INSPIRING INNOVATION | INNOVANTE PAR TRADITION

Ecole Nationale Supérieure des Mines SAINT-ETIENNE

CHU CENTRE HOSPITALIER UNIVERSITAIRE SAINT-ÉTIENNE

Centre for Biomedical and Healthcare Engineering
LGF CNRS UMR 5307

www.emse.fr

Stéphane Avril and coll.

Biomechanics of soft tissues surrounding the major veins in compressed human legs

MINISTÈRE DE L'ÉCONOMIE DES FINANCES ET DE L'INDUSTRIE

INTRODUCTION

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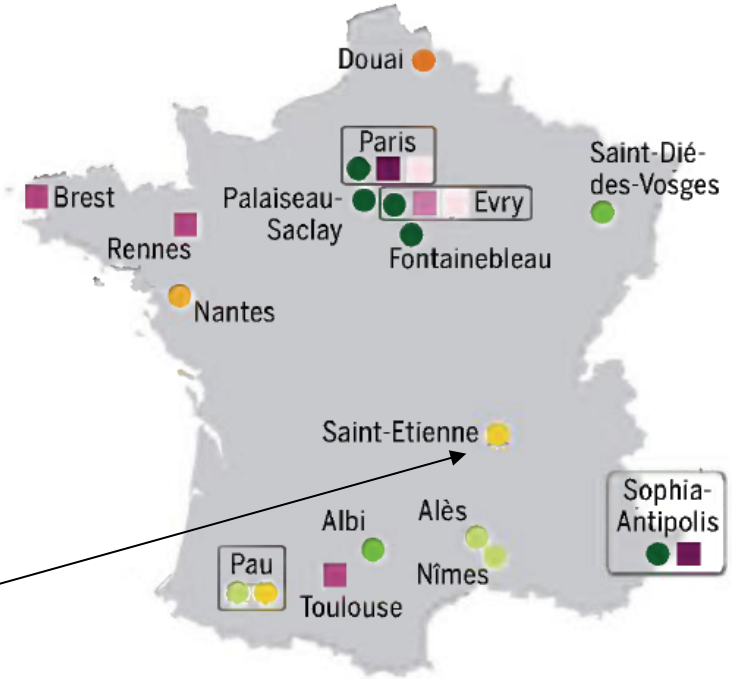

Center for Biomedical and Healthcare Engineering

Campus with hospital, medical school, prevention center, college of engineering and companies manufacturing medical devices

4 topics

Healthcare engineering

Soft tissue biomechanics

ifresis
Institut Fédératif de Recherche en Sciences et Ingéniérie de la Santé
Saint-Etienne

22 permanent staff

35 postgraduate students and postdocs

Biotoxicity of inhaled nanoparticules

Biomaterials for bone replacement

Research strategy:

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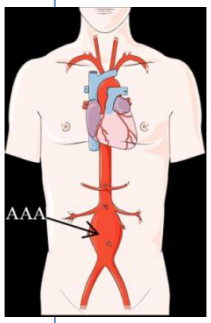
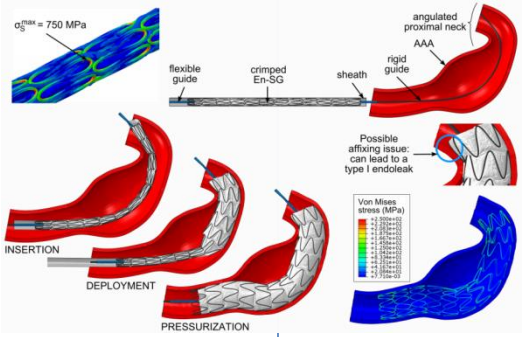
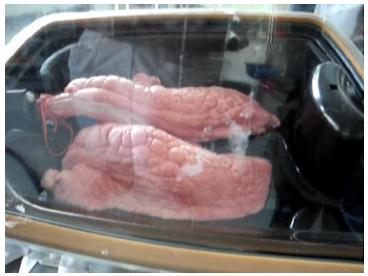


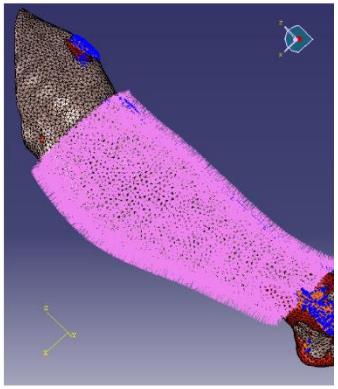


- Predictive biomechanical models for treatments with medical devices;
- Inverse methods for soft tissue biomechanics;
- Biodistribution and biopersistence of nanoparticles in tissues.

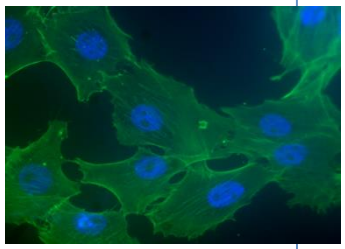


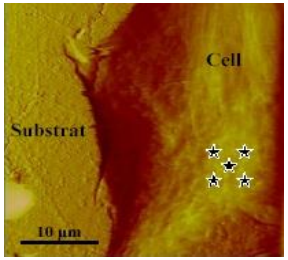
Education:

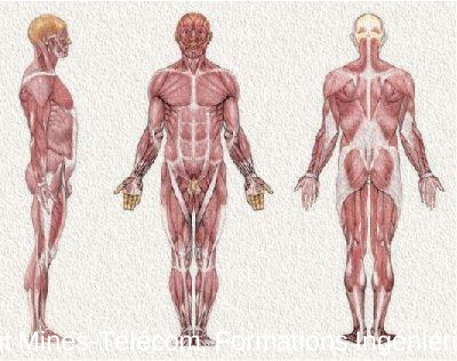
Ecole Nationale Supérieure des Mines SAINT-ETIENNE

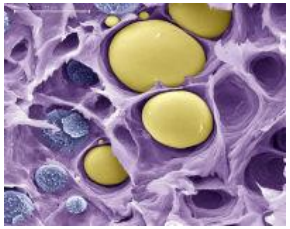


- Master and PhD degree in engineering
- Very selective recruitment
- International MSc in biomedical engineering and design
- Unique double degree with the faculty of medicine and with the medical school.

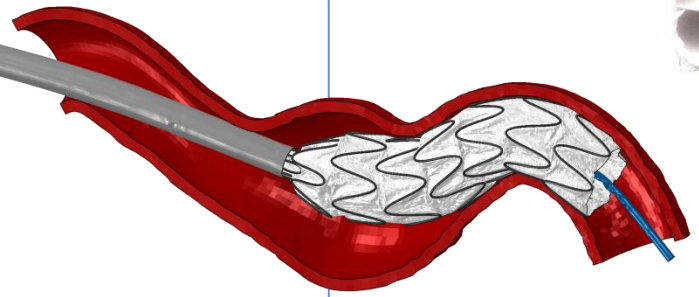


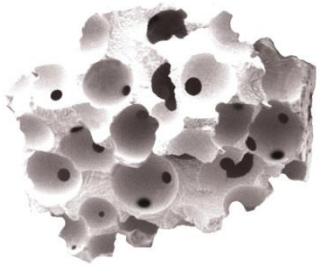


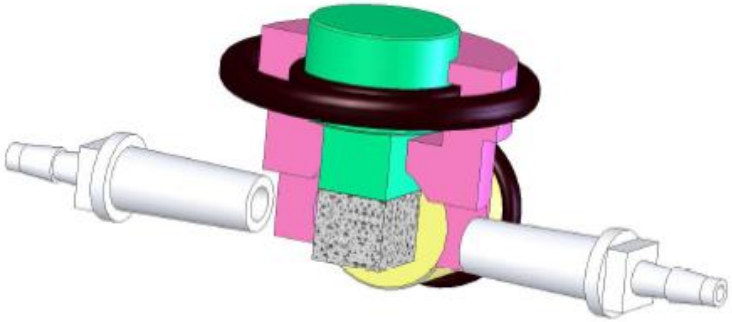




Visit us:







http://cis.mines-stetienne.fr

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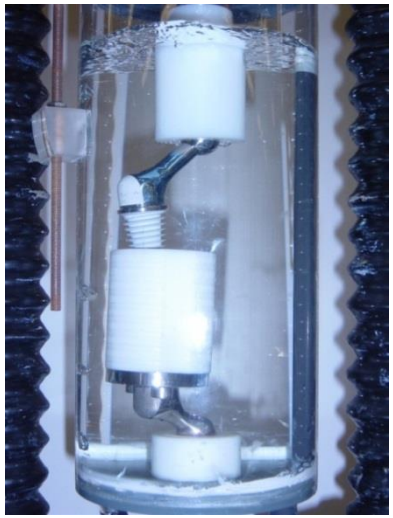


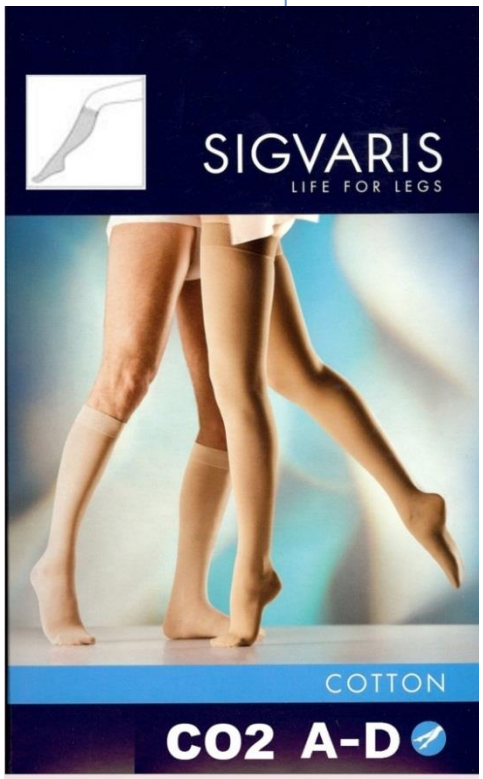
Today's seminar

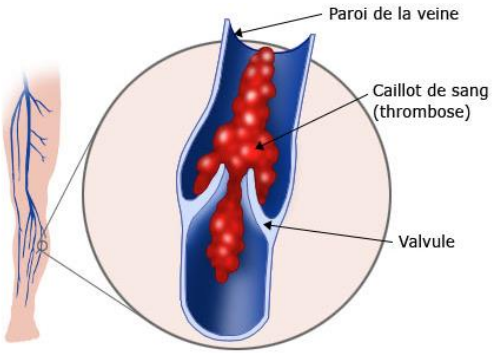
1. **Leg compression biomechanics**
2. Vascular biomechanics -> BSSM conference

Biomechanics of soft tissues surrounding the major veins in compressed human legs

Introduction

Leg compression





Source 1 : http://www.swissorthoma.ch / Source 2 : Hincapi au tour de France 2012, http://www.onlinetri.com / Source 3 : http://www.macirculation.com / Source 4: http://www.sante.univ-nantes.fr

Vein hemodynamics

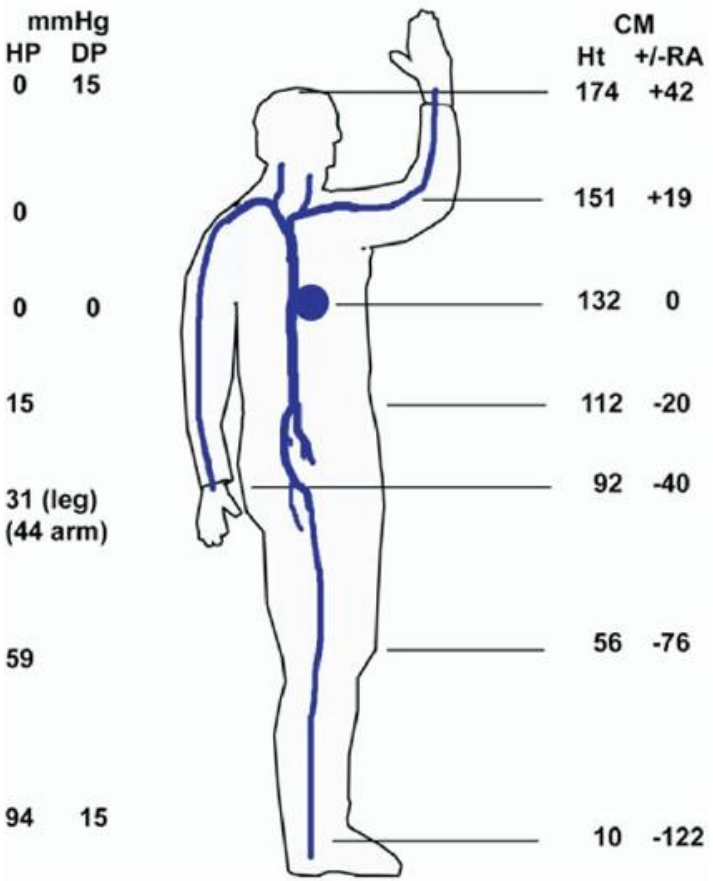


Fig 7. Relative venous hydrostatic (*HP*) and dynamic (*DP*) pressures at various heights (*Ht*) and distances from the right atrium (*RA*) in the upright individual. Dynamic pressure derive from the activity of the cardiac pump while hydrostatic pressures are related to position and gravity. The figure has been standing motionless with the dependent veins filling by gravity. Upper extremity pressures vary with the position of the arm.

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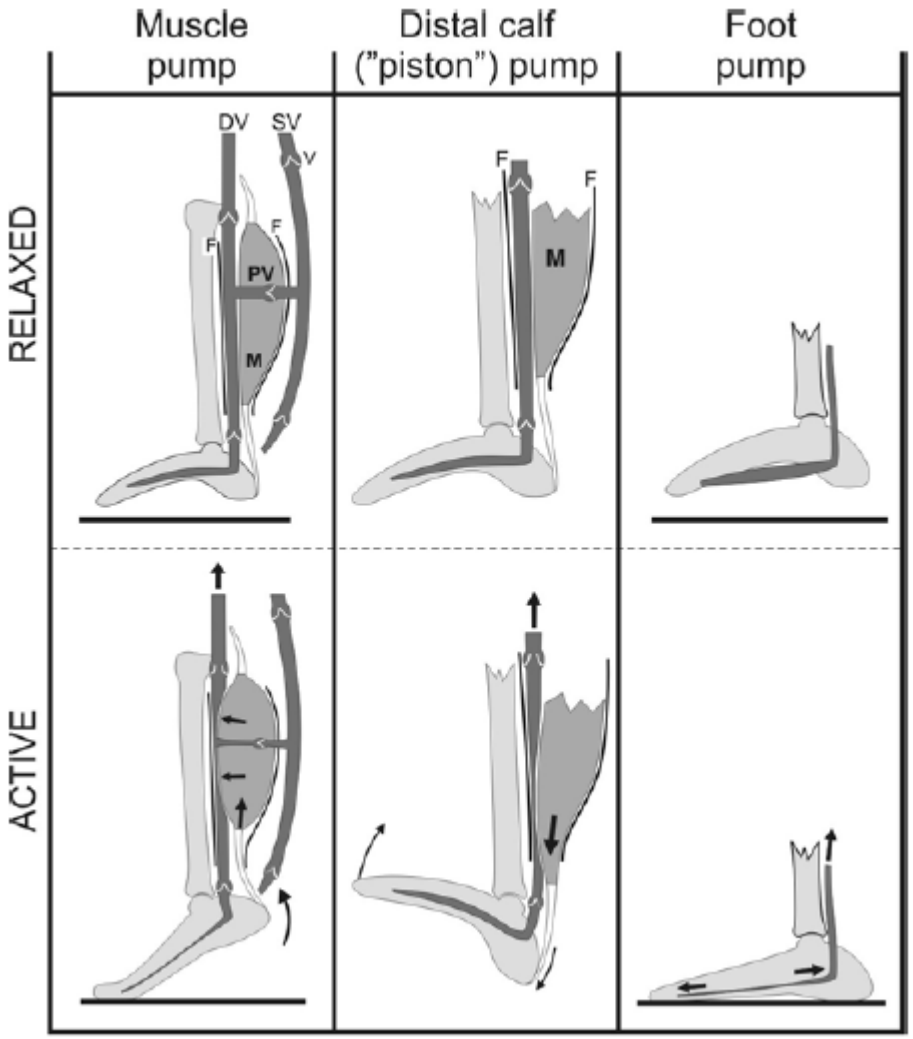
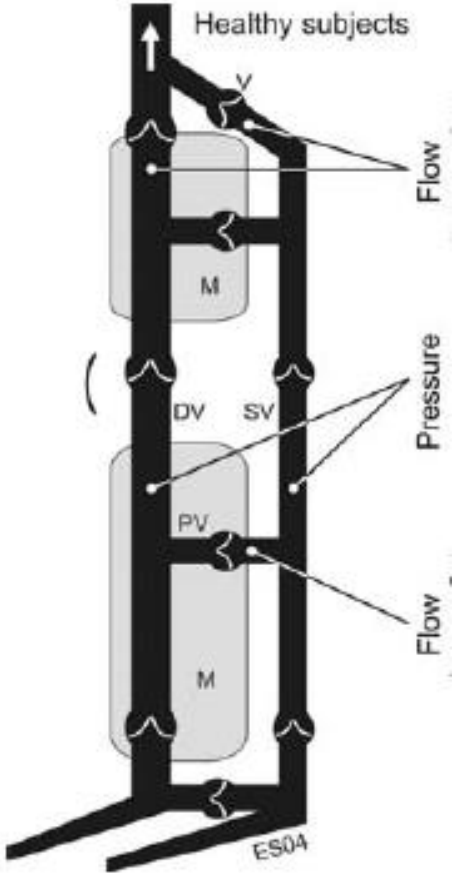
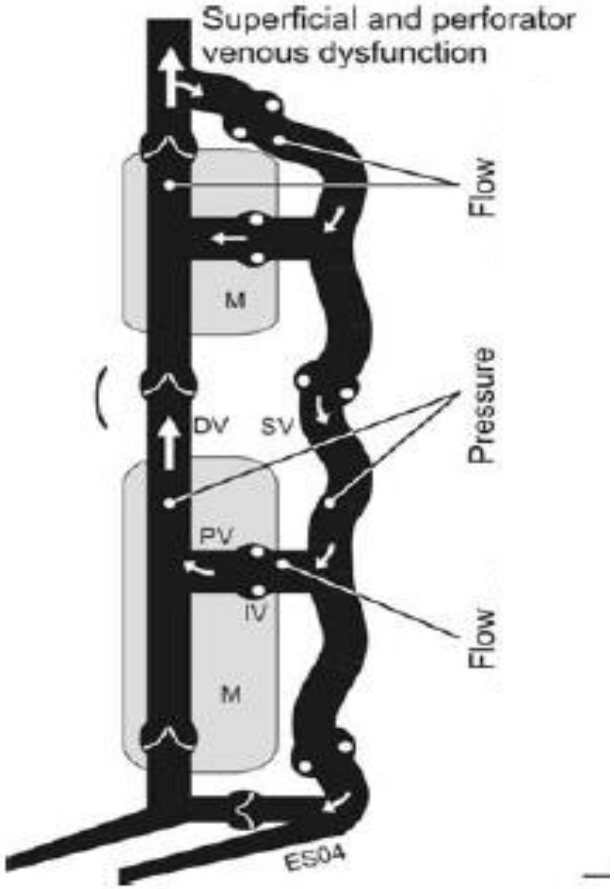
Volume 46, Number S

Vein hemodynamics

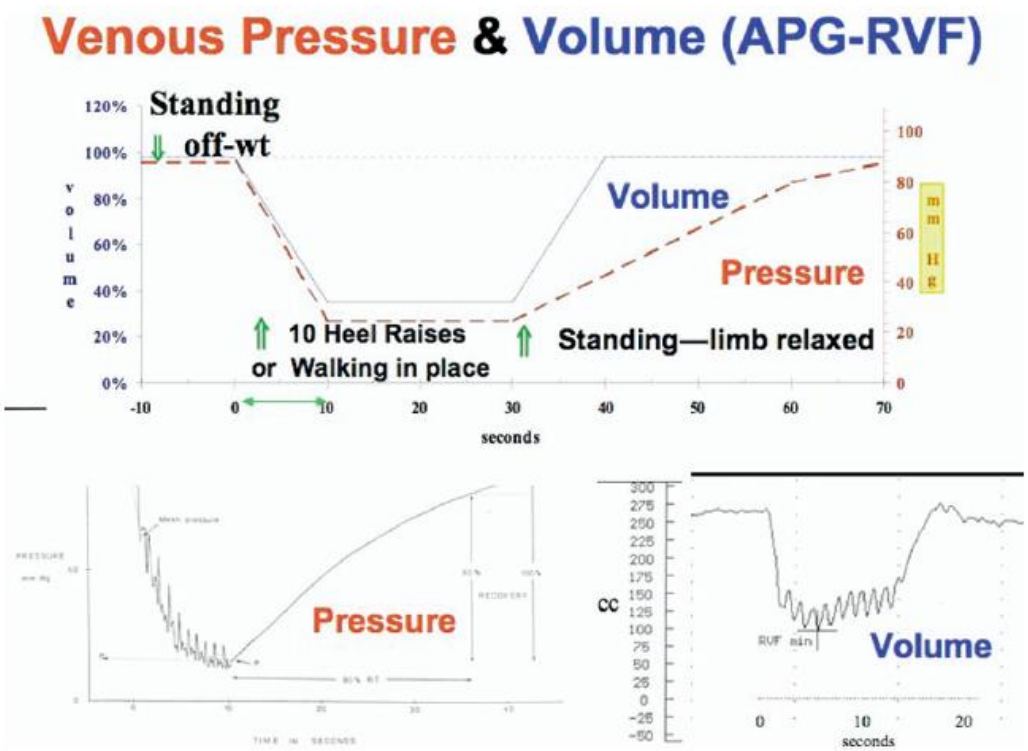


Vein hemodynamics





Vein hemodynamics



JOURNAL OF VASCULAR SURGERY
Volume 46, Number S

Fig 8. The pressure and volume changes with activation of the calf muscle pump are demonstrated. Beginning in the standing posture, the hydrostatic pressure baseline is demonstrated in a dependent, but non-weight bearing limb. The subject then performs 10 tip-toe (*heel-raising*) maneuvers and resumes the non-weight bearing posture. **A,** This schematic compares the pressure and volume changes along a concomitant timeline. Note the efficiency of the calf pump in rapidly reducing either volume or pressure upon commencement of muscle activity. Although volume filling begins within 5 to 7 seconds, pressure does not rise substantially for 30 to 40 seconds. Alterations in these relationships can generate chronic, sustained venous pressure elevations, the end products of which are the symptoms and findings of chronic venous insufficiency. **B,** Pressure changes during these maneuvers are illustrated in this recording from cannulation of a dorsal foot vein reported in mm Hg. **C,** Volume changes during these maneuvers are illustrated in this air plethysmographic examination. The volume remaining in the limb after exercise divided by the venous volume standing still is reported as the residual volume fraction (*RVF*, %).

Vein biomechanics

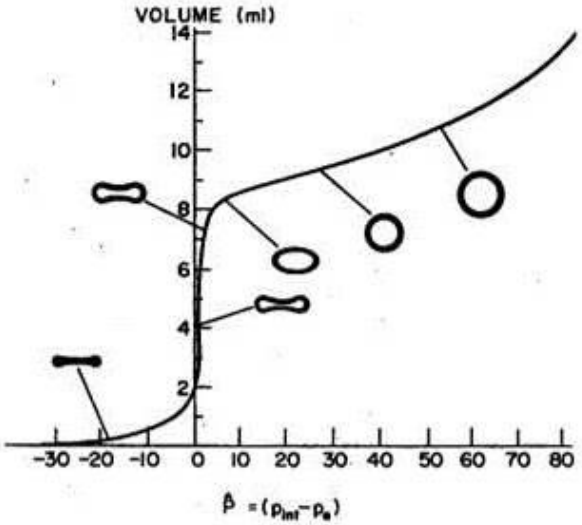
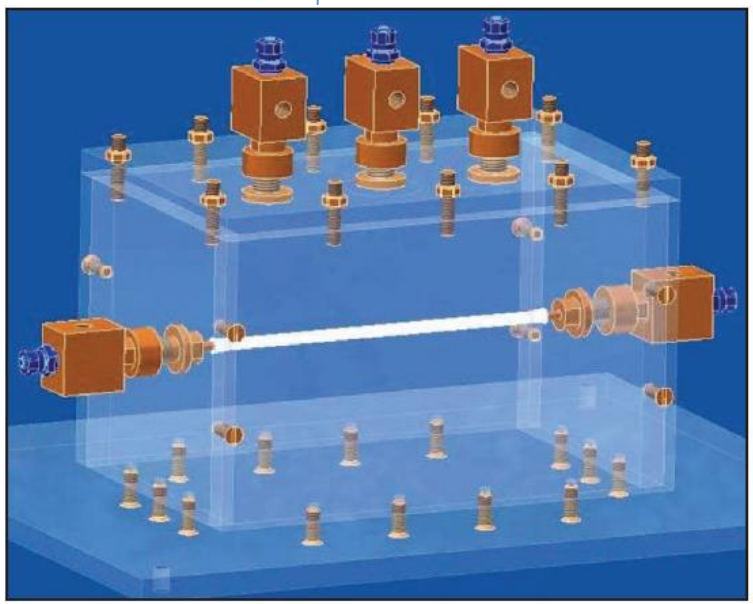


FIGURE 1 Volume in a collapsible tube as a function of transmural pressure. Typical transverse cross-sections are shown at various points on the curve.

Collapsible tubes



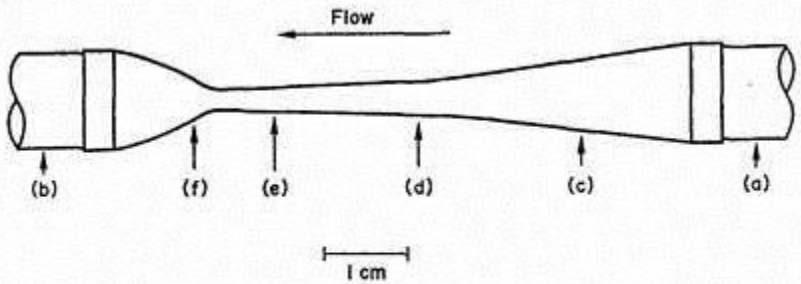
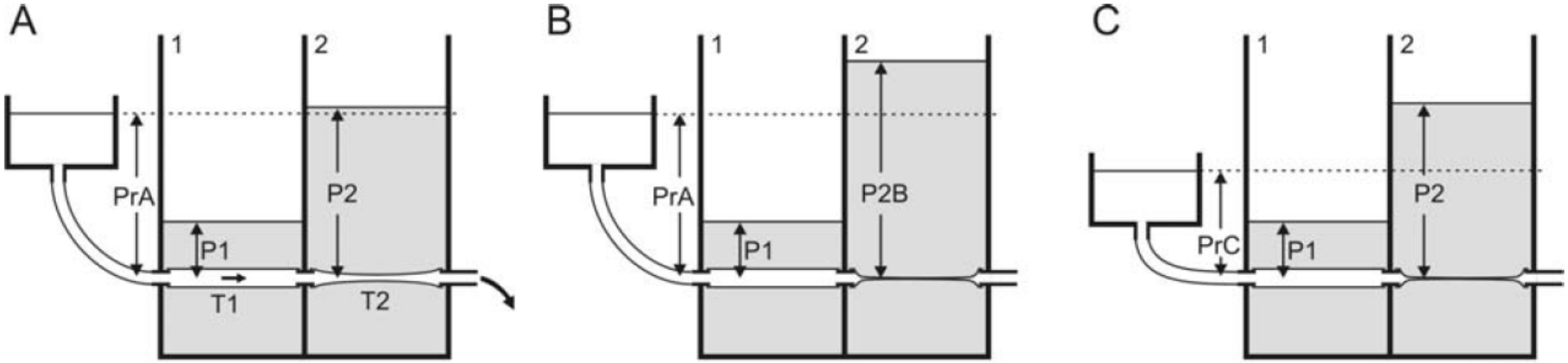


FIG. 1. Typical shape of collapsed tube during steady flow, as observed by CONRAD (1969). (a), (b) rigid tubes; (c) region of subsonic flow; (d) approximate position of elastic constriction; (e) region of supersonic flow; (f) hydraulic jump.

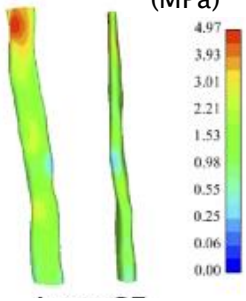


State of the art

1. Venous blood flow

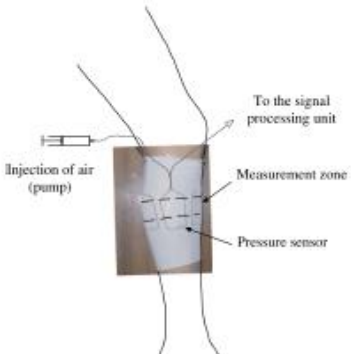
Without EC

Shear stress (MPa)

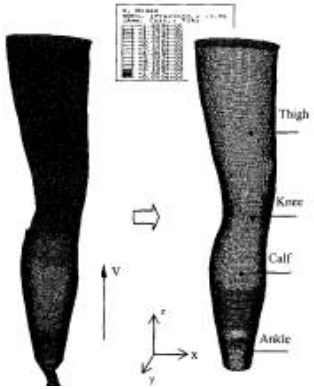


With EC

2. Applied pressure

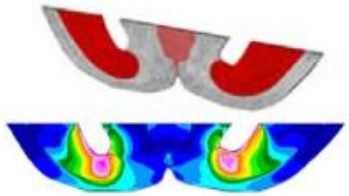


Guesdon *et al.* (2007)
Downie *et al.* (2008)



Gaied *et al.* (2006)
Liu *et al.* (2006)

3. Tissue deformation



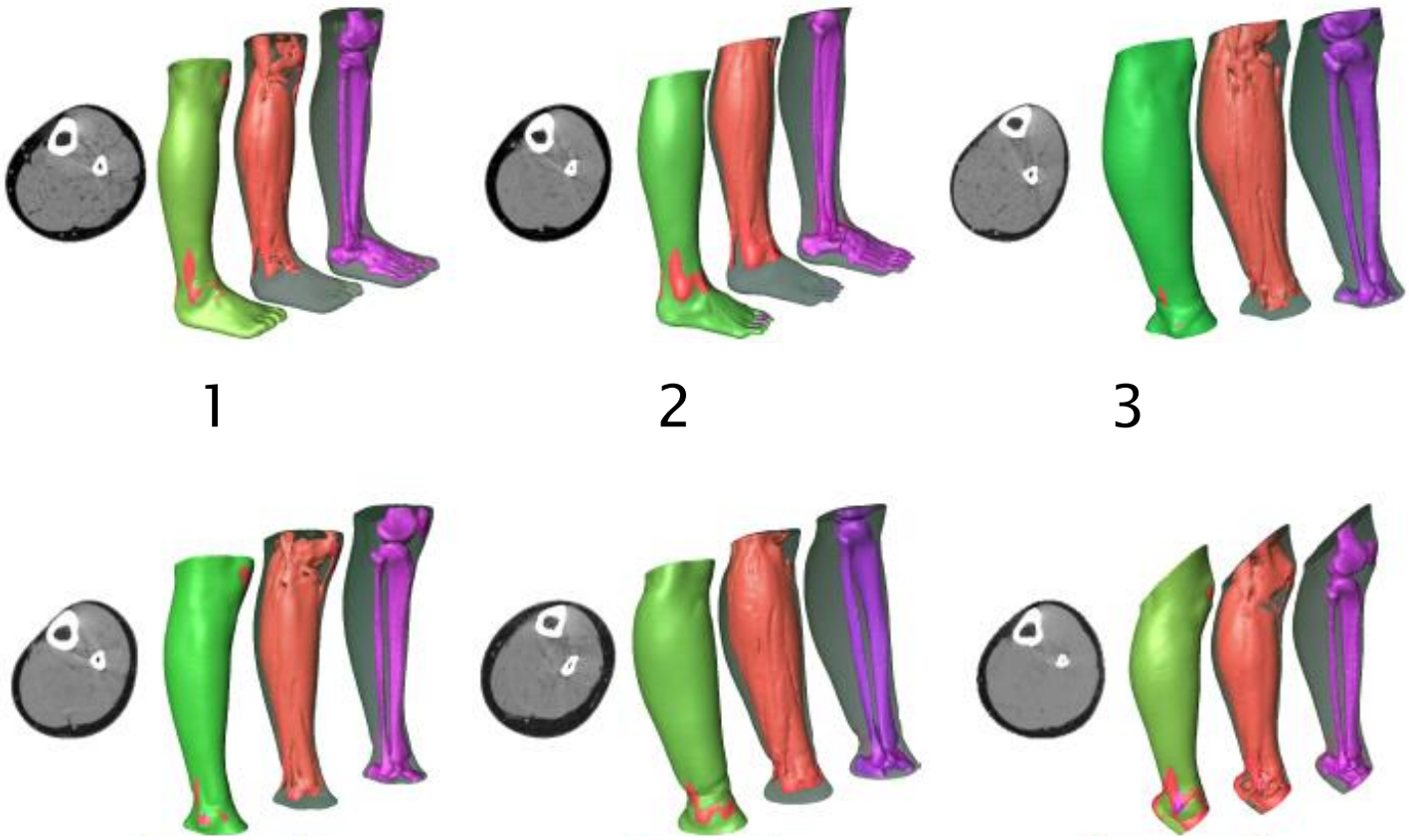
Linder-Ganz *et al.* (2008)
Portnoy *et al.* (2008)
Vogl *et al.* (2010)

Hydrostatic pressure induced by the compression garment in the soft tissues:

Patient-specific modeling

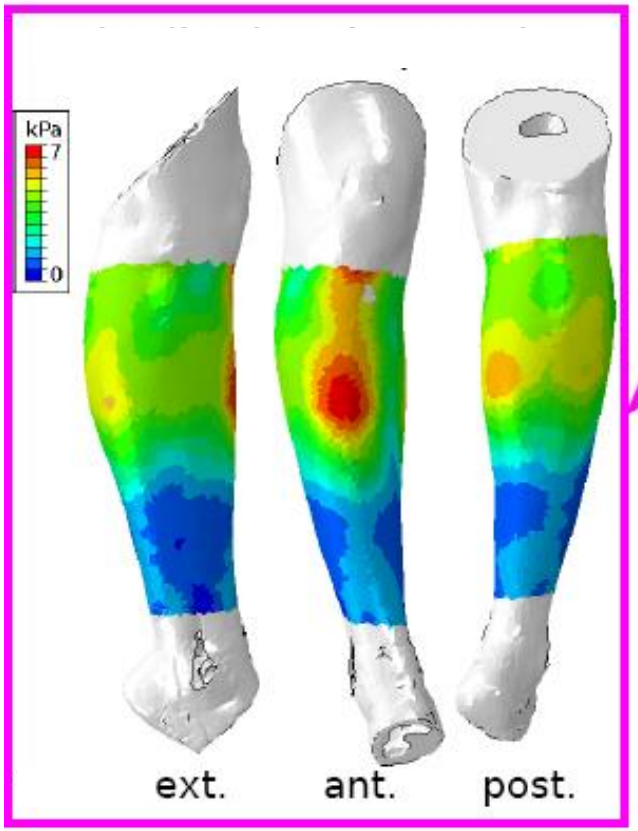
Patient-specific FE modelling: the geometry

3D reconstruction

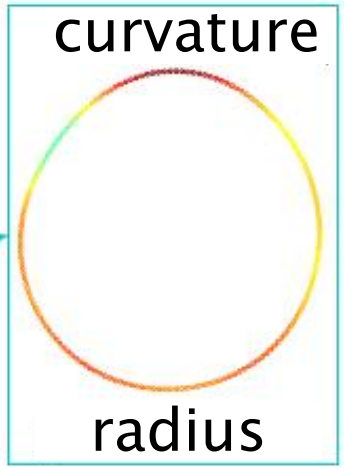


Patient-specific FE modelling: the boundary conditions

$$\frac{\text{Leg circ} - \text{Sock circ}}{\text{Sock circ}}$$

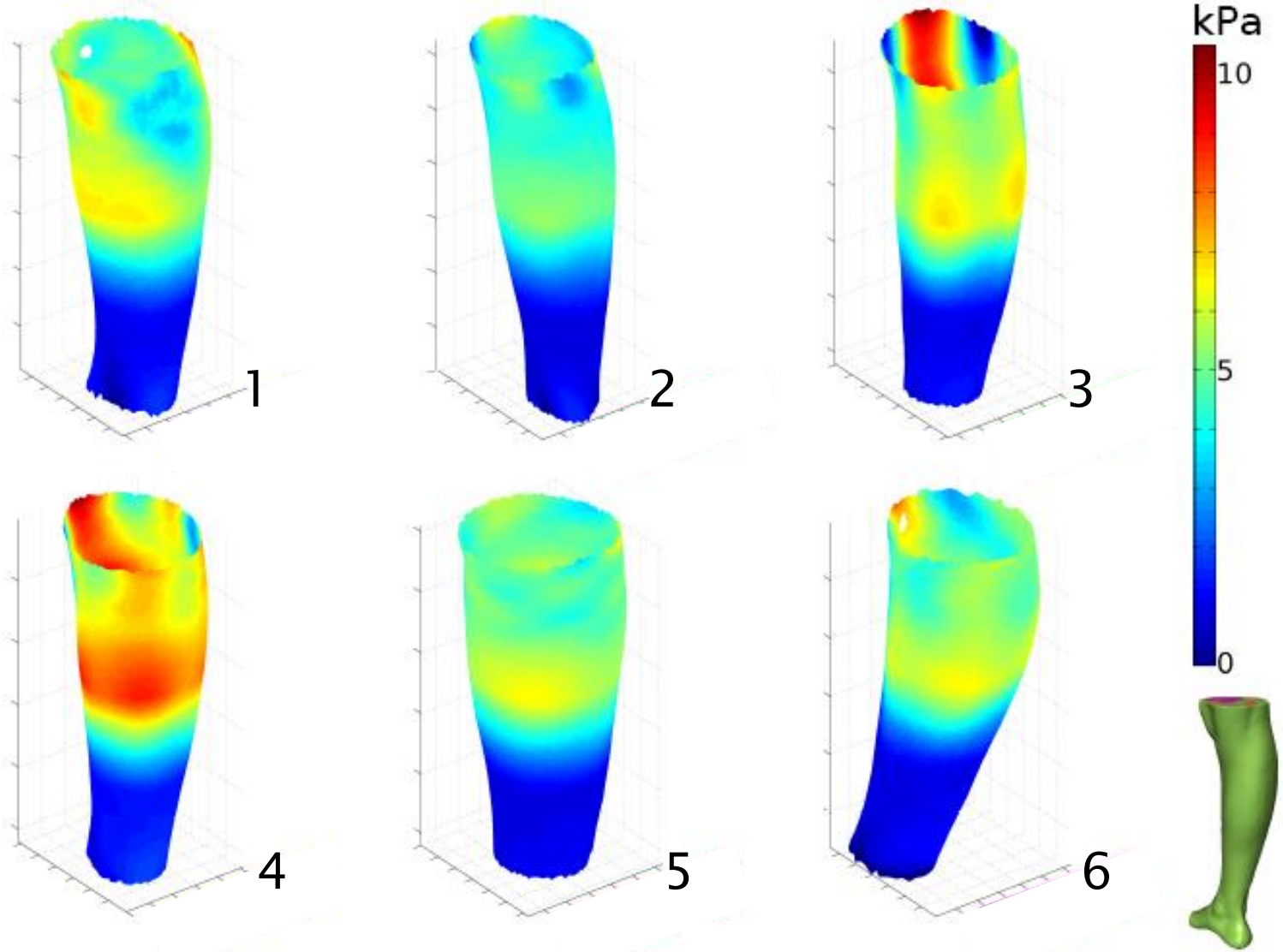


$$P = \text{Stiff}\,\frac{\varepsilon}{Rc}$$



L. Dubuis, S. Avril, J. Debayle and P. Badel, Identification of the material parameters of soft tissues in the compressed leg, *Computer Methods in Biomechanics and Biomedical Engineering, vol 15, number 1, pages 3-11, 2012.*

Patient-specific FE modelling: the boundary conditions

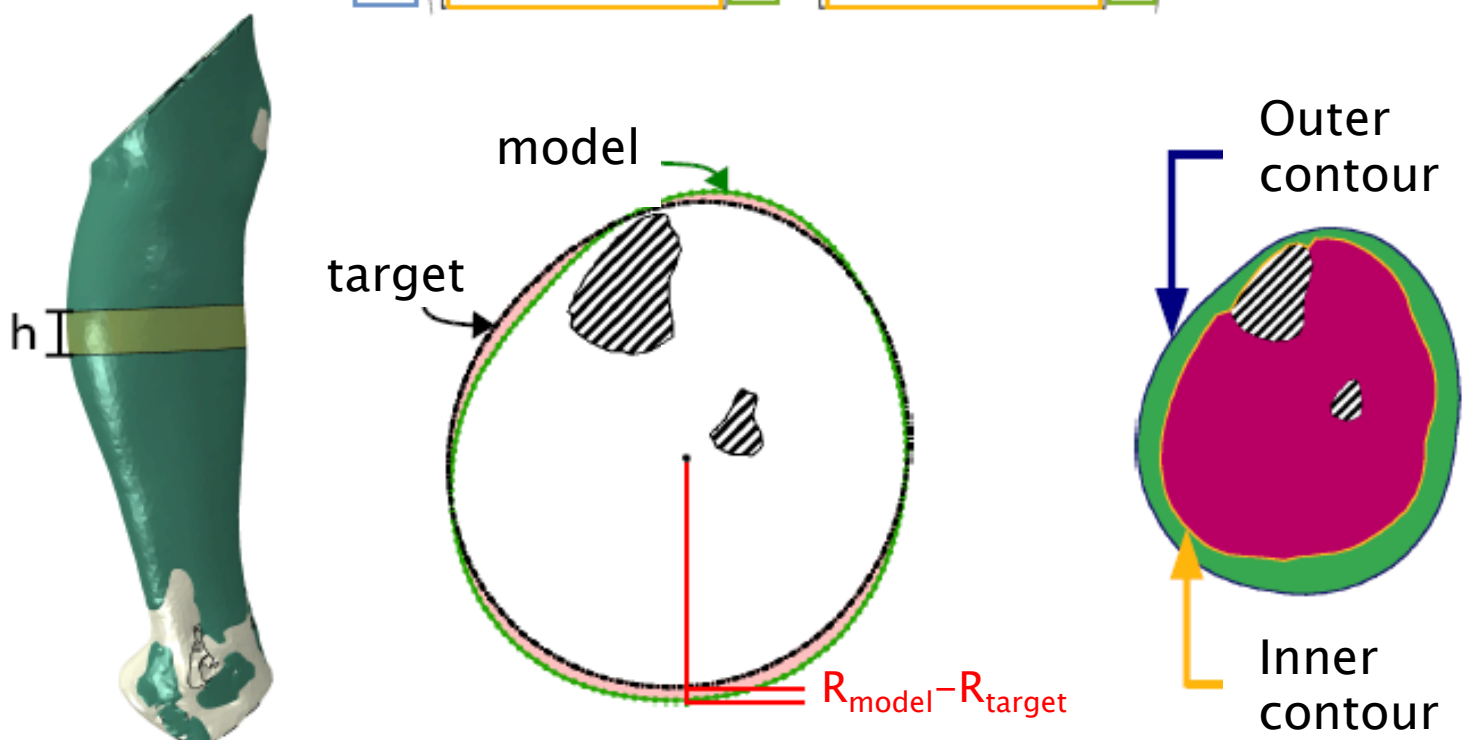


Patient-specific FE model: the material properties

INVERSE METHOD

$$C = \sum_h \left(\left[\frac{R_{simul} - R_{cible}}{R_{cible}} \right]^2_{ext.} + \left[\frac{R_{simul} - R_{cible}}{R_{cible}} \right]^2_{int.} \right)$$

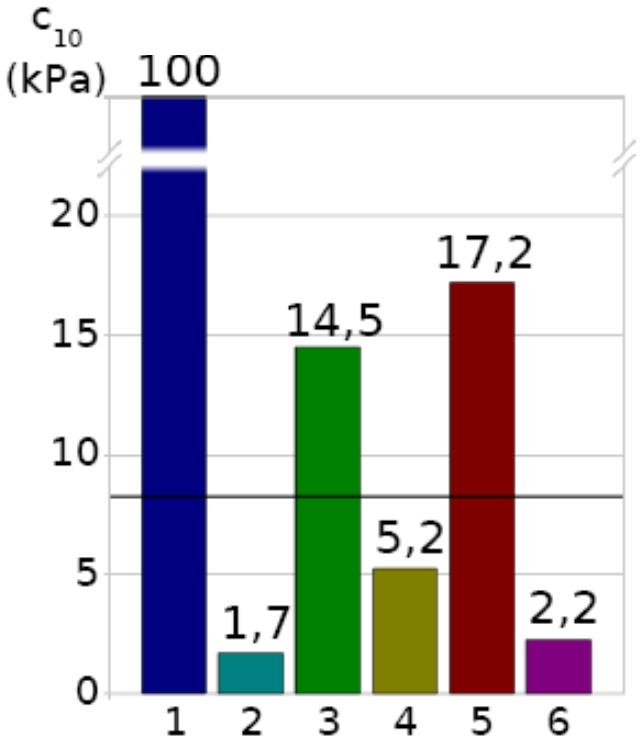
$$W = \frac{G}{2}\left(\bar{I}_1 - 3\right) + \frac{K_v}{2}\left(J - 1\right)^2$$



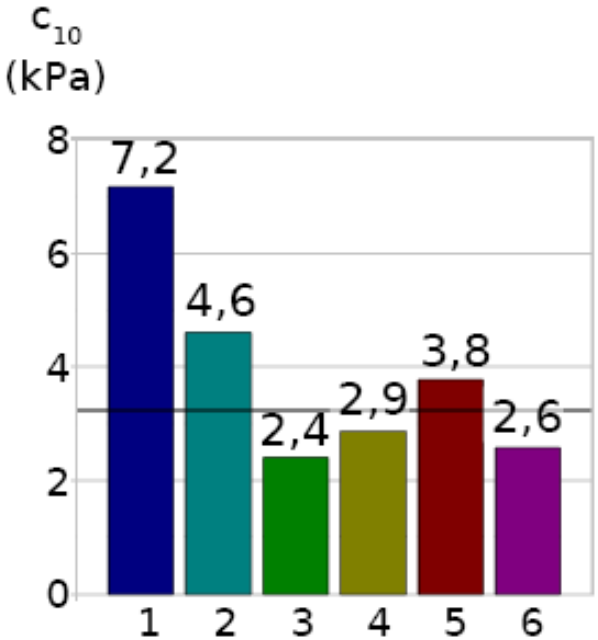
« Mixed experimental and numerical approach for characterizing the biomechanical response of the human leg under elastic compression »,
S. Avril, L. Bouten, L. Dubuis, S. Drapier, J.-F. Pouget, *Journal of Biomechanical engineering*, Vol.5, pp 51-54, 2010.

Results

Subcutaneous soft tissue



Deep soft tissue

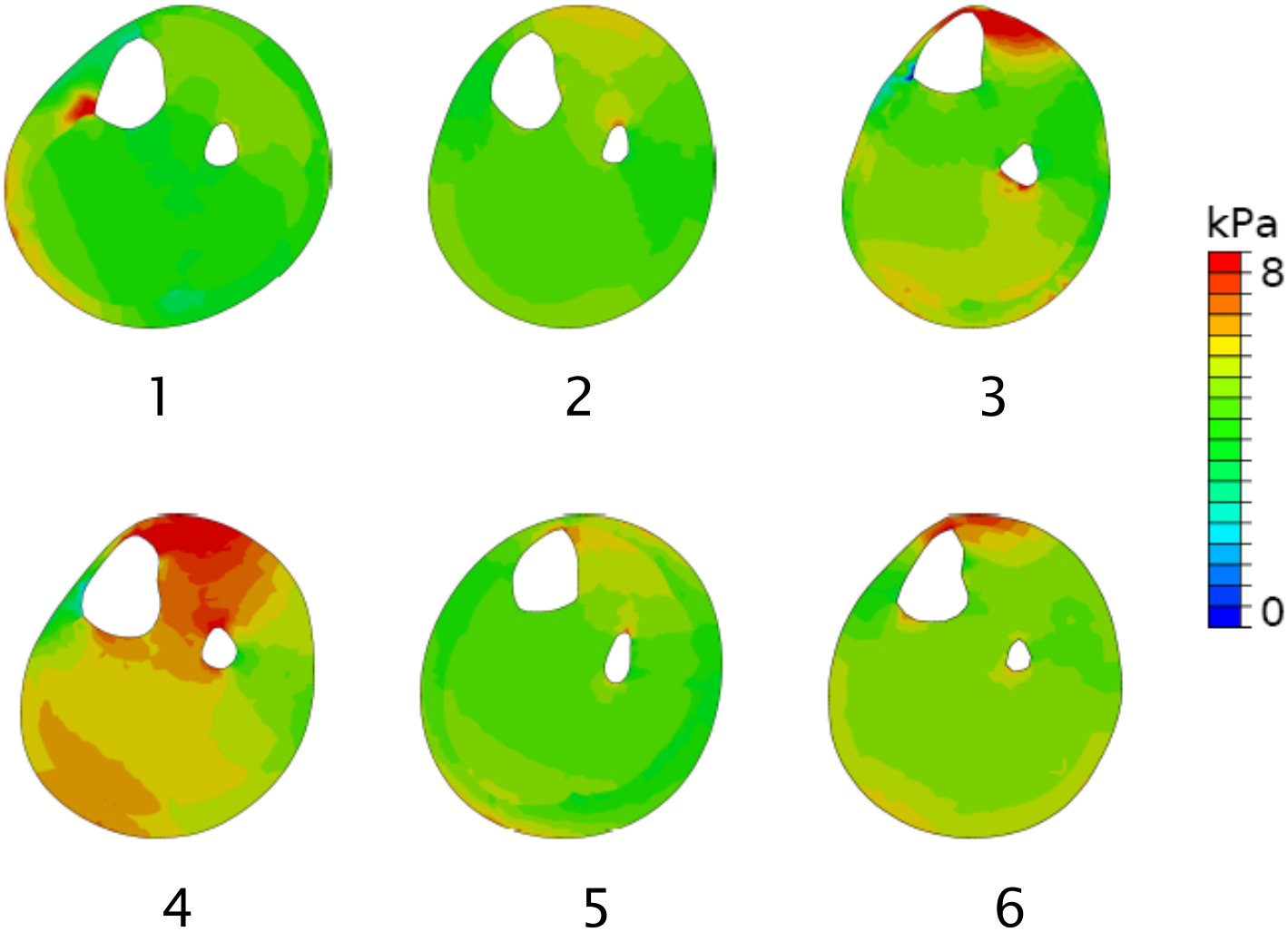


Averages:

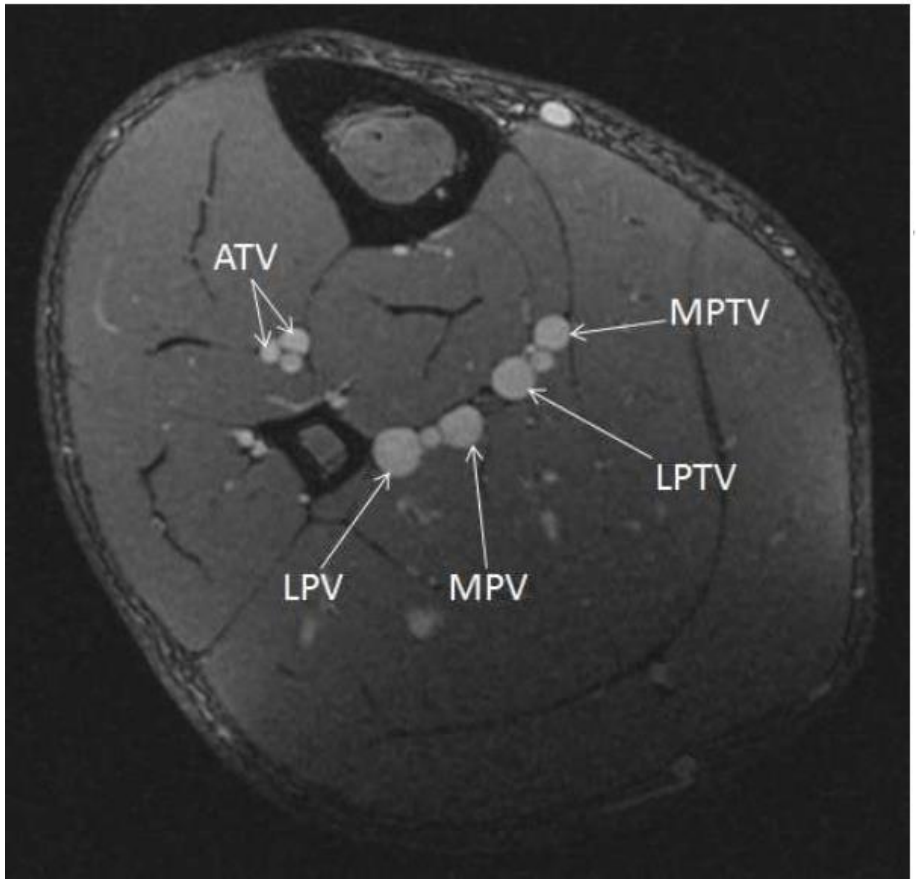
8.2 ± 7 kPa

3.25 ± 0.9 kPa

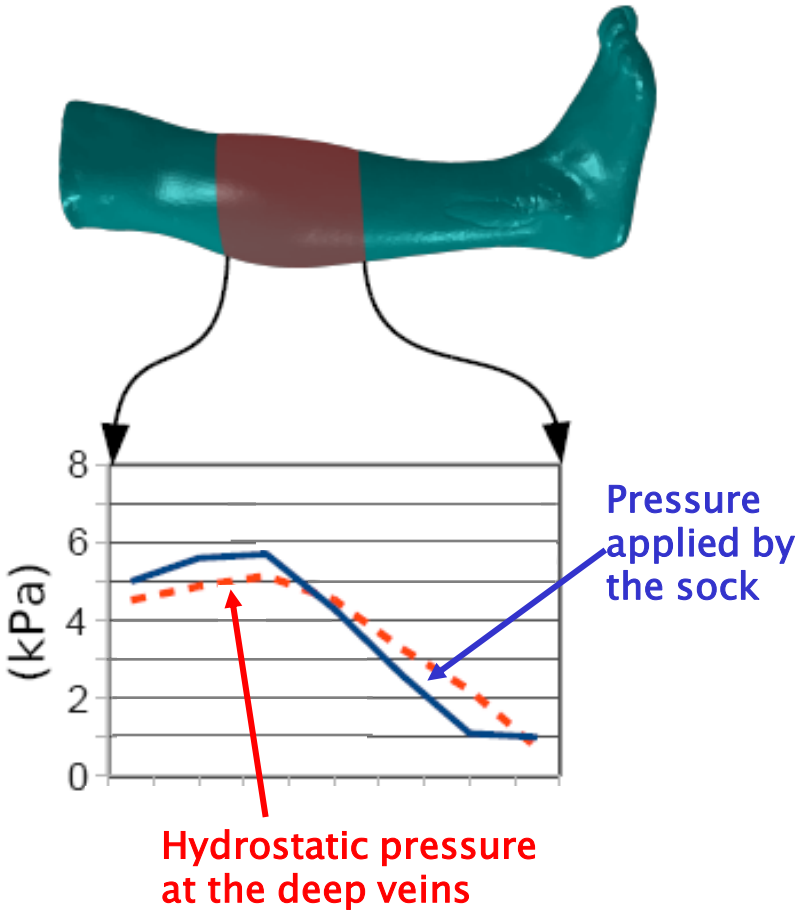
Results



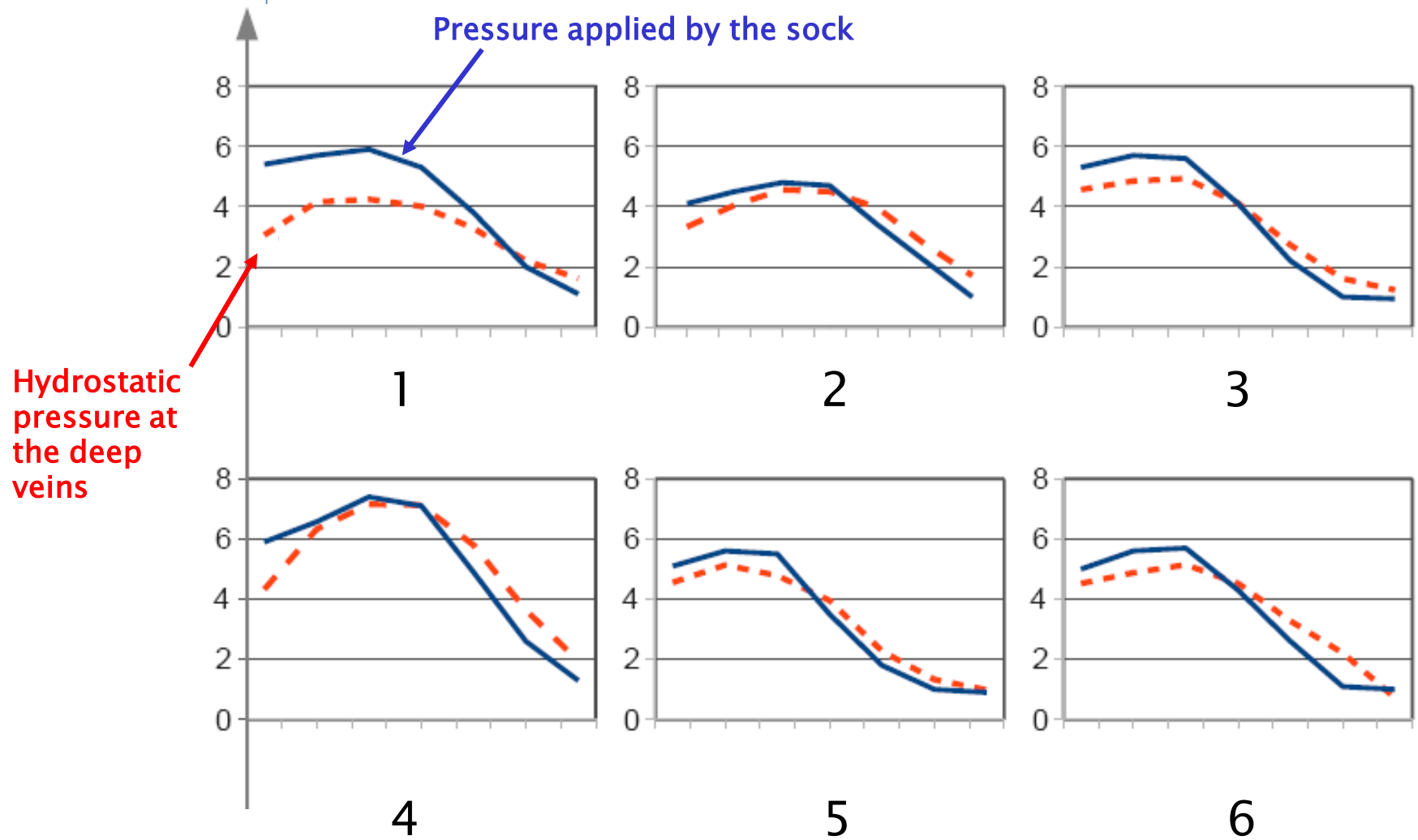
Deep vein locations



Pressure vs height

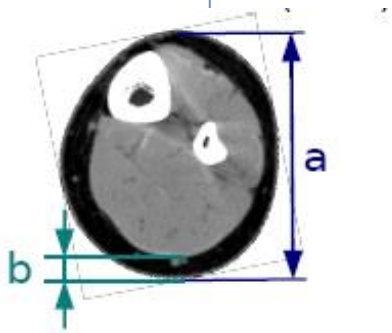


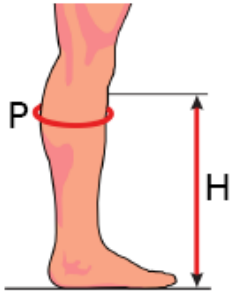
Results


Pressure applied by the sock
Hydrostatic pressure at the deep veins
8
6
4
2
0
1
2
3
4
5
6

Conclusions

- **The compression treatment should be patient-specific**
- **Importance of comfort issues**





S. Avril, L. Bouten, L. Dubuis, S. Drapier, JF Pouget. Mixed experimental and numerical approach for characterizing the biomechanical response of the human leg under elastic compression. *ASME Journal of Biomechanical Engineering* -2010, 132, 031006.

L. Dubuis, S. Avril, J. Debayle, P. Badel. Patient-specific numerical model of soft tissues in the compressed leg: application to six subjects. *Computer Methods in Biomechanics and Biomedical Engineering*, 2012, 15(S1) pp 44-45

S. Avril, P Badel, L Dubuis, J Debayle, S Couzan, JF Pouget, Patient specific modeling in venous deficiency, in "Patient-Specific modeling in tomorrow's medicine" (Studies in mechanobiology, tissue engineering and biomaterials), Edited by Amit Gefen, Springer-Verlag, 2012, 09, 217-238, ISBN 978-3-642-24618-0

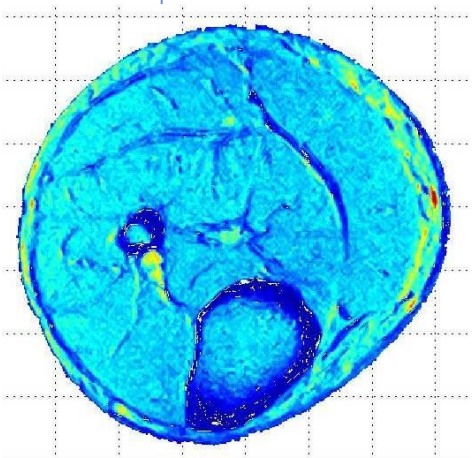
Vein and soft tissues interactions

Generic modelling

P.Y Rohan, P. Badel, S. Avril, D. Rastel, B. Lun, Biomechanical response of varicose veins to elastic compression: a numerical study. Journal of Biomechanics, 2013, 46(3), pp 599-603..

Superficial veins

- MRI et US data



Supine – no EC

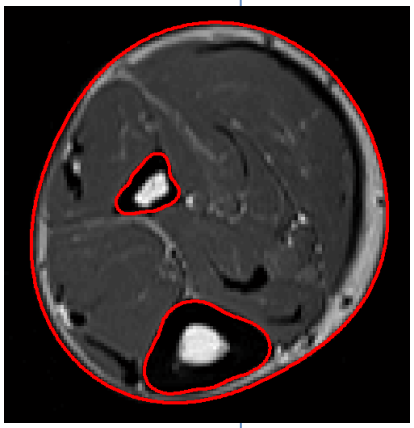
Supine – with CE

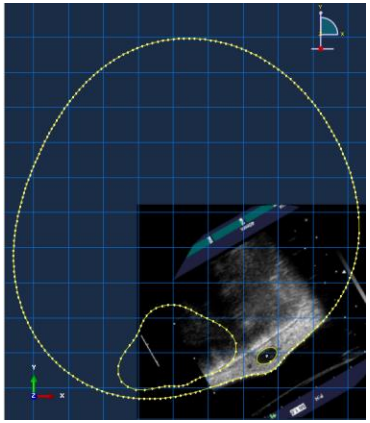
Standing – No CE

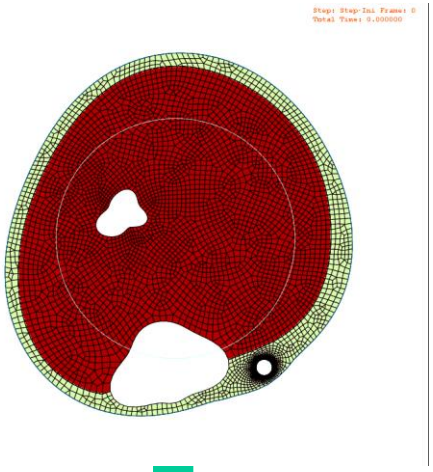
Standing – with CE

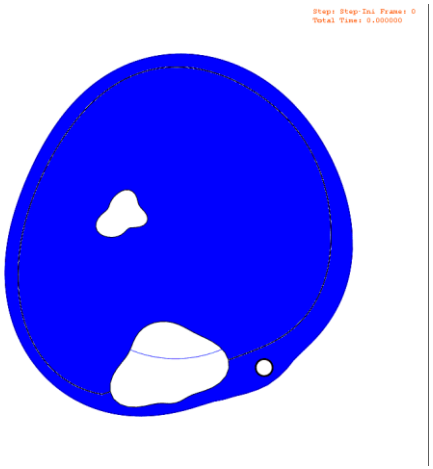
SIGVARIS
LIFE FOR LEGS

Finite-Element Modeling approach







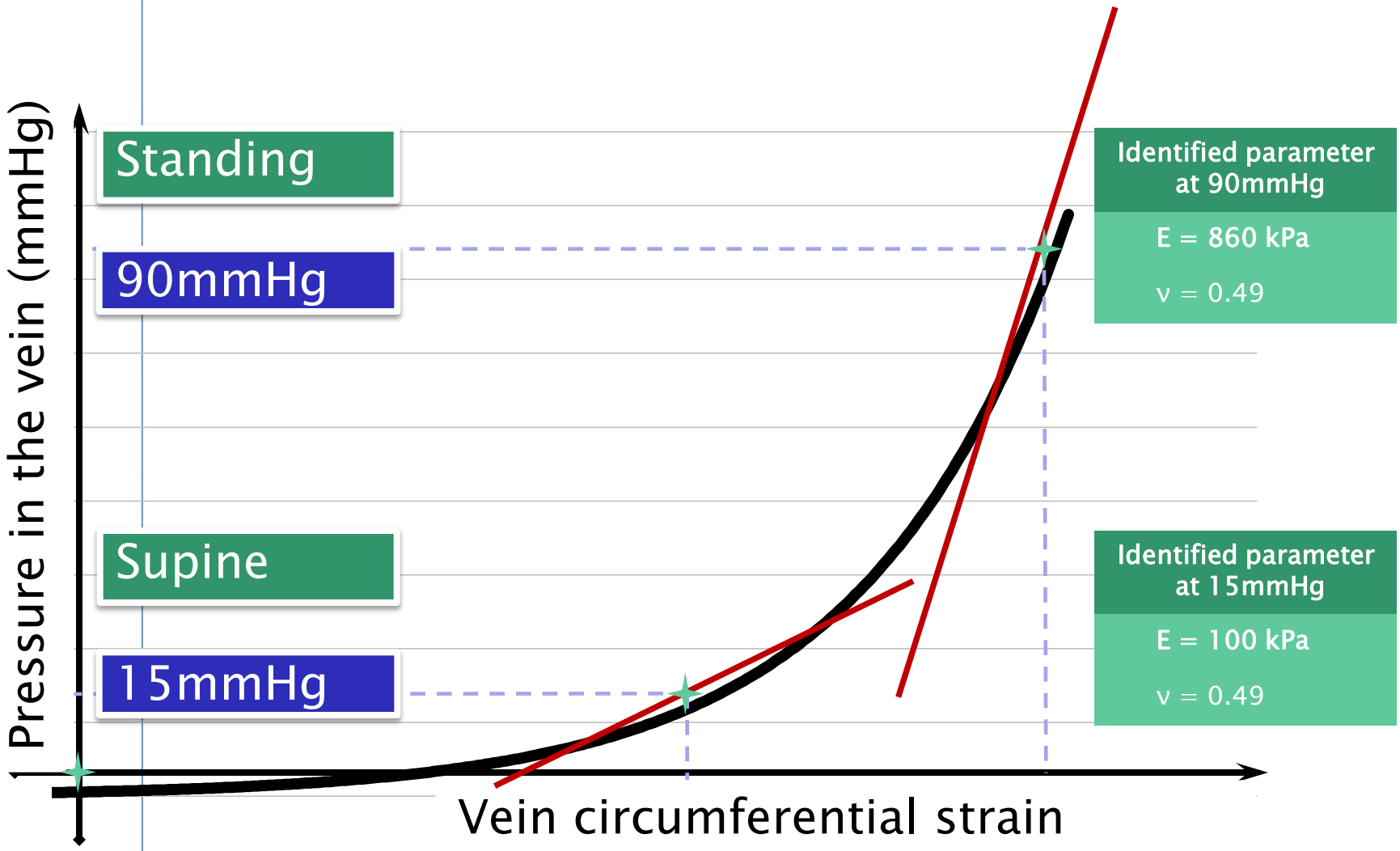


Superficial veins

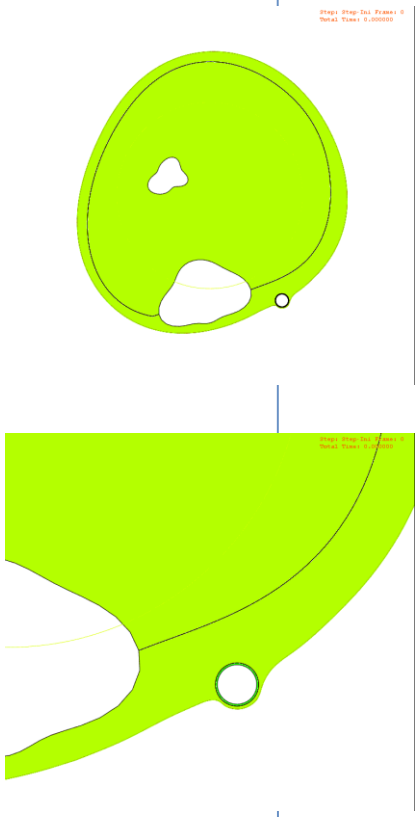
Material properties

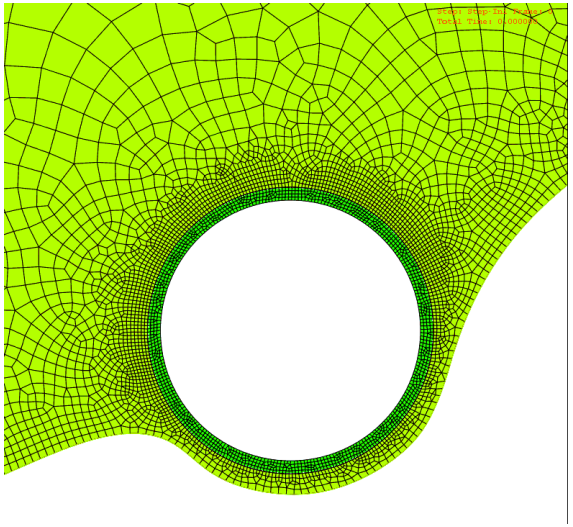
Tissu	Modèle	paramètres	Source
Fat	Hyper-elastic Neo-Hooke	C_{10}= 0.005 MPa D_1 = 0.14 MPa^{-1}	(Dubuis et al., 2011)
Muscles	Hyper-elastic Neo-Hooke	C_{10}=0.003 MPa D_1 = 0.14MPa^{-1}	(Dubuis et al., 2011)
skin	Hyper-elastic Neo-Hooke	C_{10}= 0.1 MPa D_1 = 0.14 MPa^{-1}	(Iivarinen et al., 2011) (Hendriks et al., 2006)
Fascia	Hyper-elastic Neo-Hooke	C_{10}= 10 MPa D_1 = 80 MPa^{-1}	(Wu, 2007)
stocking	Linear elastic	E = 0.39 ν = 0.49	NF-G30-102 (AFNOR, 1986)
Vein	?		

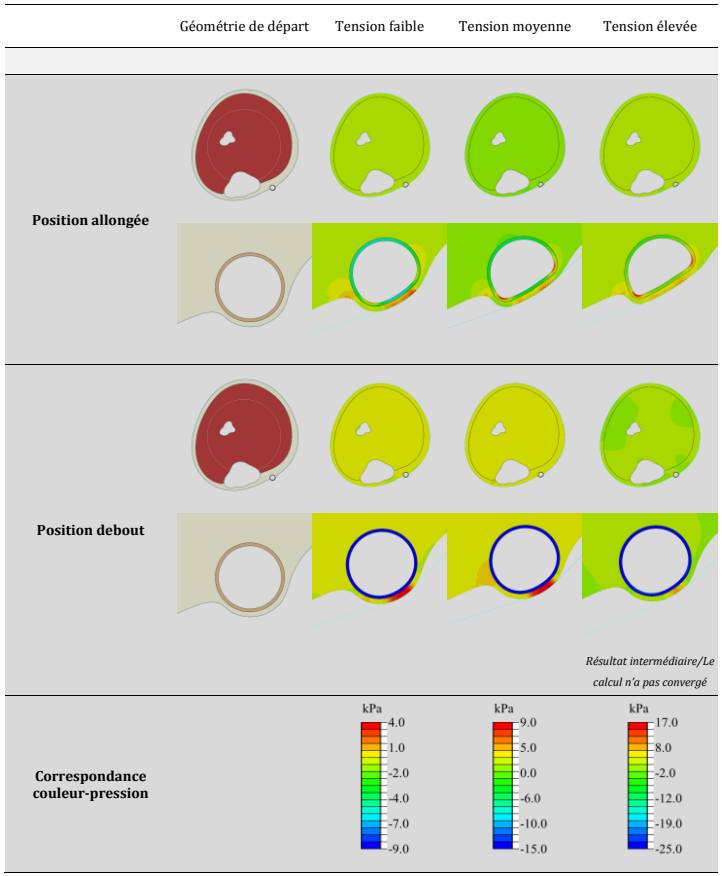
Superficial veins



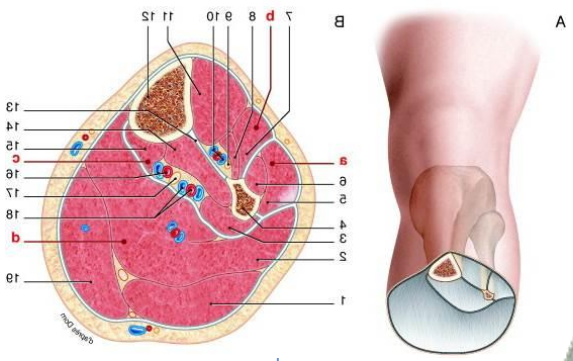
Superficial veins

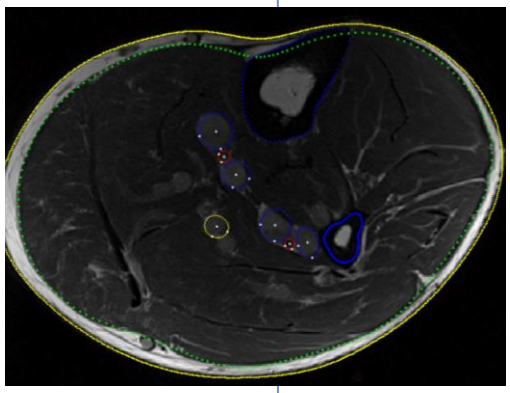


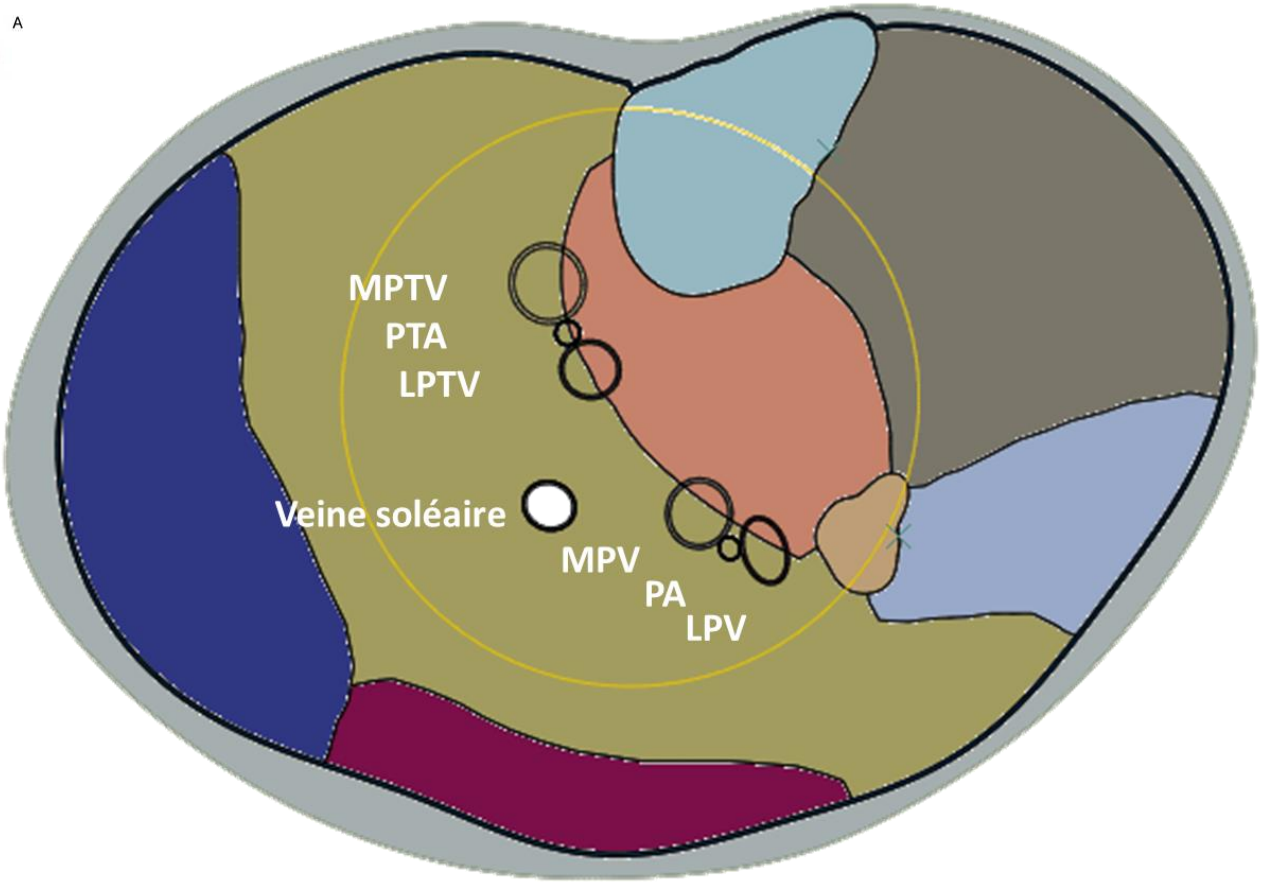




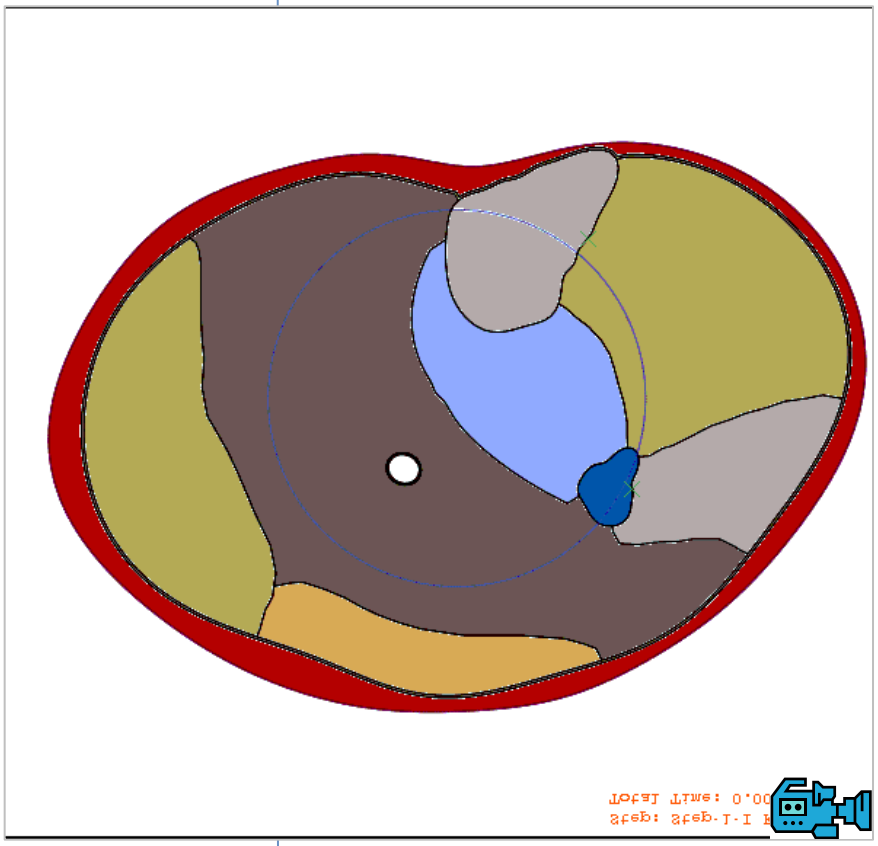
Deep veins

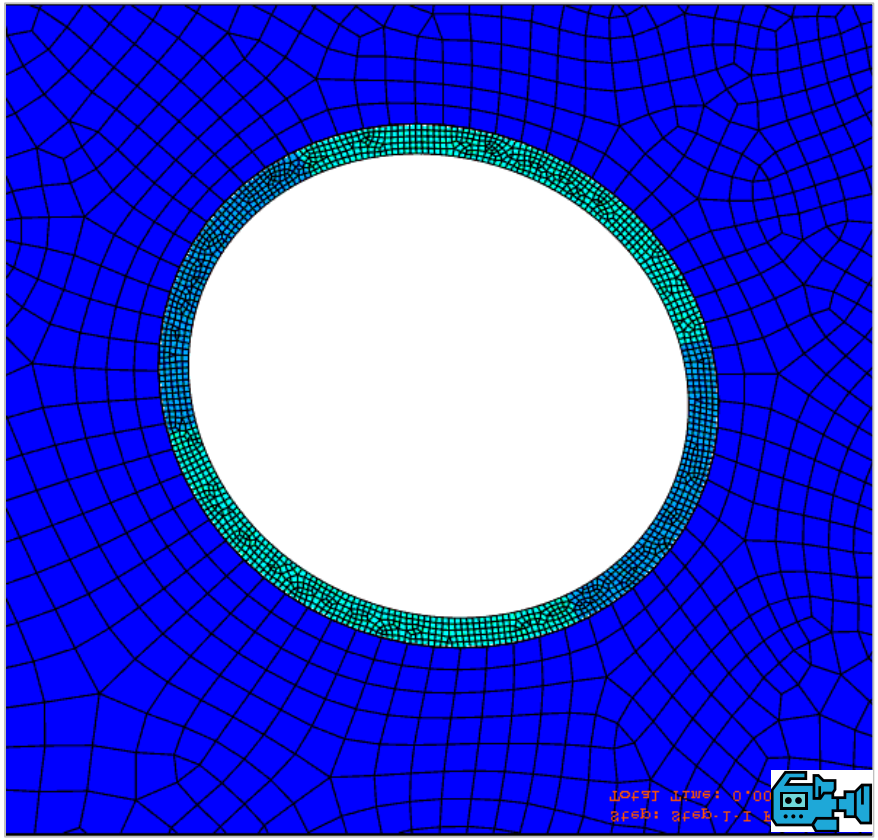




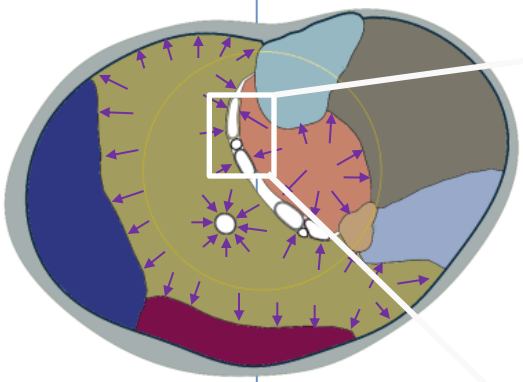


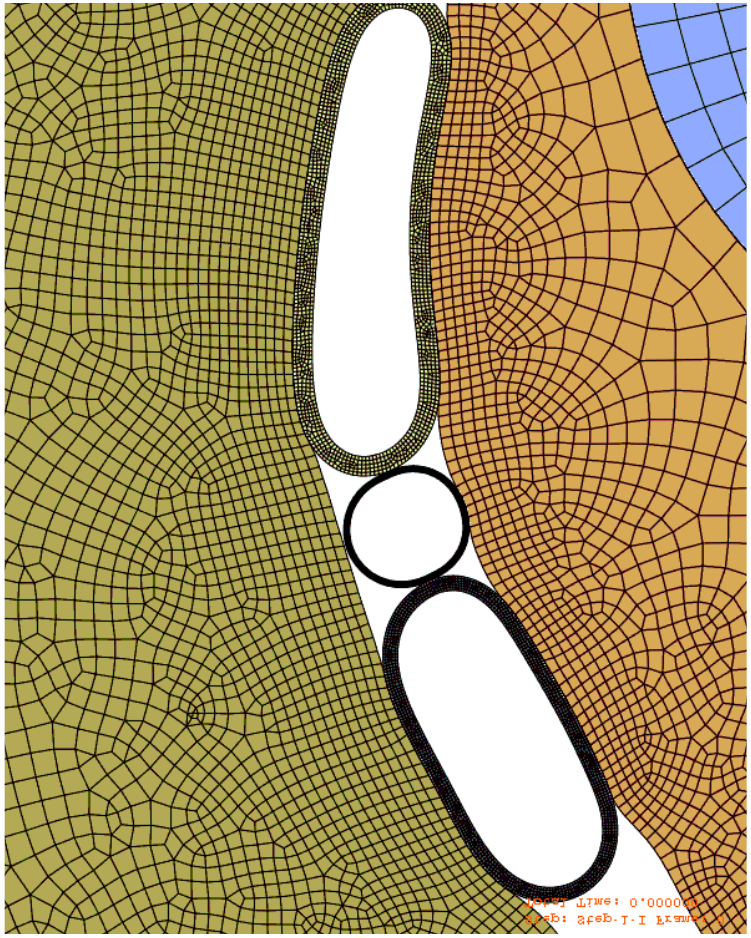
Deep veins -intra



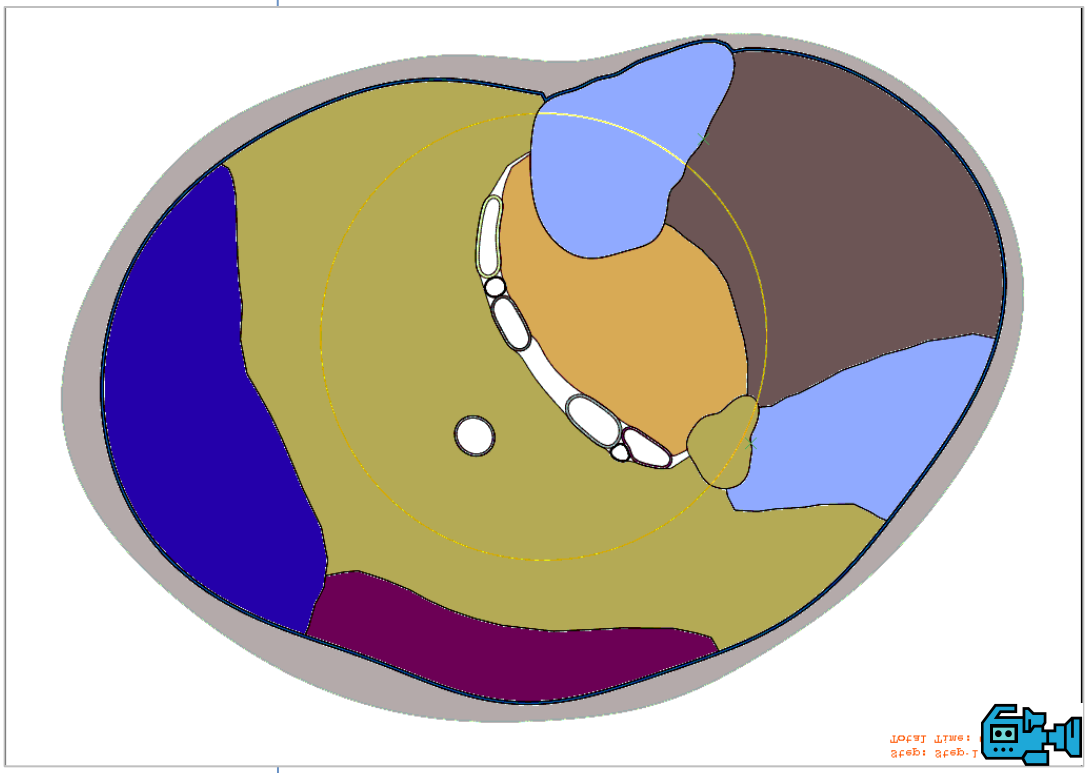


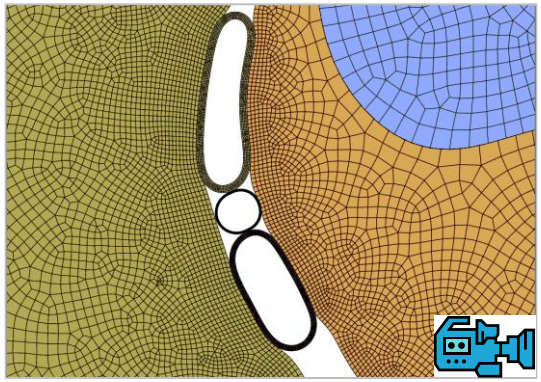
Deep veins – inter

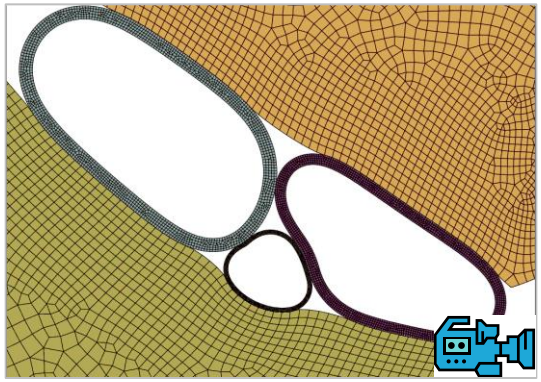




Deep veins – inter



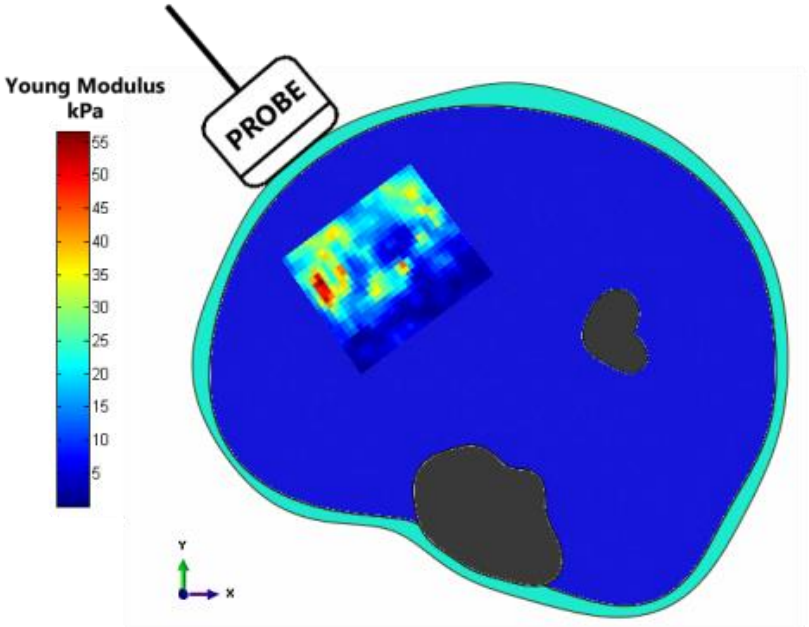




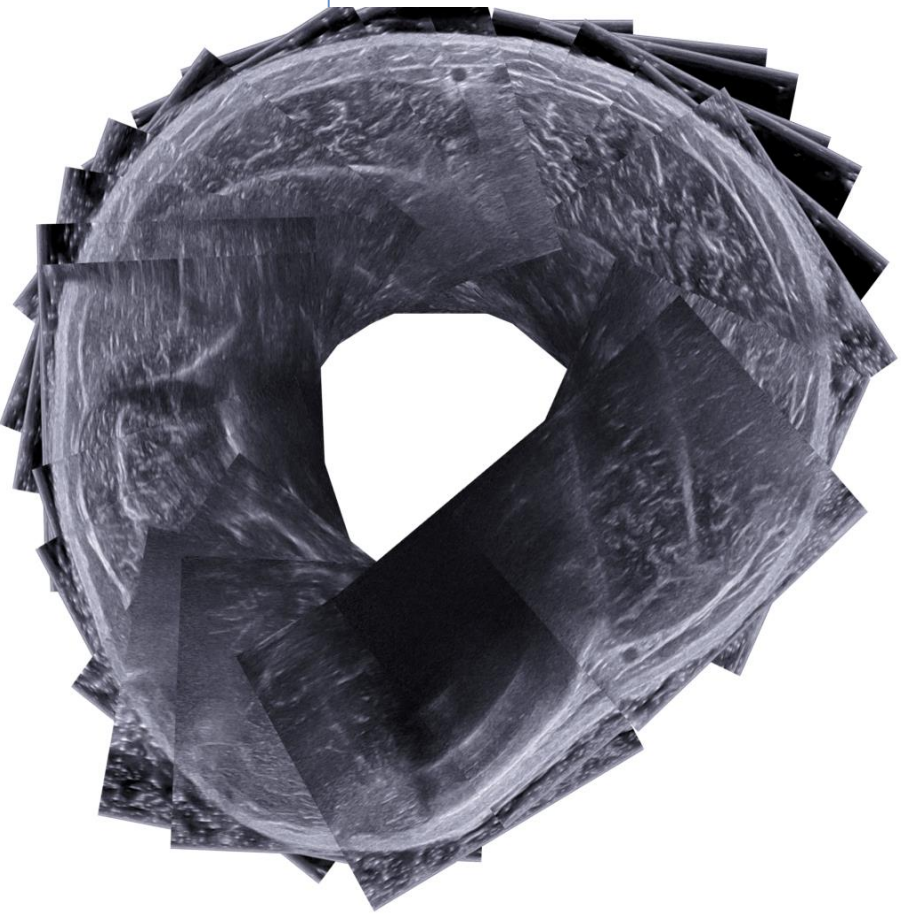
Vein and soft tissues interactions

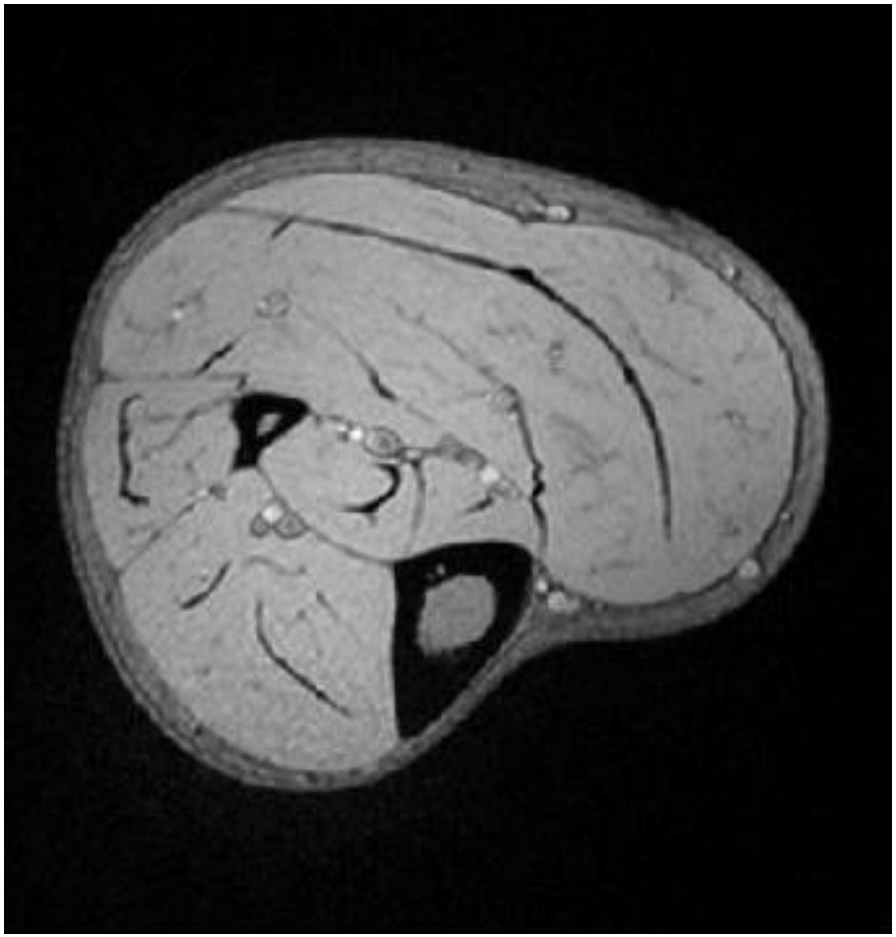
Towards patient-specific modelling

US elastography



Comparison – Manual stitching/MRI





Future work

- Patient-specific modeling
- Dynamic response
- Fluid-structure interactions