Experimental tensile tests on specimens of animal aorta: a literary review

Giovanna Nicora
Supervisor: **Simone Morganti**

Università degli Studi di Pavia
Dipartimento di Ingegneria Industriale e dell'Informazione
Corso di Laurea Triennale in Bioingegneria

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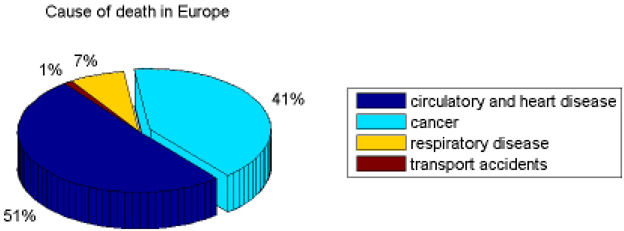
Introduction: Why should we perform tensile tests on specimens of animal aorta?

- **Cardiovascular diseases** constitute the first cause of mortality in industrialized country.

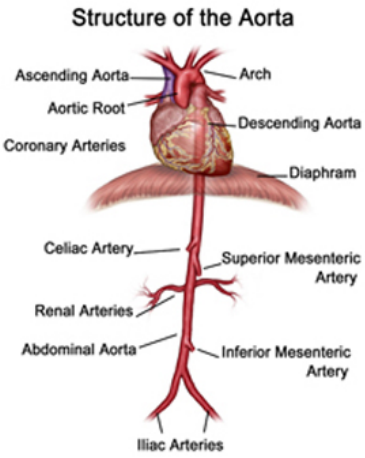
Figure : Source: http://epp.eurostat.eu.



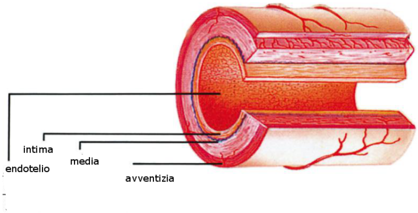
- To give an insight on cardiovascular diseases
- To design more appropriate prostheses, giving a particular tissue response.
- To define constitutive models that could predict the behaviour of the vessels.

Aorta: Anatomy e Composition

- **Aorta** is the biggest and most important artery of mammals:
  - it supplies oxygenated blood to all their body
  - it is divided in sections, with **different mechanical properties**.



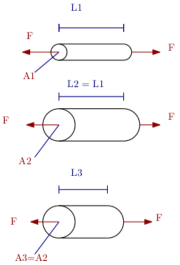
- **intima**: internal layer, made of endothelial cells
- **media**: made of elastin and collagen
- **adventitia**:external layer, made of elastin and collagen

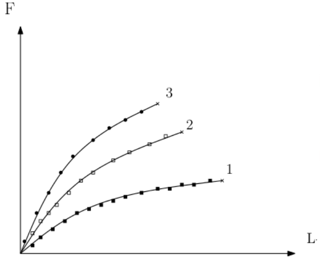


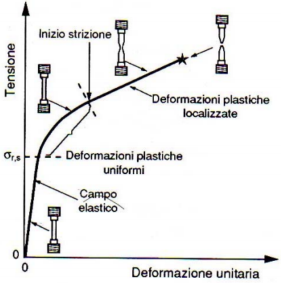
collagen *and* **elastin** *determine* **mechanical properties** *of the vessels*

Mechanical properties

- Could be determined with a **tensile test**:
  - **uniaxial**
  - **biaxial**
- The result of the tensile test is the stress and strain curve:
  - strain: $\varepsilon = \frac{l - l_0}{l_0}$
  - stress: $\sigma = \frac{F}{A}$





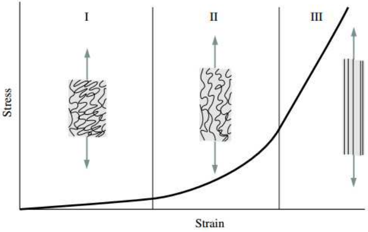


Mechanical properties of biological tissues

- Biological tissues are often **pre-stressed** and **viscoelastic**.
- **Problems**:
  - degradation
  - variability between samples
  - difficulty in gripping samples on the machine.

Figure : Sample in longitudinal test

Figure : Typical stress and strain curve



Articles

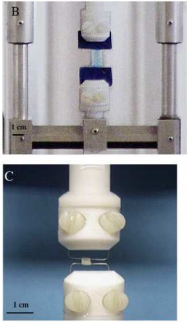
Specimens from rat aorta:

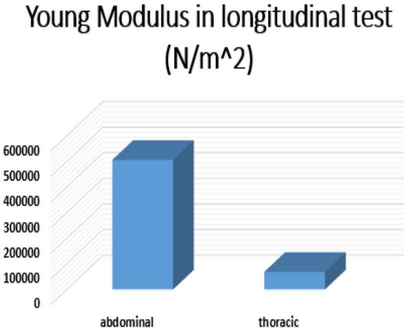
- **Rat thoracic and abdominal aorta, Assoul et al., 2008 (*uniaxial*)**
- **Rat medial and adventitial layer, Han et al., 2010 (*uniaxial*)**
- **Role of collagen in rat aorta, Vouyouka et al., 2001 (*uniaxial*)**
- **Role of elastin in mice aorta, Clarck, 2013 (*uniaxial*)**

Rat thoracic and abdominal aorta, Assoul et al.

- **aim**: to calculate Young Modulus **E** of thoracic and abdominal aorta and to compare them.
- **tensile test**: longitudinal, trasversal on 30 aorta.
- **result**: abdominal aorta is stiffer than thoracic one
- **model**:

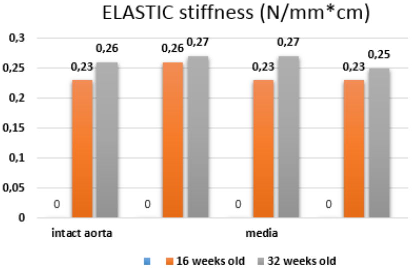
$$\sigma(\varepsilon) = E_e \frac{N_e}{N}(\varepsilon - 1) + E_c \frac{(N - N_e)}{N} \int_1^{\varepsilon} \frac{\varepsilon - \varepsilon_i}{\varepsilon_i} v_c(\varepsilon_i) d\varepsilon_i \quad (1)$$

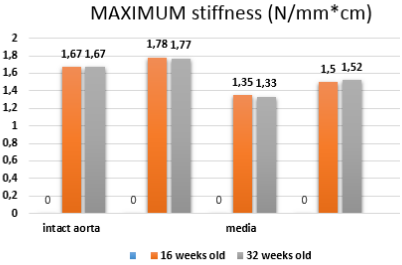


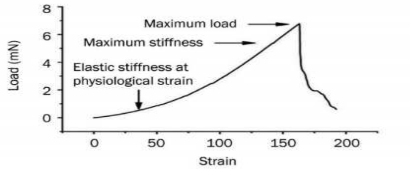


Rat medial and adventitial layer, Han et al., 2010

- **aim**: mechanical properties of tunica media and adventitia in thoracic aorta .
- **tensile test**: trasversal, ring-shaped specimens from hypertensive and normal rats, 16 and 32 weeks old.
- **results**:the removal of adventitia reduces maximum stiffness but not elastic stiffness in both group.

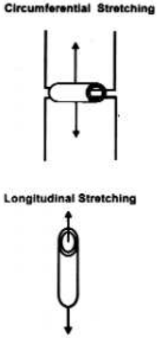


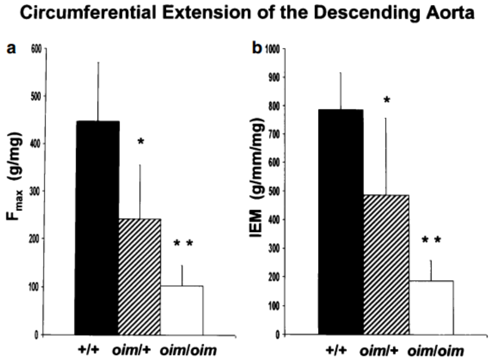




Role of collagen in rat aorta, Vouyouka et al.

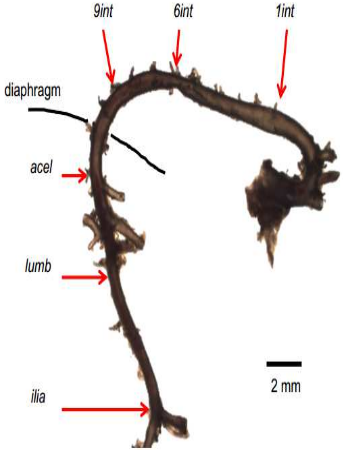
- **aim**: evaluate the absence of α_2 chain in collagen fiber.
- **tensile test**: longitudinal and circumferential. Specimens from aortic arch and the hole descending thoracic aorta
- **results**: F_{max} and IEM ($= \triangle$ f/$\triangle$ l)decreases. More evident in descending aorta since it contains more collagen.



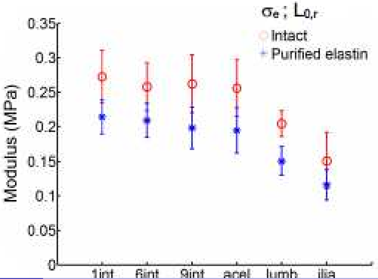


Role of elastin in mice aorta, Clarck, 2013

- **aim**: to evaluate the role of elastin in mechanical properties.
- **tensile test**: circumferential. Ring shaped specimens from 9 female mice.



- **results**: Young Modulus varies along the aorta, in contrast with what found by Assoul et al.; intact aorta has a higher Yong Modulus, so collagen increases the stiffness of the aorta.



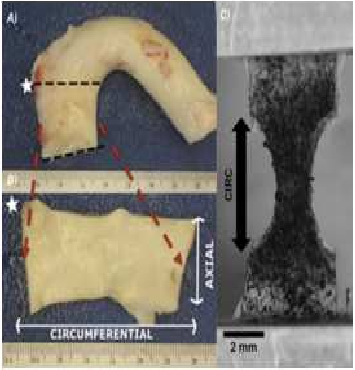
Articles

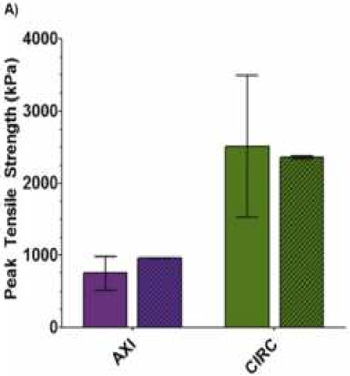
Specimens from pig aorta:

- Model of porcine ascending thoracic aorta, Shah et al., 2014 (*uniaxial, biaxial*)
- Protocols for tensile test on abdominal aorta, Bailly et al., 2014 (*uniaxial*)
- Analysis of passive mechanical properties of aorta, Sokolis, 2006 (*uniaxial*)
- Role of smooth muscle cells in pig aorta, Tremblay et al., 2010 (*biaxial*)

Model of porcine ascending thoracic aorta, Shah et al., 2014

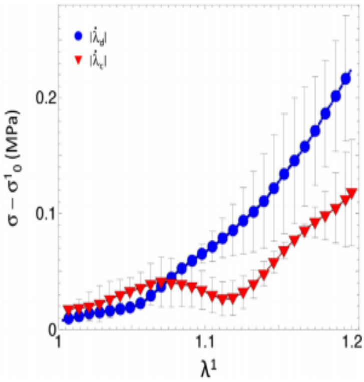
- **aim**: development a model of ascendent thoracic aorta.
- **tensile test**: longitudinal, circumferential for uniaxial tests, biaxial. Adventita and intima removed from specimens.
- **results**: maximum load higher in circumferential than in longitudional direction (pvalue<0.001).





Protocols for tensile test on abdominal aorta, Bailly et al., 2014

- **aim**: to investigate the influence of different elongation rates
- **tensile test**: longitudinal, .



- **results**: application of the higher elongation rate yields to a stress-hardening effect
  - Peterson Modulus =

$$E_p = D_d \frac{P_s - P_d}{D_s - D_d} \quad (2)$$

  - periodical maximal elongation

$$\lambda_m = 1 + \frac{D_s - D_d}{D_d} = 1 + \frac{P_s - P_d}{E_p} \quad (3)$$

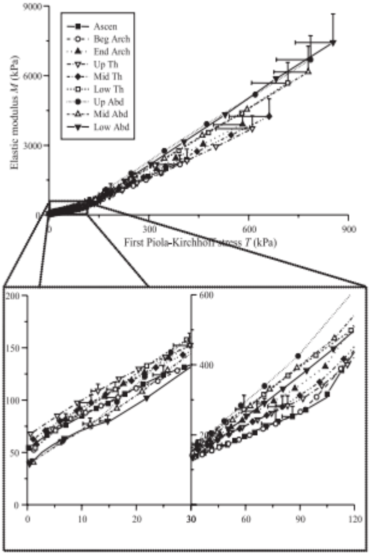
  - average elongation rage during diastole and systole

$$|\lambda_d| = \frac{|\lambda_m - 1|}{|\triangle t_d|} \quad (4)$$

$$|\lambda_d| = \frac{|\lambda_m - 1|}{|\triangle t_s|} \quad (5)$$

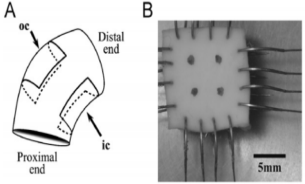
Analysis of passive mechanical properties of aorta, Sokolis, 2006

- **aim**: to evaluate segmental changes in the mechanical properties of aorta at low, physiologic and high stresses, in relation with wall composition.
- **tensile test**: circumferential. Six samples from each aorta
- **results**: distal segments of the aorta are significantly stiffer than the proximal ones at physiologic and higher stresses, collagen content increases along the aorta. Hovewer at low stress aortic wall is stiffer in the upper thoracic segment.

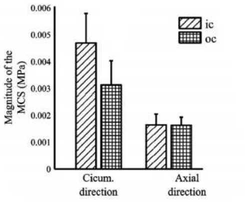


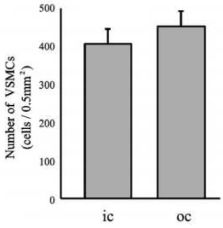
Role of smooth muscle cell in pig aorta, Tremblay et al., 2010

- **aim**: to underline the effetc of vascular smooth muscle cell in mechanical properties of outer and inner curvature of aortic arch.
- **tensile test**: biaxial



- **results**: activation of VSMCs leads to an increase of stiffness, more evident at low strain (7.5 %) than at high strain (25 %). Inner curvature bears higher maximum contractive stress than outer curvature, which contains more VSMCs





Conclusions

Tensile test represents a possible method for determining mechanical properties of materials:

- **uniaxial tests** can be relatively easily performed, but cannot help in defining constitutive laws in three dimensions
- **biaxial tests** could give complete information about the behaviour of material in two dimensions, but they are much more difficult to perform on small size specimens
- all the studies agree that **mechanical properties change along the aorta**, so **the choice of the location of samples is fundamental**
- **each layer has different mechanical properties**; in particular, tunica adventitia provides stiffness to the vessels, while tunica media provides elasticity
- The **understanding of the mechanical properties of the aorta** and of **how experimental tests can be performed** on animal samples represents the **starting basic step of a research activity** whose aim is to perform mechanical tests and propose specific constitutive laws to be included in computational predictive models; this represents the future development of my work.

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Thank you!

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