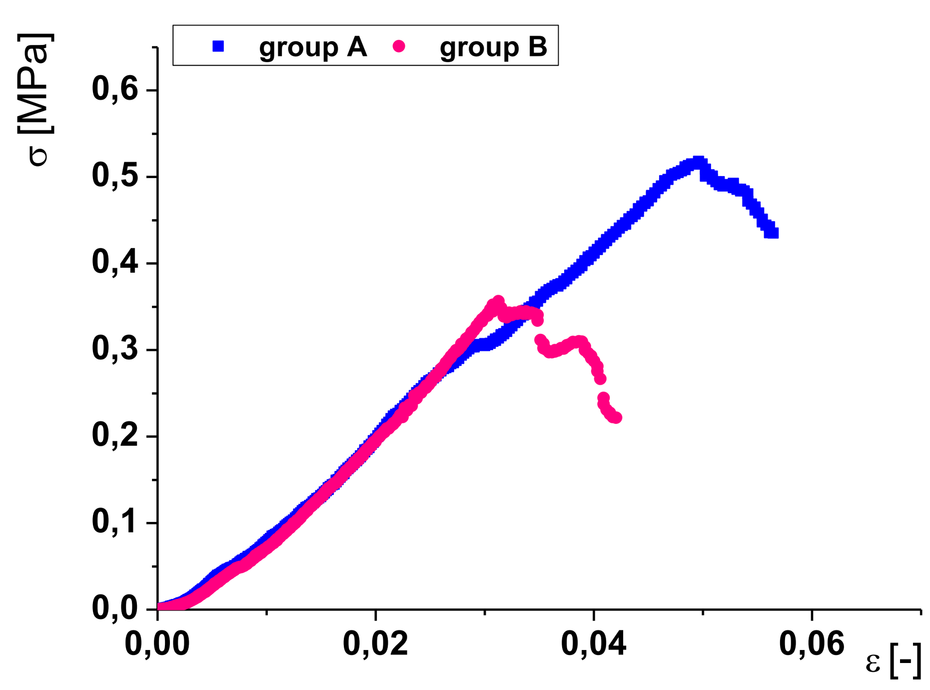
RESULTS

The cardioplegic solution successfully maintained smooth muscle cells alive:



Smooth muscle cells isolated from the wall of the aneurysm after 4 days of incubation.

For each type of specimens Cauchy stress – Green strain curves were determined and then strength (σ_{max}), maximum strain (ε_{max}) and elastic modulus (E) were estimated:



Stress-strain curve obtained for two groups of samples.

The values of mechanical properties obtained for two groups: group A (kept in cardioplegic solution) and group B (kept in saline).

	σ_{max} [MPa]	E [MPa]	ε_{max} [-]
Group A	0,72±0,05	15±4	0,06±0,01
Group B	0,29±0,02	12±4	0,05±0,01

CONCLUSIONS

The results demonstrate the mechanical properties of two groups of artery wall specimens: with relaxed smooth muscle cells (group A) and with smooth muscle cells in unrecognized state (group B). Due to significant differences between values of mechanical properties obtained between groups we conclude that state of smooth muscle cells is important for methodology of mechanical properties investigation. According previous knowledge SMC are active element of mechanical behavior of aortic wall. They are not only component actively contribute to mechanical response of material but their condition is crucial for mechanical response of extracellular matrix.

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The effect of smooth muscle cells relaxation on mechanical properties of abdominal aortic aneurysm wall

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Key words: *smooth muscle cells, abdominal aorta aneurysm, mechanical properties*

1. Introduction

The main structural components of the abdominal aorta are collagen fibers (40%), elastin fibers (25%) and smooth muscle cells (20%) [1]. Mechanical response of the arterial walls are mostly determined by them. Collagen and elastin fibers are the main load bearing components and determinant of passive mechanical properties of soft tissues in general [2, 4]. Collagen fibers are responsible for strength of the artery wall and they bear load in the high strain phase. Elastin fibers give extreme elasticity of the artery wall and they are connected with the phase of low strain. Smooth muscle cells (SMC) thanks to contraction and relaxation [3] have strong influence of the mechanical function of the artery wall. Interaction between smooth muscle cells and fibers forming extracellular matrix is critical for the further evolution of mechanical properties investigations. MES analysis on micro- levels are required appropriate experimental information how SMC may alter passive mechanical response of fibers families. Hence, the main aim of this work was investigation of mechanical properties of aneurismal samples in solution causing SMC relaxation.

2. Material and Method

The material consists of 3 human abdominal aorta aneurysm (AAA) (males, average age: 73±6yr). They were harvested during cardiac surgery and after it they were kept in cardioplegic solution. It is means by which the muscle cells are protected from death. In the next step 11 rectangular specimens in circumferential direction were prepared. The dimension of them were 25 mm (length) and 2 mm (width). In order to determine the mechanical properties the uniaxial tensile test were conducted. The speed of loading was 2mm/min. During test specimens were kept in cardioplegic solution (group A) and in physiologic solution of saline (group B).

3. Result

For each type of specimens Cauchy stress – Green strain curves were determined (Fig. 1) and on the basis of them strength (σ_{max}), maximum strain (ε_{max}) and elastic modulus (E) were estimated.

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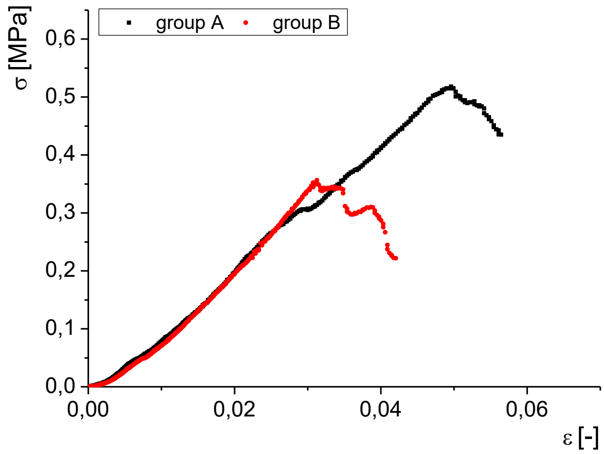

Fig. 1 Stress-strain curve obtained for specimen of group A and group B

Average results indicate that all mechanical parameters are higher for specimens of group A (Table 1). The difference is about 60% for strength, 17% for maximum strain and 23% for elastic modulus.

Table 1. Average values of strength (σ_{max}), elastic modulus (E) and maximum strain (ε_{max}) obtained for specimens of group A and B

	σ_{max} [MPa]	E [MPa]	ε_{max} [-]
group A	0,72±0,05	15±4	0,06±0,01
group B	0,29±0,02	12±4	0,05±0,01

4. Discussion

The results showed in this work demonstrate the mechanical properties of two groups of artery wall specimens: with relaxed smooth muscle cells (group A) and with smooth muscle cells in unrecognized state (group B). Due to significant differences between values of mechanical properties obtained between groups we conclude that state of smooth muscle cells is important for methodology of mechanical properties investigation. According previous knowledge SMC are active element of mechanical behavior of aortic wall. They are not only component actively contribute to mechanical response of material but their condition is crucial for mechanical response of extracellular matrix.

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ABDOMINAL AORTIC ANEURYSM FROM MECHANICAL POINT OF VIEW

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Introduction

Abdominal Aortic Aneurysm (AAA) from mechanical point of view is big issues. For patients, it means strong threat of sudden death occurs as consequence of rupture of AAA. For physicians, it is complex problem demanding decision when the surgical procedure is the most optimal for each individual. For engineers, it is a challenge, how to precisely describe mechanical behavior of AAA as load-bearing structure, taking into account specific structural composition of wall.

Pathological remodeling connected with AAA development is crucial for understanding of big dispersion of mechanical properties of AAA presented in many reports and papers. Hence our main goal is to describe mechanical properties of AAAs in strict connection with their structural composition and arrangements.

Material and Methods

Mechanical properties were studied on tensile testing machine MTS Synergie 100. Specimens were cut in both directions: axial and circumferential from AAA walls. Stress-strain curves were determined for each case. Constitutive model proposed by Holzapfel et al. in 2000 [1] were utilized to describe mechanical behavior of AAA.

Histological and immunohistochemical analysis of structure was performed for each specimen.

Results

Stress-strain curve exhibit strongly nonlinear character for all specimens. For circumferential direction AAAs were usually stiffer, however for few cases higher stiffness was observed for axial directions (Fig. 1). Performing analysis of AAA stiffness in connection with structural composition revealed that increasing of stiffness in axial direction is connected with greater destruction of extracellular matrix, loss of laminar composition of vessels walls and presence of ulcerations, hematomas and calcified deposits within wall (Fig. 2). Observation of inverse relation for stress-strain curves between directions is untypical for blood vessels walls. Structural data will be supported by quantitative assessment of collagen and elastin within AAA walls. Hence, it will be possible to evaluate how significant is destruction of load-bearing components of extracellular matrix of AAA wall and how these results correlate with parameters of constitutive models.

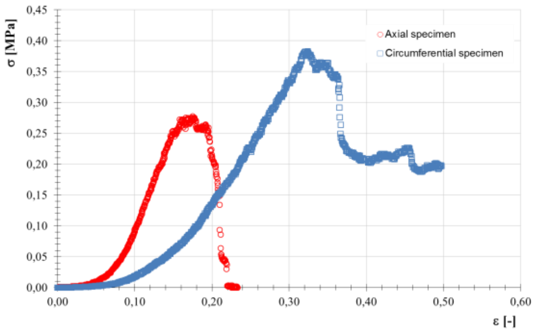

Figure 1: Example of stress-strain curves for AAA obtained from uniaxial tensile stress for circumferential and axial directions.

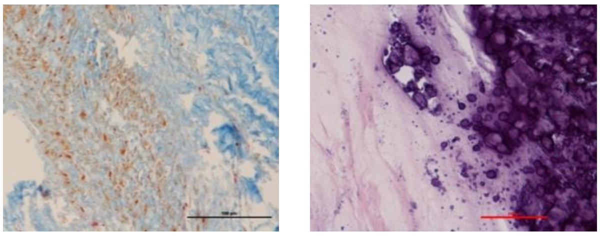

Figure 2: Histological images of destroyed AAA wall.

Discussion

One of the most popular and important part of consideration of AAA from mechanical point of view is constitutive modeling of material behavior. There are two constitutive modeling approaches: phenomenological, still popular and useful and structural-based. Application of structural-based models is justified, but demanding. The most advanced models take account of more than one structural parameters, i.e. direction of collagen bundles and dispersion in two planes [2]. It is worth noting that orientation of collagen fibers in both planes is strongly dependent on all types of disorganization and rearrangement and inclusions. In case of AAA pathological remodeling can lead to even inverse relations for stress-strain curve.

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Acknowledgements

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EXPERIMENTAL VERIFICATION OF ABDOMINAL AORTIC ANEURYSM INCOMPRESIBILITY

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Introduction

Blood vessels walls are considered as incompressible material under physiological strains. Assumption of the incompressibility is based on the volume conservation principle during the material deformation. The incompressibility assumption is correct for biological tissues containing large amounts of water since water is incompressible in physiological conditions. From Carew et al. [1] it is known that blood vessels walls also are incompressible under physiological deformations. Abdominal aortic aneurysm (AAA) arise and develop as result of complex structural remodelling leading to destruction of extracellular matrix. Hence, there is a likelihood that incompressibility of wall is not preserved for AAA. In this paper the experimental verification of AAA incompressibility was performed on the basis of uniaxial tensile test.

Material and Methods

The material incompressibility assumptions are correct when the product of the stretch ratios is constant and equal to 1. The assumptions were verified for the uniaxial tensile test of specimens excised from AAA in two directions: circumferential (AAA_c) and the axial (AAA_a). The preconditioned specimens were tested with constant speed and in real time during a mechanical test geometrical dimensions of specimens were recorded by videoextensometer (*ME 46-350, Messphysik*) (Fig. 1). From the geometric dimensions of the samples, the stretch ratios in three orthogonal directions ($\lambda_1, \lambda_2, \lambda_3$) were calculated.

Results

The average products of the stretch ratios calculated from data obtained from three orthogonal directions during extension of specimens are equal for circumferential and axial directions: 0,98±0,21 vs. 0,99±0,25, respectively. The obtained results show that regardless of the specimens cut direction the AAA wall incompressibility assumption is correct since the product of stretch ratios is equal to approximately 1,00 in each considered case. The standard deviation values were found to be relatively high. The possible reasons is consideration all cases of AAA in one group. Clustering in separate group, AAAs without signs of rupturing obtained from elective surgical procedures and ruptured AAAs came from emergency procedures can potentially explain observed phenomena. Authors imply connection between increases wall permeability accompanying rupture or leaking and local disturbances in incompressible material AAA walls.

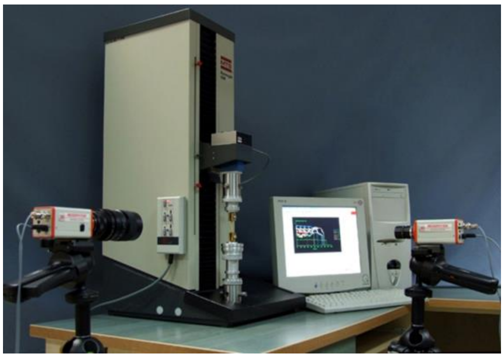

Figure 1: Experimental set-up; testing machine Synergie 100 (MTS) and videoextensiometer (ME 46-350, Messphysik) [2].

Discussion

The assumption about the incompressibility leads to many simplifications in the constitutive modelling and allow for easier stress analysis. On the basis presented results, the walls of abdominal aortic aneurysms can be regarded as an incompressible material. The development of an AAA does not result in a loss of the vascular wall's ability to maintain its volume constant as the vessel's structure is subjected to deformation. The influence of the degree of advancement of the disease on the incompressibility of AAAs should be the subject of further research, especially in range of ruptured or leaking AAA in comparison of non-ruptured.

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Acknowledgements

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