Biomechanical simulations and 3D printing for endovascular device testing

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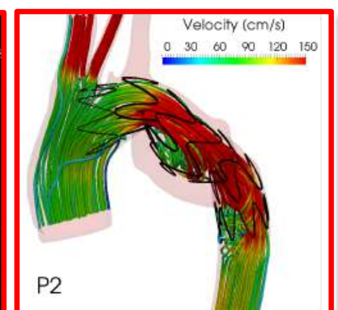
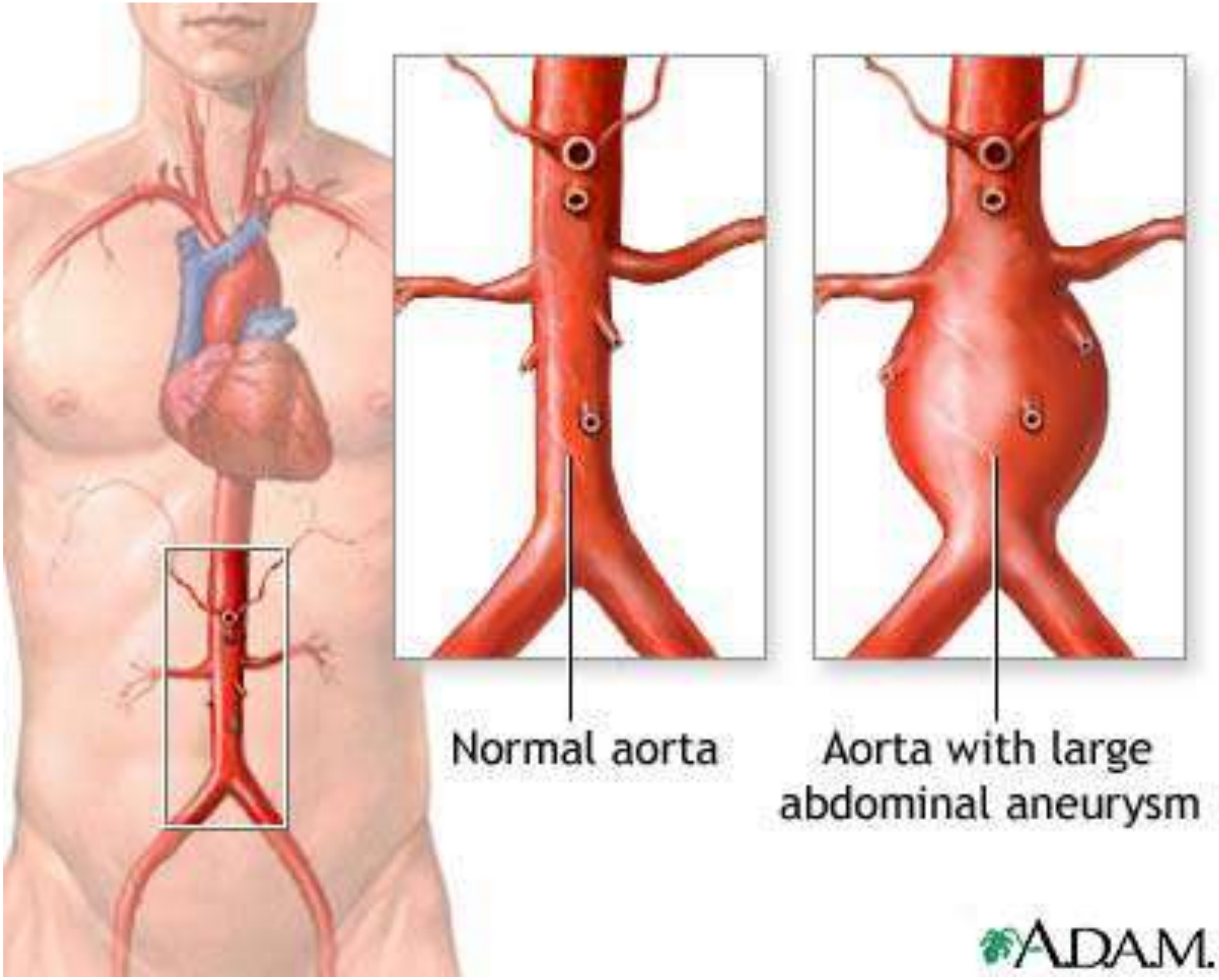
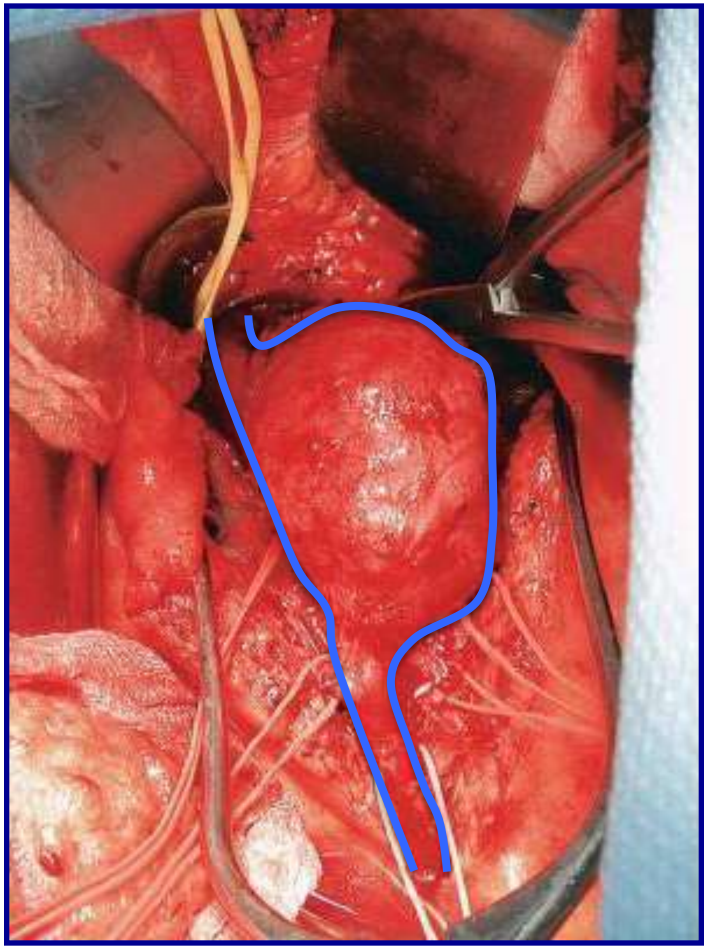
www.unipv.it/compmech/

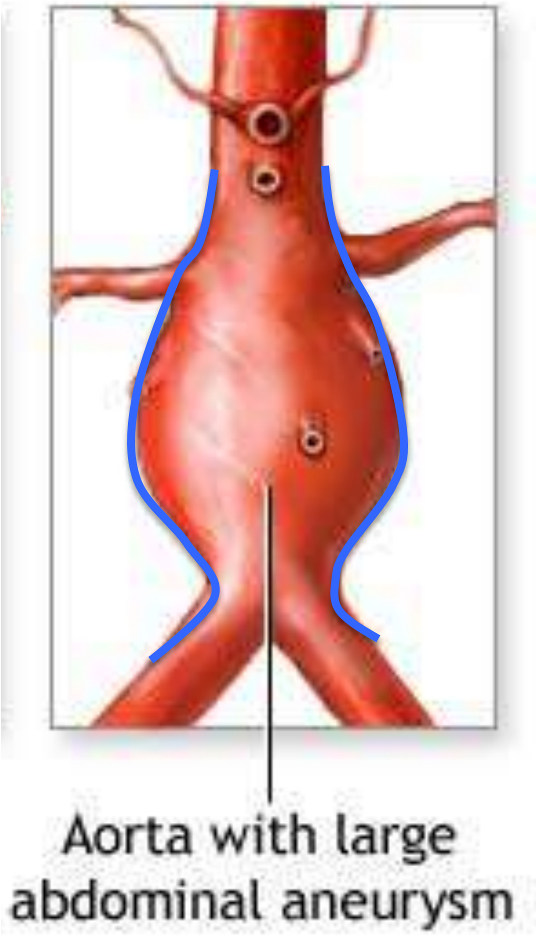


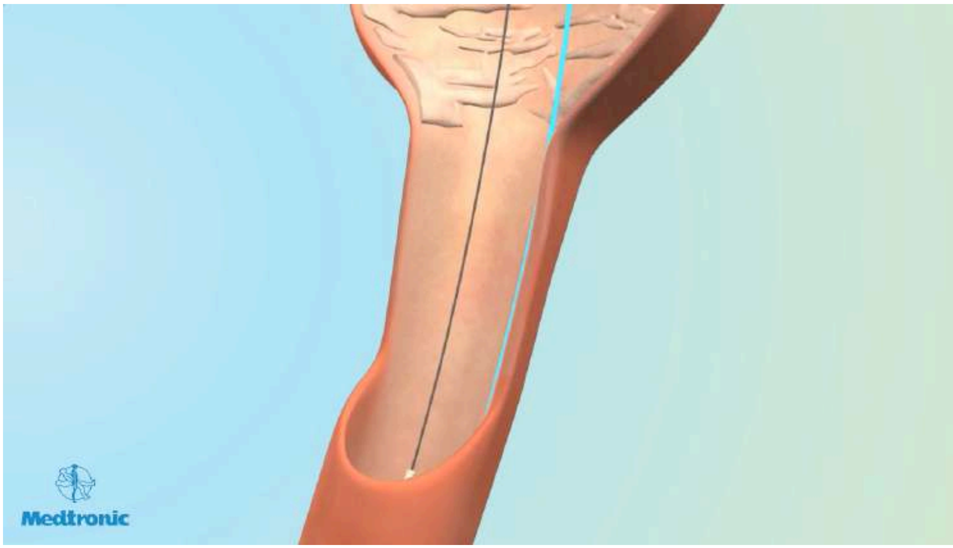
Credits: CompMech Group (Prof. Auricchio); 3D4Med (Dr. Marconi, Prof. Pietrabissa); Prof. Trimarchi's group (UniMI); Prof. Moll's group (UMCU-NL)


Normal aorta
Aorta with large abdominal aneurysm
A.D.A.M.

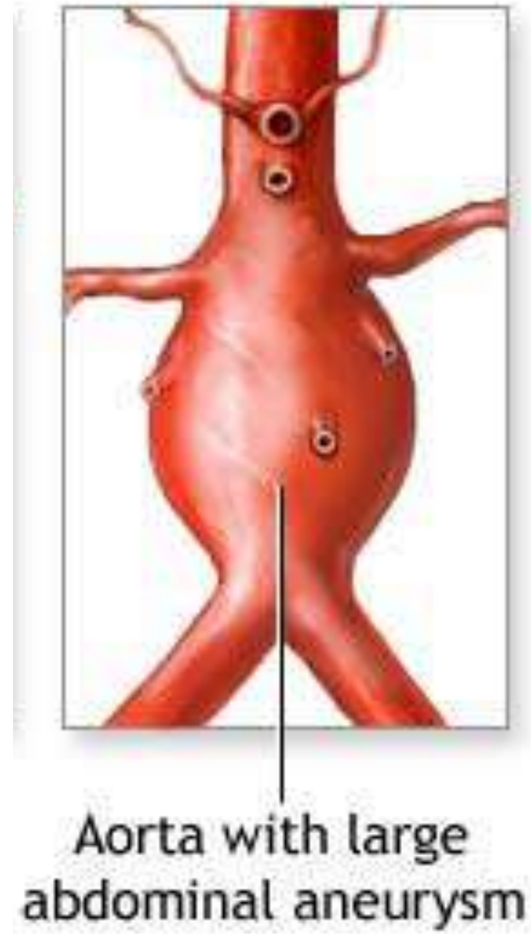


Classical surgery





Endovascular Surgery



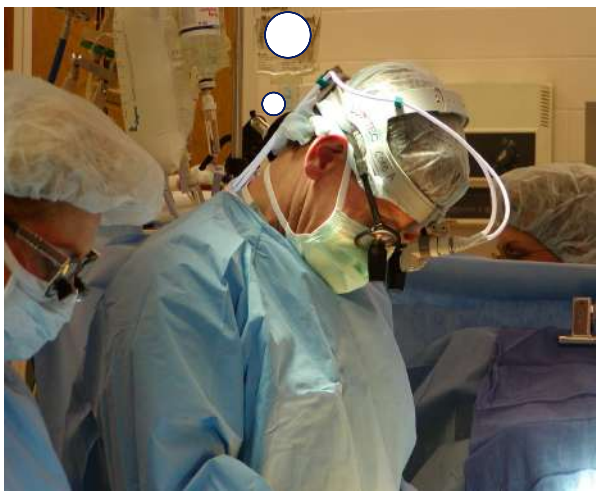
A.D.A.M.

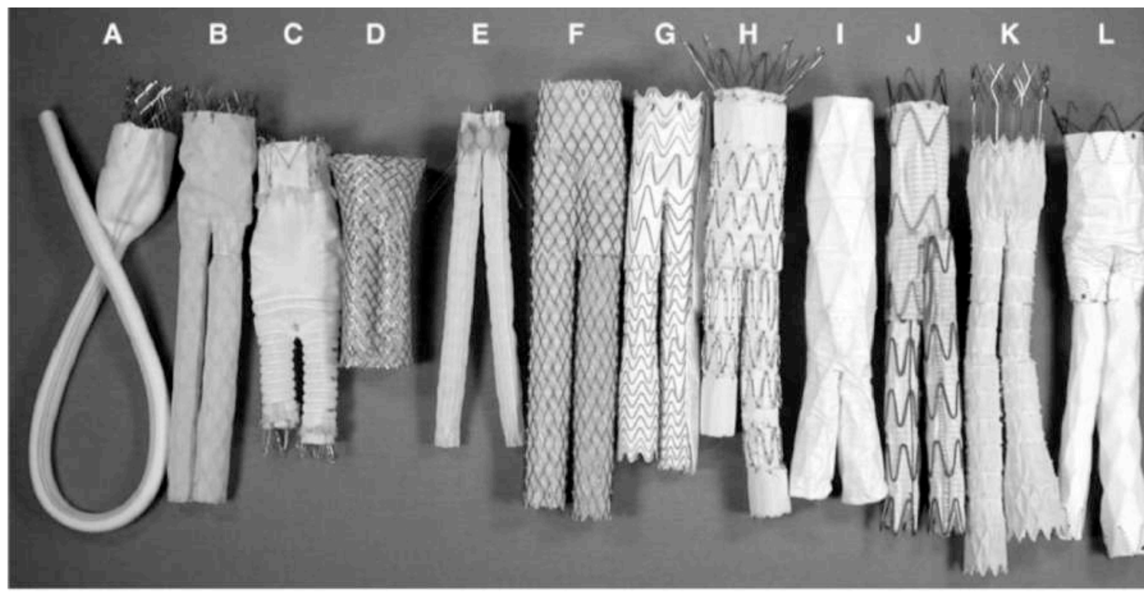
Procedure planning of endovascular surgery: key question

Which device for which specific patient?

Endograft design and biomechanical aspects

- Radial force
- Vessel wall damage
- Hemodynamic effects
- Compliance/stiffness

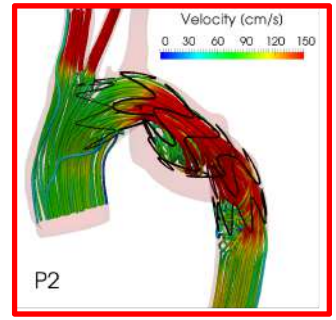




How can we investigate all these issues?

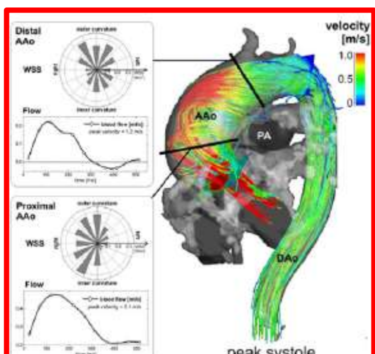
Tools to measure aortic biomechanics

Computational simulations



Aortic Biomechanics

(forces, displacements, deformations, stresses, flow velocity and pressure)

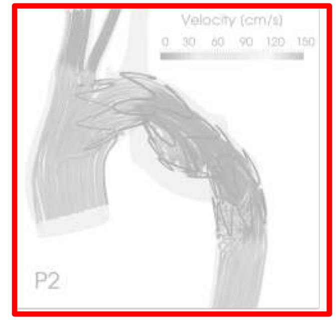


(4D-)MRI
Dynamic CT scan

In-vitro models and mock circulatory loop

Tools to measure aortic biomechanics

Computational simulations



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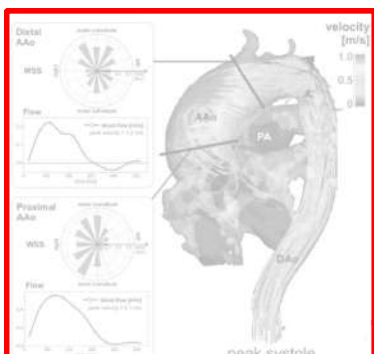
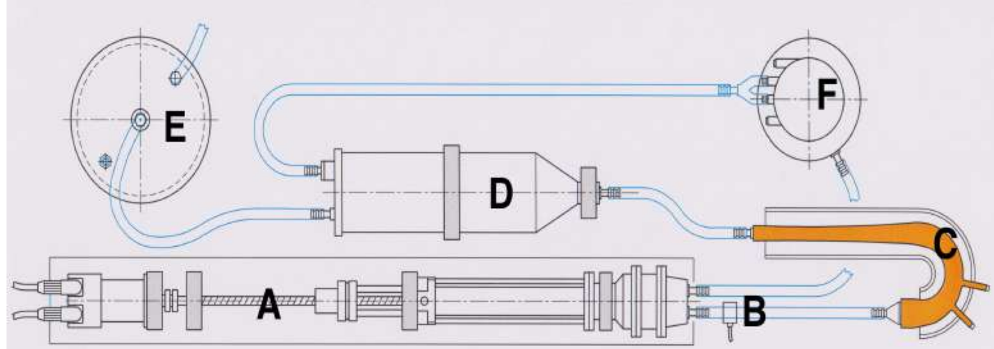


In-vitro models and mock circulatory loop

Ex-vivo porcine aortas to measure aortic stiffness

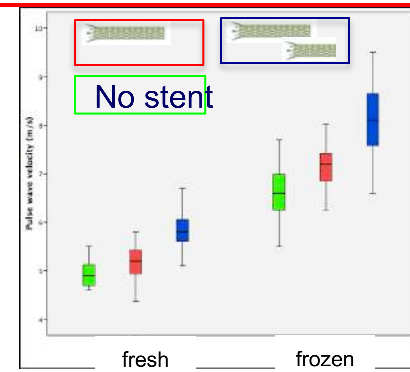
- Fifteen thoracic aortas of healthy pigs of a hybrid breed (10- to 12-month-old, 160-180 kgs) No pigs were sacrificed specifically for the purpose of this study
- The aortas were collected within 30 min after slaughter and transported at 4C in isotonic saline solution and used for experiments on the same day
- Each specimen was surgically prepared from the aortic root to the celiac trunk by removing excess connective tissue and ligating side branches.



Pulsatile system based on Windkessel principle

Measuring PWV in vitro

TEVAR stiffens the artery



About the model:

- [🙂] Geometry and mechanical behaviour
- [☹] Extensive leakage not easy to handle
- [😐] Timimg for experimensts: material properties and mechanical response change in time

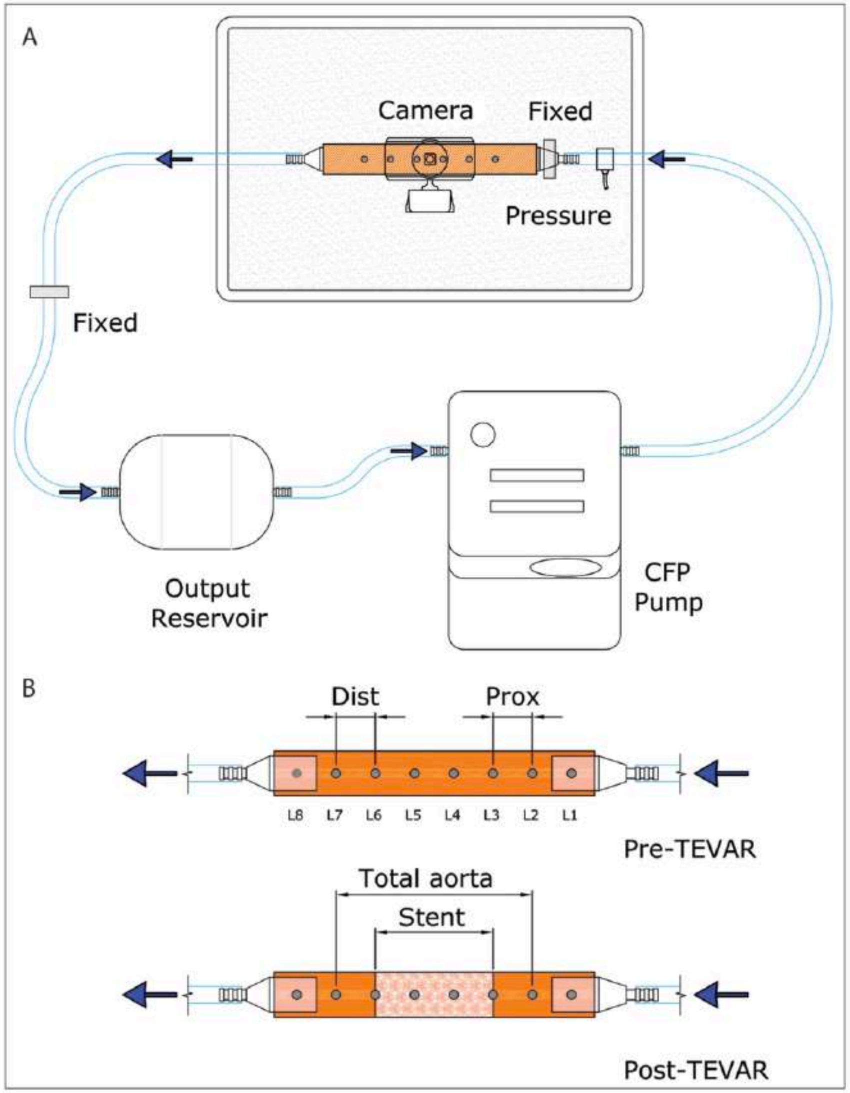

Annals of Vascular Surgery

Stent-Graft Deployment Increases Aortic Stiffness in an Ex Vivo Porcine Model


PLOS ONE

Changes in aortic pulse wave velocity of four thoracic aortic stent grafts in an *ex vivo* porcine model

Ex-vivo porcine aortas to measure aortic elongation



EDITOR'S CHOICE

An experimental investigation of the impact of thoracic endovascular aortic repair on longitudinal strain FREE

Foeke J.H. Nauta ✉, Michele Conti, Stefania Marconi, Arnoud V. Kamman, Gianluca Alaimo, Simone Morganti, Anna Ferrara, Joost A. van Herwaarden, Frans L. Moll, Ferdinando Auricchio ... Show more

Author Notes

European Journal of Cardio-Thoracic Surgery, Volume 50, Issue 5, November 2016, Pages 955–961, https://doi.org/10.1093/ejcts/ezw180

Published: 30 May 2016 **Article history ▾**

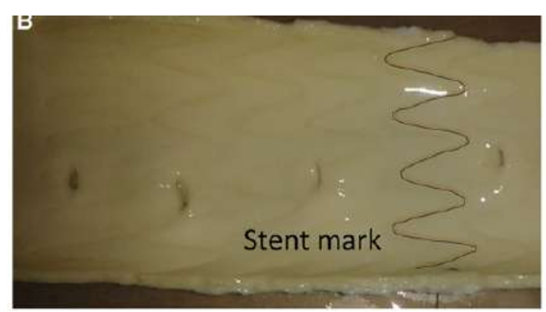
Impact of thoracic endovascular aortic repair on radial strain in an *ex vivo* porcine model FREE

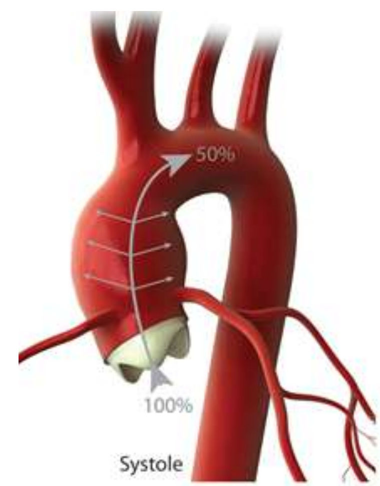
Foeke J H Nauta ✉, Hector W L de Beaufort, Michele Conti, Stefania Marconi, Arnoud V Kamman, Anna Ferrara, Joost A van Herwaarden, Frans L Moll, Ferdinando Auricchio, Santi Trimarchi

Author Notes

European Journal of Cardio-Thoracic Surgery, Volume 51, Issue 4, April 2017, Pages 783–789, https://doi.org/10.1093/ejcts/ezw393

Published: 30 December 2016 **Article history ▾**





Model reliabilty

Is porcine model a representative model of the human population experiencing endovascular repair?

Eur J Vasc Endovasc Surg (2018) 55, 560–566

Comparative Analysis of Porcine and Human Thoracic Aortic Stiffness

Hector W.L. de Beaufort [a], Anna Ferrara [d], Michele Conti [d], Frans L. Moll [c], Joost A. van Herwaarden [c], C. Alberto Figueroa [e], Jean Bismuth [f], Ferdinando Auricchio [d], Santi Trimarchi [b,*]

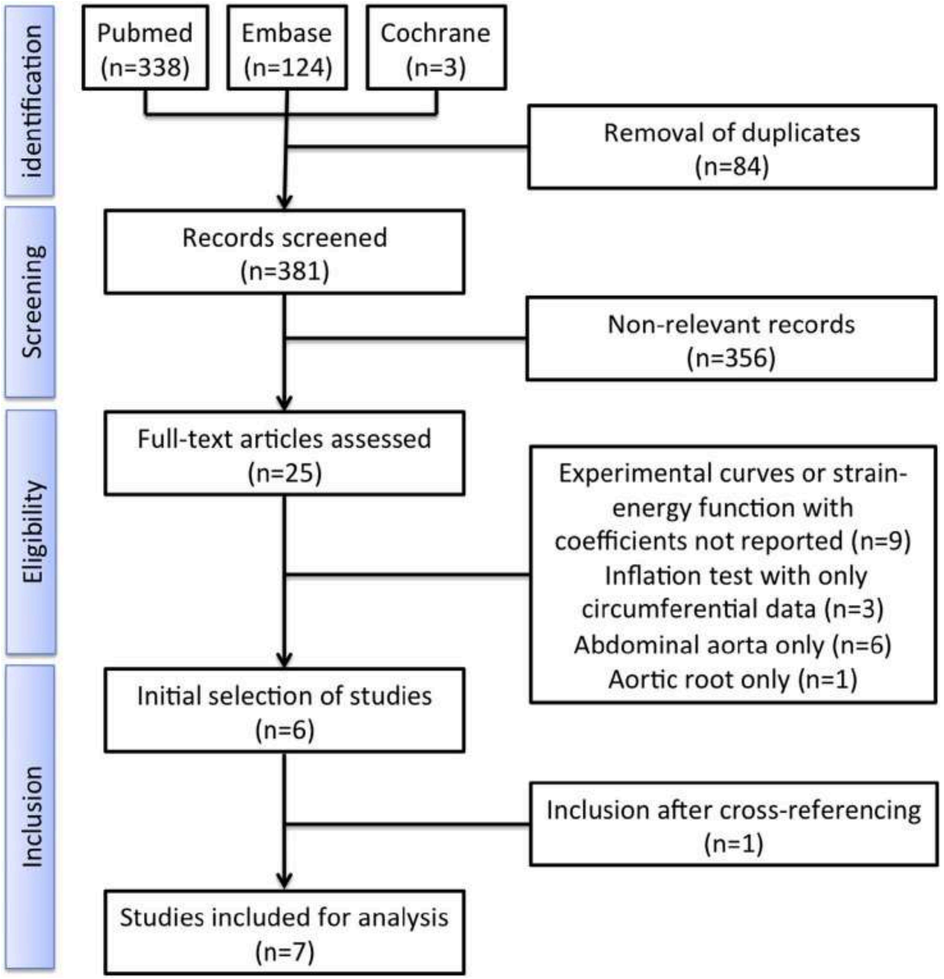
[a] Thoracic Aortic Research Centre, IRCCS Policlinico San Donato, San Donato Milanese, Italy
[b] Department of Scienze Biomediche per la Salute, University of Milan, Milan, Italy
[c] Department of Vascular Surgery, University Medical Centre Utrecht, The Netherlands
[d] Department of Civil Engineering and Architecture, University of Pavia, Italy
[e] Departments of Biomedical Engineering and Surgery, University of Michigan, Ann Arbor, USA
[f] Houston Methodist DeBakey Heart & Vascular Centre, Houston, USA

WHAT THIS PAPER ADDS

This study uses a method to compare published data on porcine and human thoracic aortic stiffness from different studies consistently. The results of this analysis show that the stiffness of young porcine aortas is similar to that of human tissue aged under 60 years and less stiff than human tissue aged 60 years or more. This has implications for using the porcine aorta as a model for human aorta in research.

Comparative Analysis of Porcine and Human Thoracic Aortic Stiffness

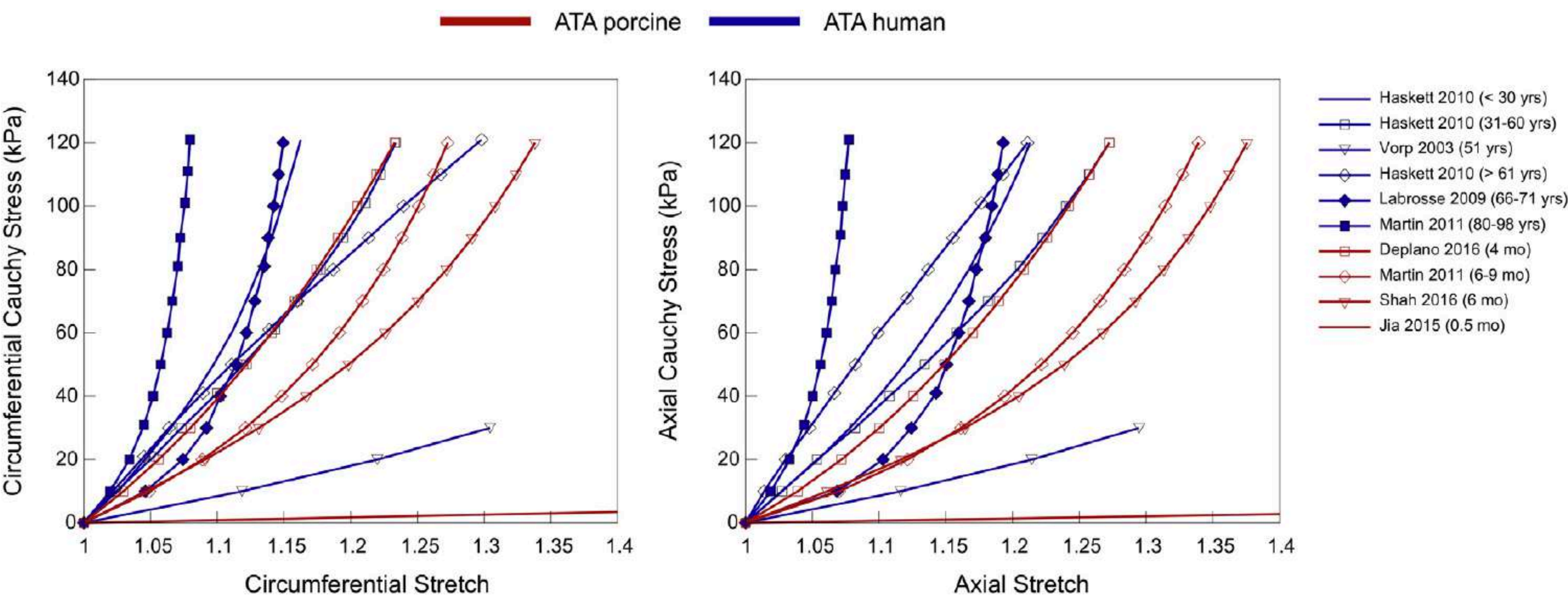
- The available literature was searched for studies reporting data on porcine or human thoracic aortic mechanical behaviour



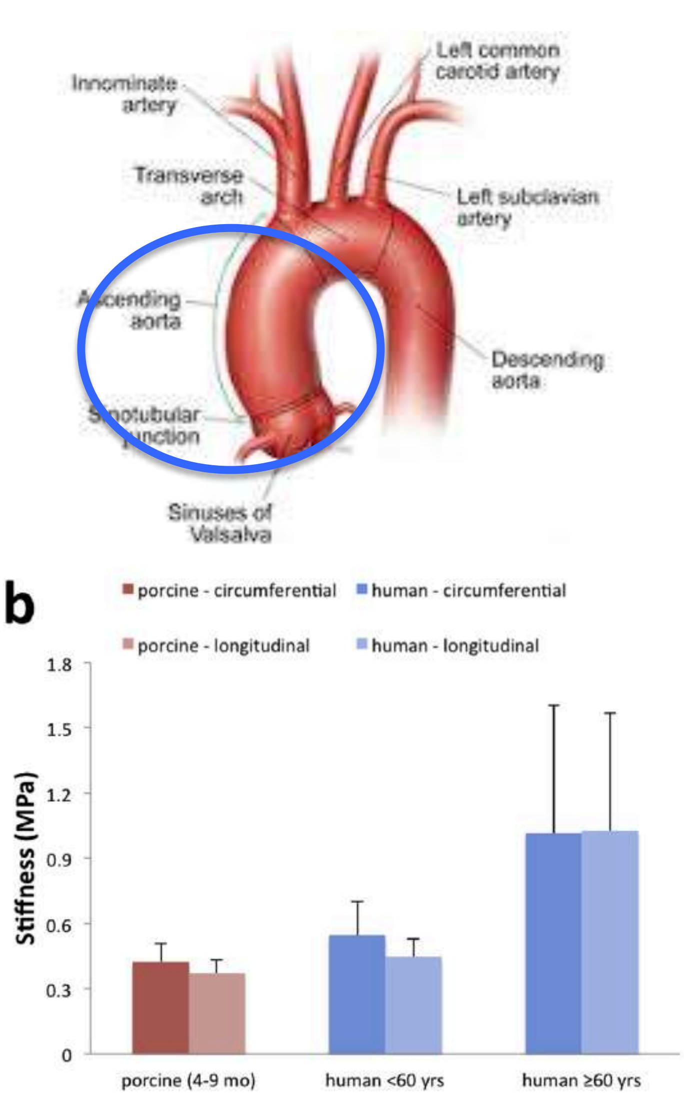
Comparative Analysis of Porcine and Human Thoracic Aortic Stiffness

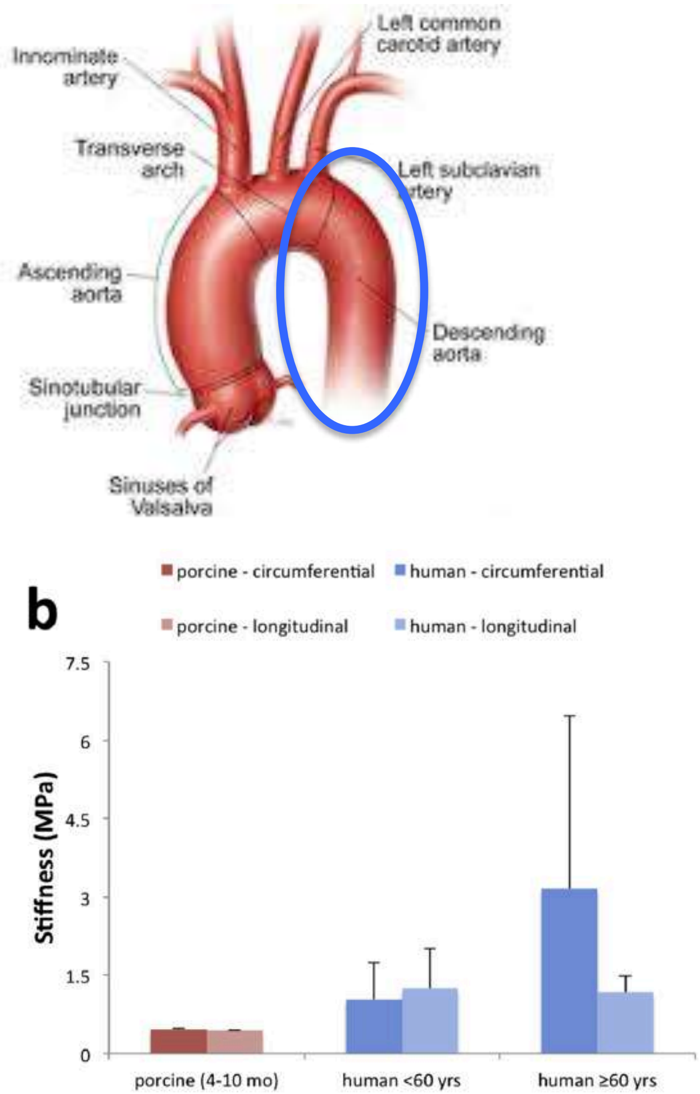
- A four fibre constitutive model was used to transform the data from included studies.
- Thus, equi-biaxial stress stretch curves were generated to calculate circumferential and longitudinal aortic stiffness

$$W = \frac{c}{2}(I_1 - 3) + \sum_{k=1}^{4} \frac{c_1^k}{4c_2^k}\left(\exp\left[c_2^k\left(\left(\lambda^k\right)^2 - 1\right)^2\right] - 1\right.$$



Comparative Analysis of Porcine and Human Thoracic Aortic Stiffness

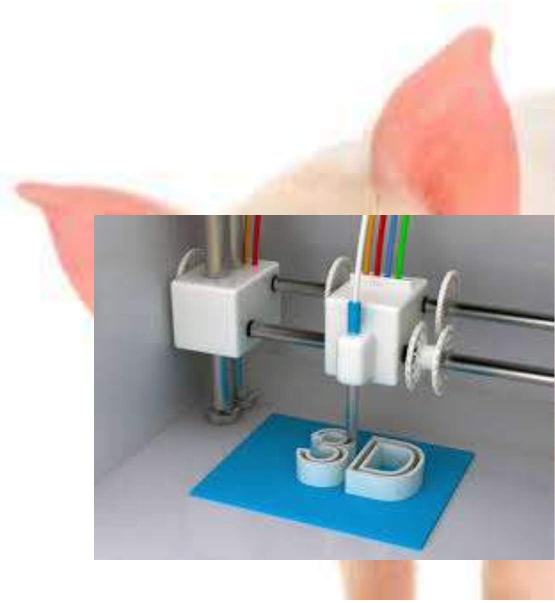




The stiffness of young porcine aortic tissue shows good correspondence with human tissue aged <60 years, especially in the ascending aorta. Young porcine aortic tissue is less stiff than human aortic tissue aged > 60 years.

Mock arteries: 3D printing as an option

Is there any other option to get mock arteries for such experiments?



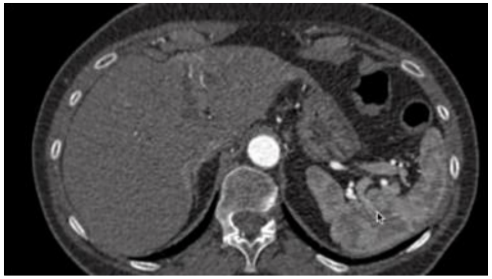
Shore hardness

Ink blending

3D printing technology

Wall thickness

Process & Image Segmentation

1.


Medical Images

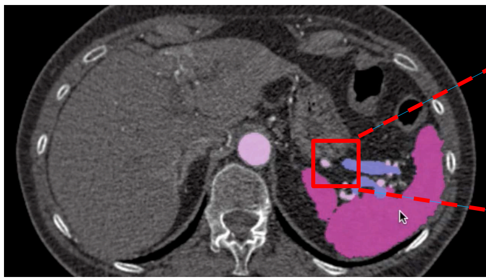
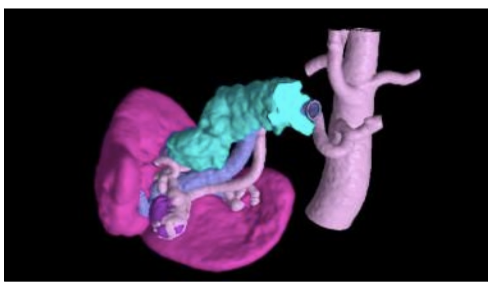
2.


Image Segmentation

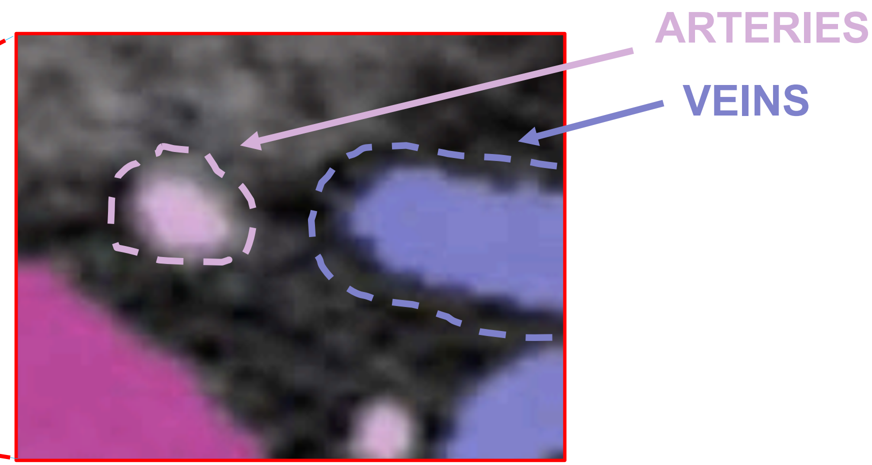
3.


3D Virtual Model

4.


3D Printed Model

PROBLEM: on MDCT images vessels' wall is **not visible**



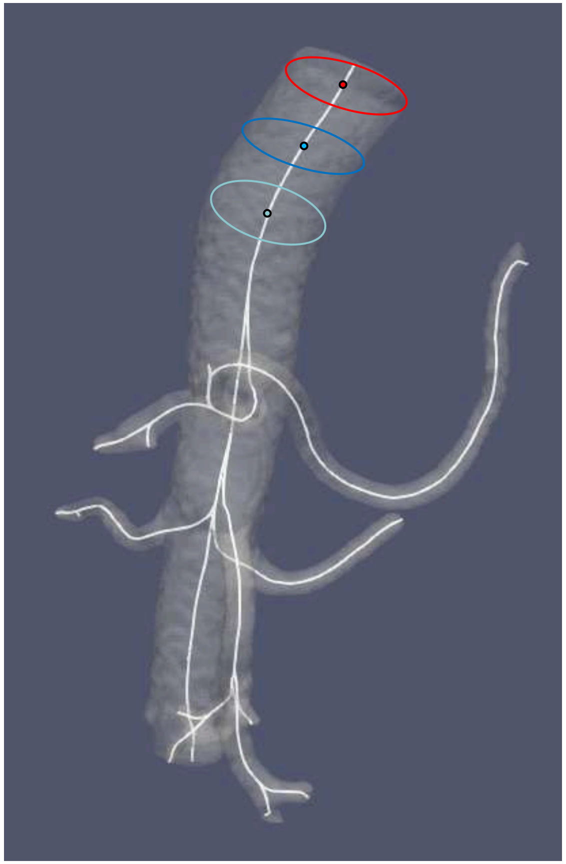
SOLUTION: procedure for **automatic vessels' wall generation**

FINAL GOAL: compute vessels' wall with **realistic morphological and mechanical** properties

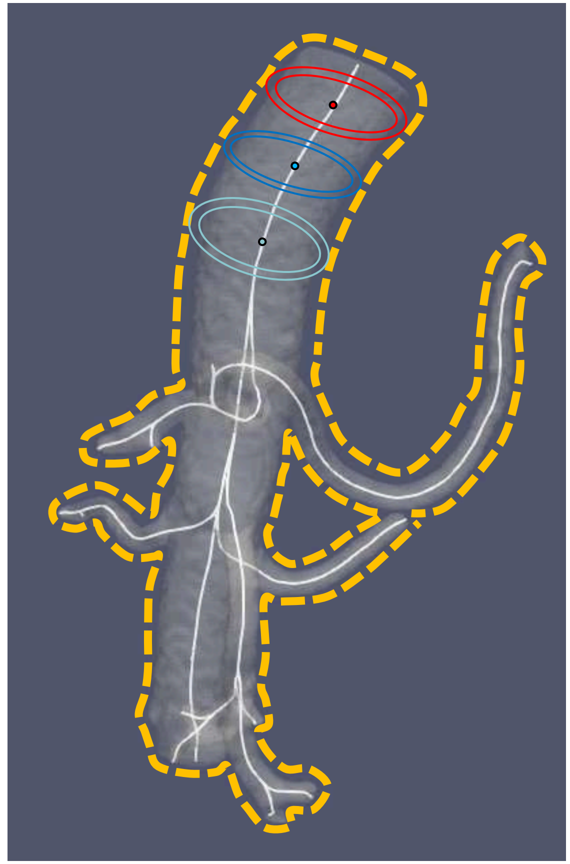
S Marconi, E Negrello, V Mauri, L Pugliese, A Peri, F Argenti, F Auricchio and A Pietrabissa, "Toward the improvement of 3D-printed vessels' anatomical models for robotic surgery training", The International Journal of Artifical Organs, 2019.

Vessels' Wall Generation

Vessels' centerline and lumen diameter at each point



Vessel's local offset at each point



Vessel's wall thickness analysis

LIMITATIONS:

- 3D printer resolution;
- Deposition modality;
- Printing material;
- Support material;

SOLUTION: *(e.g.: deformable photopolymer resins)*

- **Thickness limited to 0.8 mm to avoid delamination or tearing problems.**

S Marconi, E Negrello, V Mauri, L Pugliese, A Peri, F Argenti, F Auricchio and A Pietrabissa, "Toward the improvement of 3D-printed vessels' anatomical models for robotic surgery training", The International Journal of Artifical Organs, 2019.

ObJet 260 Connex 3 – Stratasys®

- Technology: **Material Jetting**
- PolyJet printer with **photopolymer resins**;
- Different colors & materials (**deformable** and **transparent**);
- Big/small models with fine details (16 μm);

Printing Materials

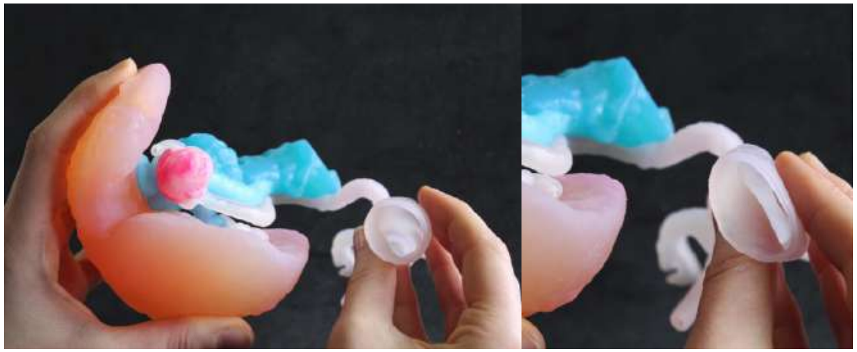
- **VeroClear** (rigid & **transparent** resin);
- **Vero** – family (rigid & colored resins) (e.g. VeroCyano, VeroWhite, VeroMagenta, etc.);
- **TangoPlus** (**deformable & semi-transparent** resin);
- **Agilus30 Clear** (**deformable & semi-transparent** resin);

To produce 3D printed models **suitable for surgical simulation** (e.g. compliant and deformable vessels)

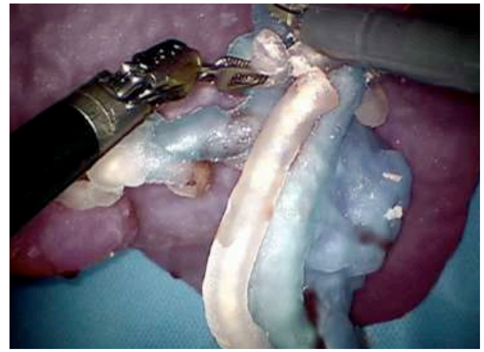
Courtesy of 3D4MED – Prof. Pietrabissa - UniPV

Robotic Surgical Simulation

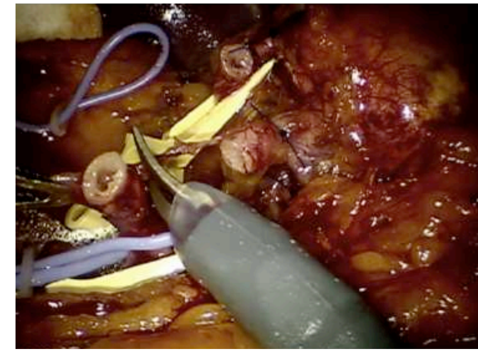
3D printed **deformable model** used to simulate the surgery



Surgical **Simulation**



Robotic Surgery



PRO

- 3D printing is a promising solution fro surgical training phantoms
- The vessels’ wall generation enables the restoration of the correct size
- Mechanical properties are satisfactory to practice on the model with surgical instruments

CONS

- Technological limitations still exists
- Delamination problems at low thickness
- Removal of support material inside vessels’ lumen

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SAVE THE DATE!

3° WORKSHOP BIOPRINTING

Dal set-up della stampa alle analisi in laboratorio

Pavia, 26 Settembre 2019

L'evento mira a condividere le esperienze maturate nel campo del bio-printing mettendo in evidenza protocolli sperimentali e aspetti pratici legati alla preparazione e all'analisi dei costrutti biologici stampati in 3D

www.unipv.it/compmech/bioprinting_home.html

CHT Centre for Health Technologies University of Pavia

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...echanical simulations and 3D printing ...endovascular device testing

THANKS FOR YOUR ATTENTION

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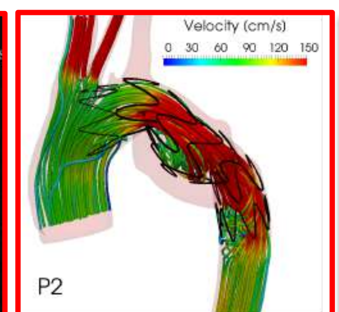

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