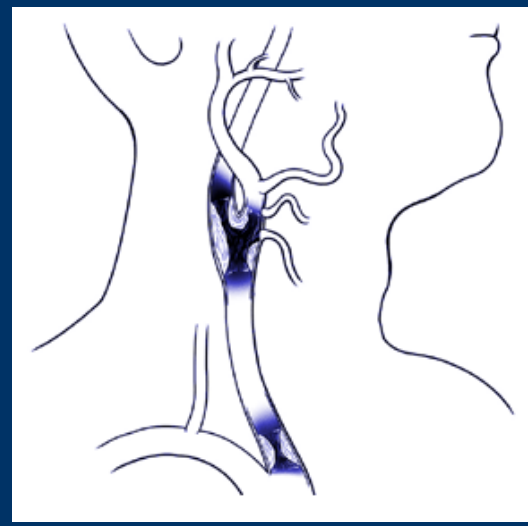

# Whole-body measurements on vascular segments under in-vitro loading

Katia Genovese

# Complex-shaped arteries

2

1



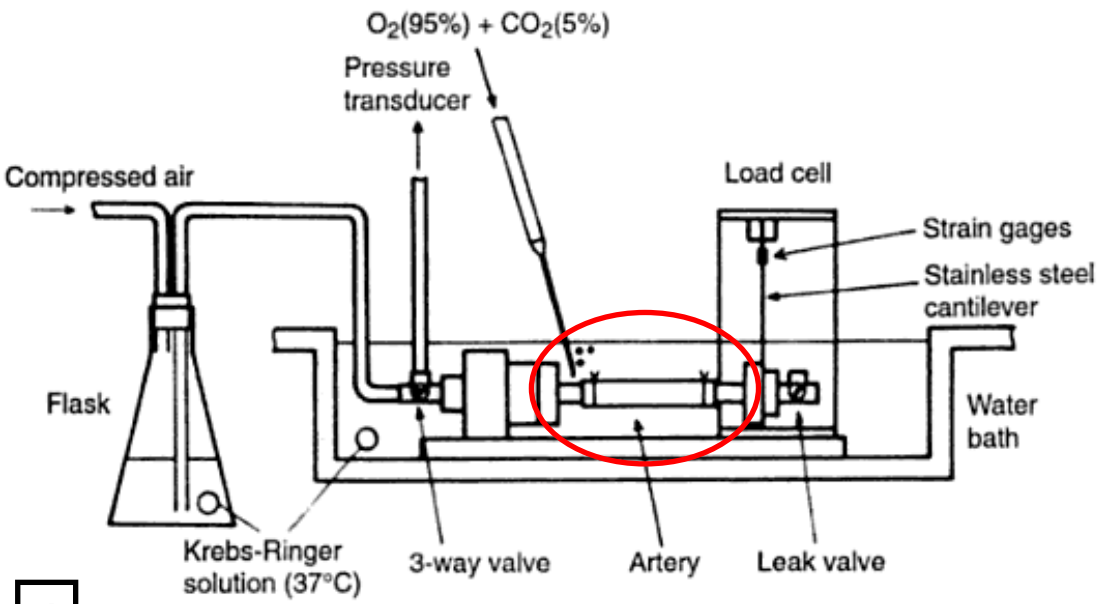
3

**1-** Asakura T, Karino T, *Flow Patterns and Spatial Distribution of Atherosclerotic Lesions in Human Coronary Arteries*, Circulation Research 1990, 66:1045-1066.

**2-** http://www.invasivecardiology.com/

**3-** http://www.azheart.com/

# Pressure/Diameter-Force/Length Tests

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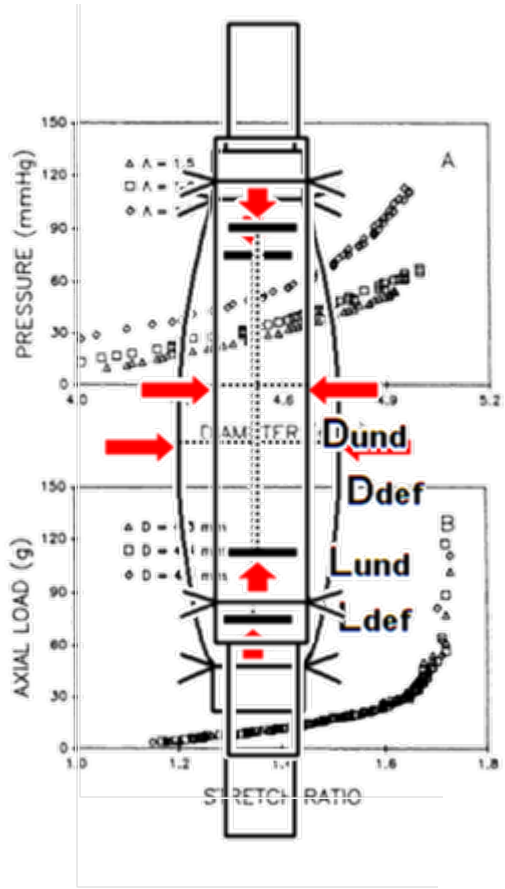



5

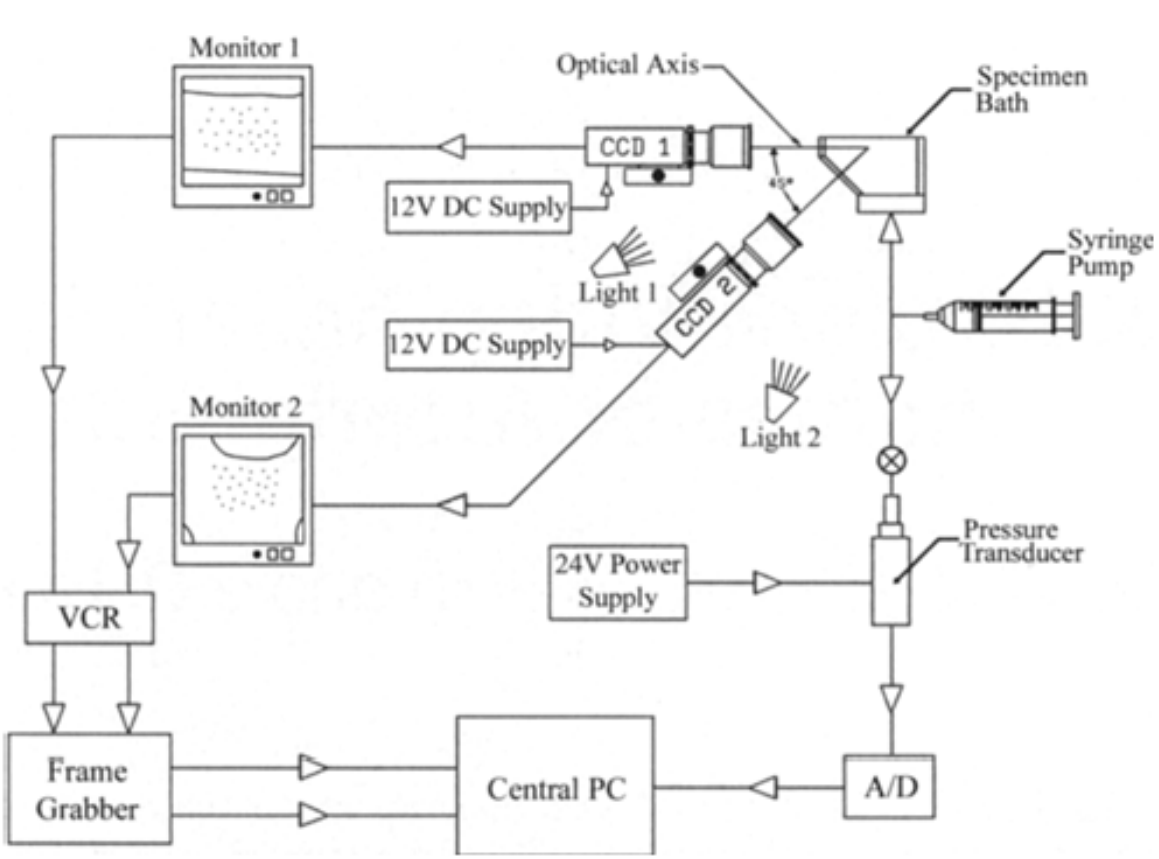
**Hp. of cylindrical shape**

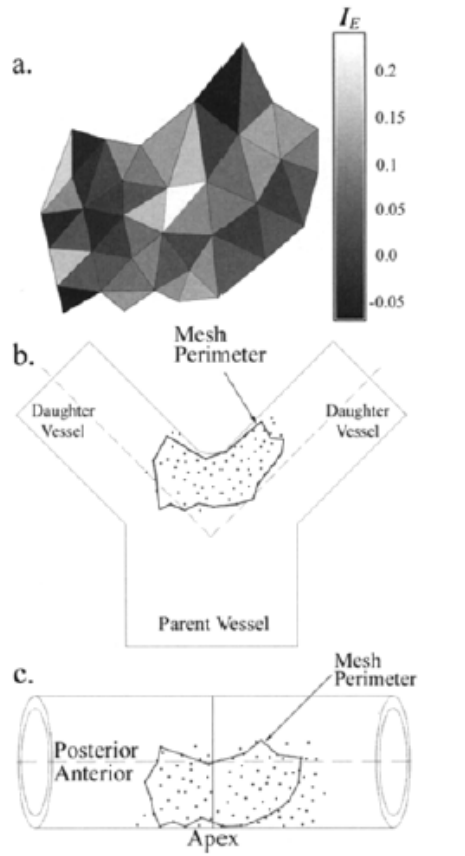
**No account of in-homogeneous deformation**

**4-** Takamizawa K, Hayashi K. *Strain energy density function and uniform strain hypotesis for arterial mechanics*, Journal of Biomechanics 1987, 20:7-17.

**5-** Humphrey JD, Kang T, Sakarda P, Anjanappa M. *Computer-aided vascular experimentation: a new electro-mechanical test system,* Annals of Biomedical Engineering 1993, 21:33-43.

# Complex-shaped arteries

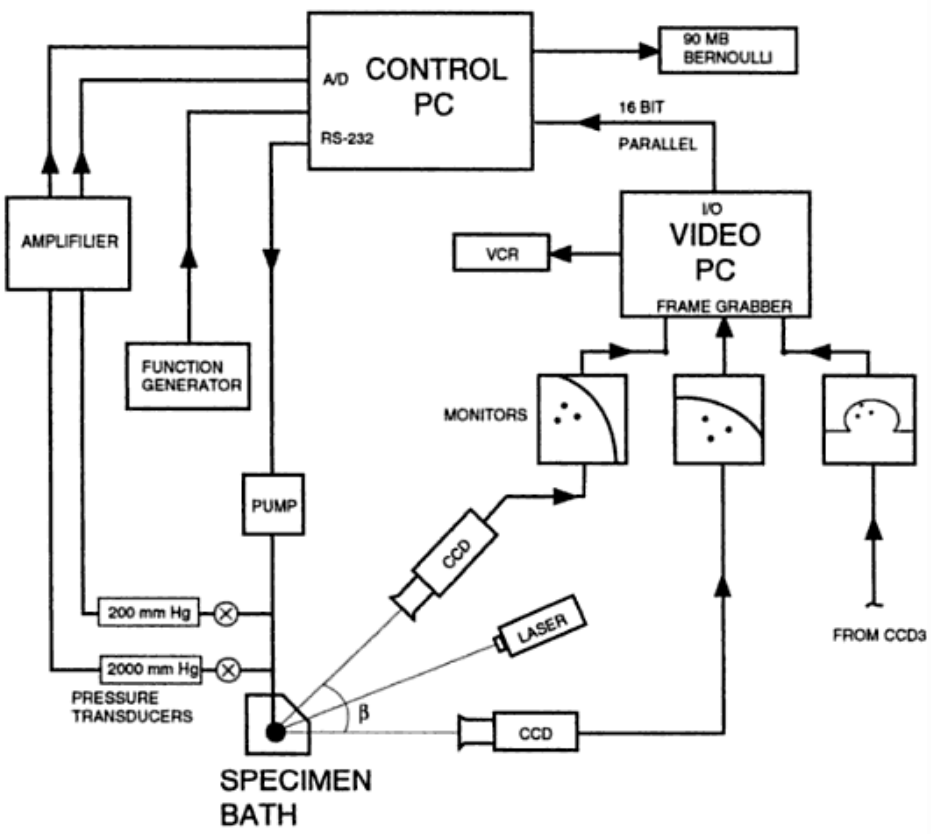


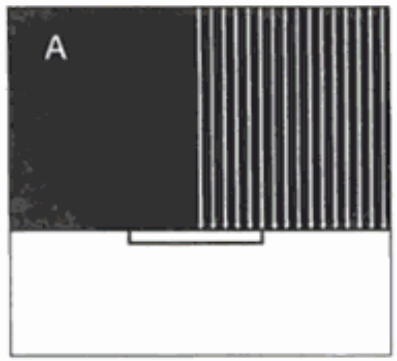



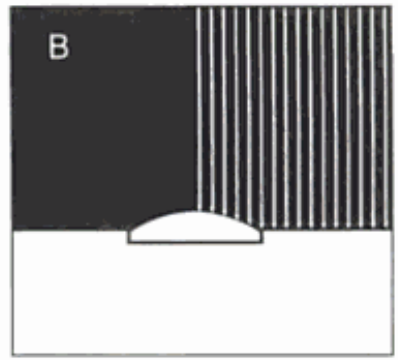

6

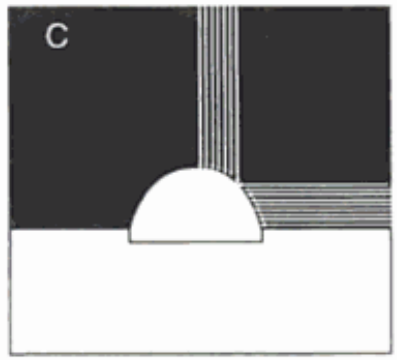
**6-** Everett WN, Shih P, Humphrey JD. *A bi-plane video-based system for studying the mechanics of arterial bifurcations*. Experimental Mechanics 2005;45/4:377–82.

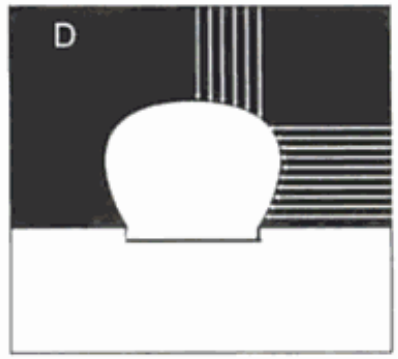
# Complex-shaped arteries






**7-** Hsu FPK, Downs J, Liu AMC, Rigamonti D, Humphrey JD. *A tri-plane video-based experimental system for studying axisymmetrically inflated biomembranes*. IEEE Transactin of Biomedical Engineering 1992;114:462-466.

# Problem statement

***Measuring the 3D whole deformation of vascular segments during in-vitro test***

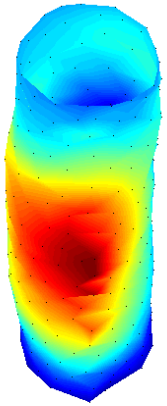
# HYBRID TECHNIQUES

EXPERIMENT

FEM

ERROR

$$ERROR = f\left(\bar{u}_{exp} - \bar{u}_{num}\right)$$



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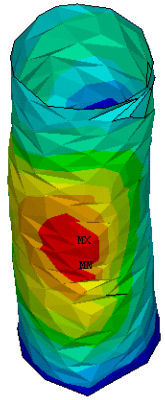
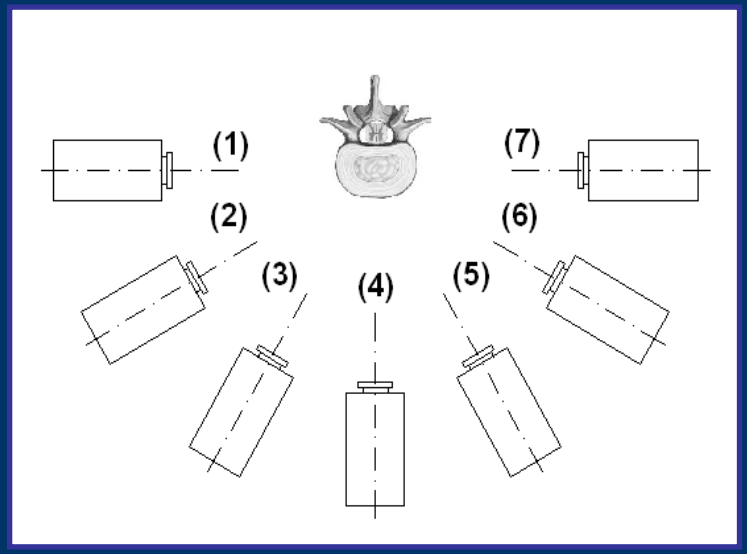
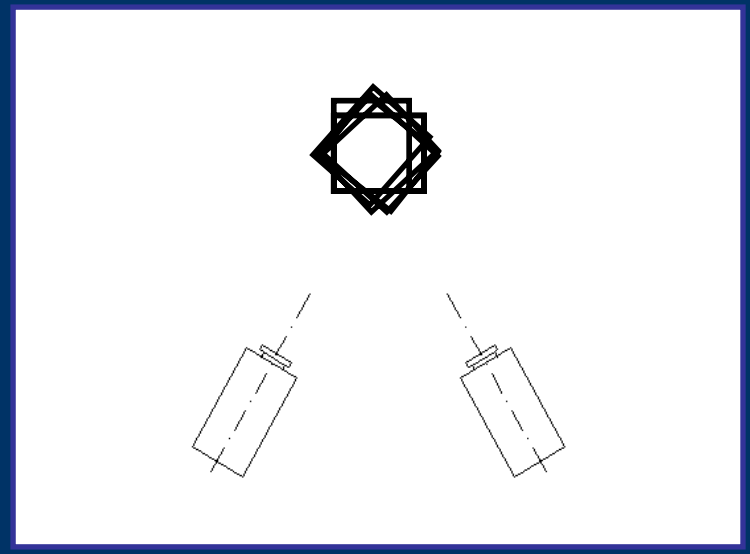


=0

Update
aterial parameters

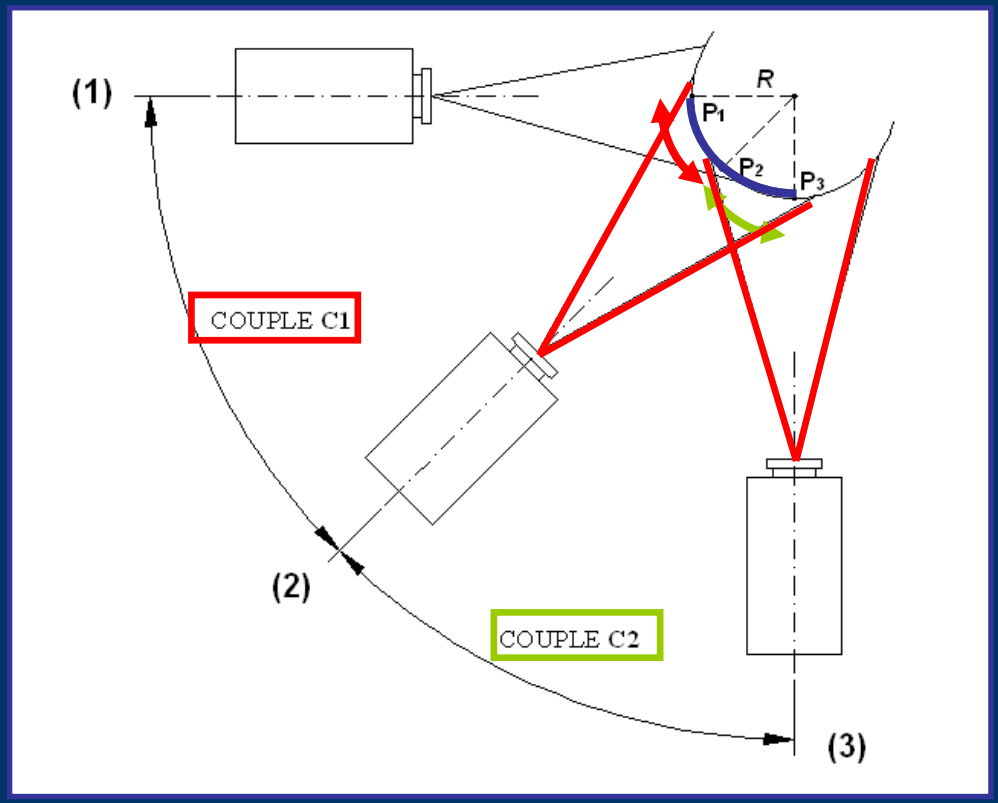
# WHOLE-BODY 3-D MEASUREMENTS

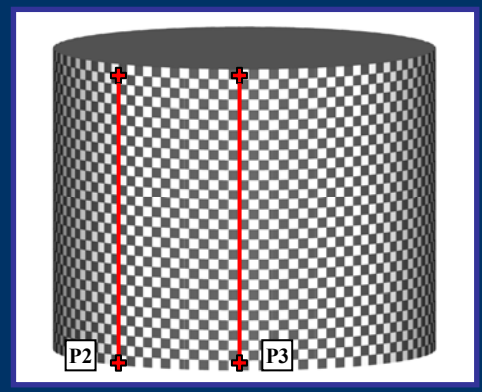


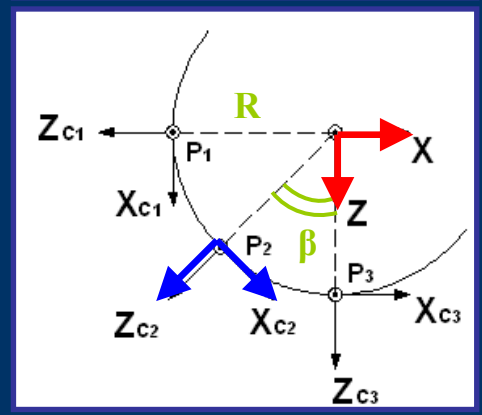



*Camera-turntable arrangement*

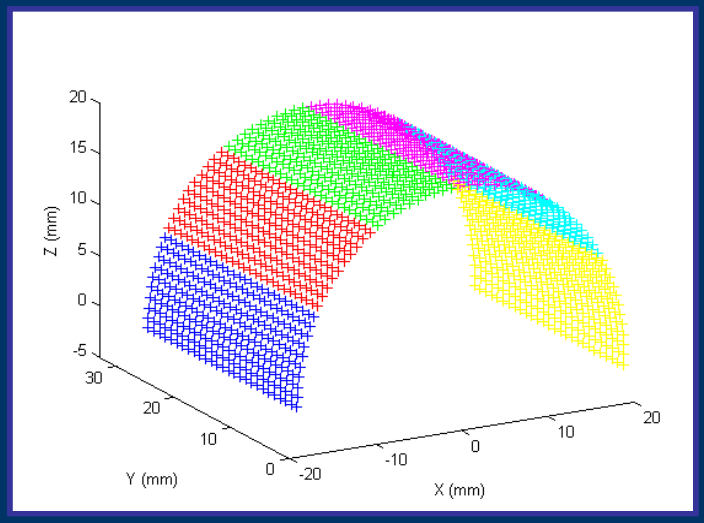
# MULTI-CAMERA SYSTEM CALIBRATION

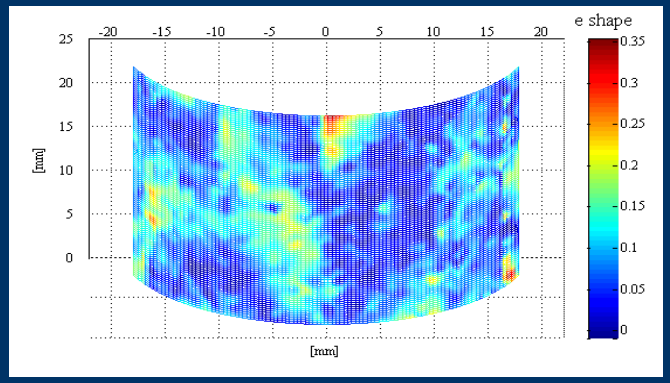


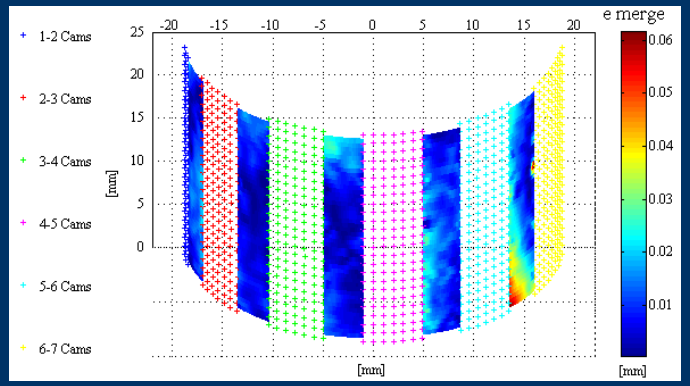



# Stereo-DIC multi-camera system errors




Error in shape reconstruction

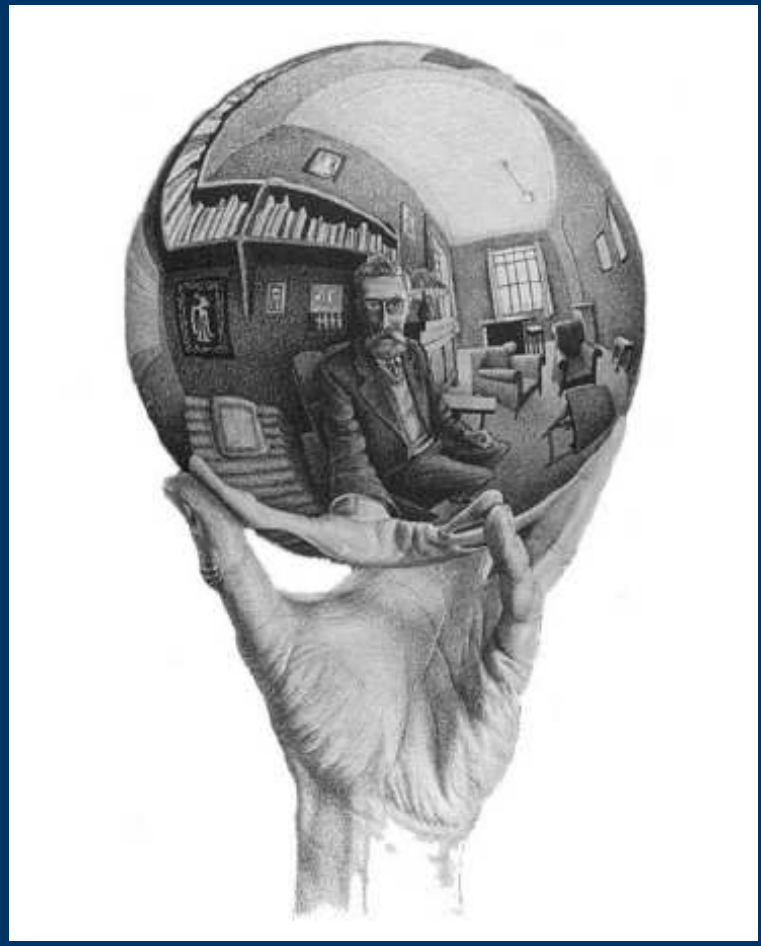



Error in the merging process

Limitation: Not time-resolved measurements

Limitation: Only 360° can be covered

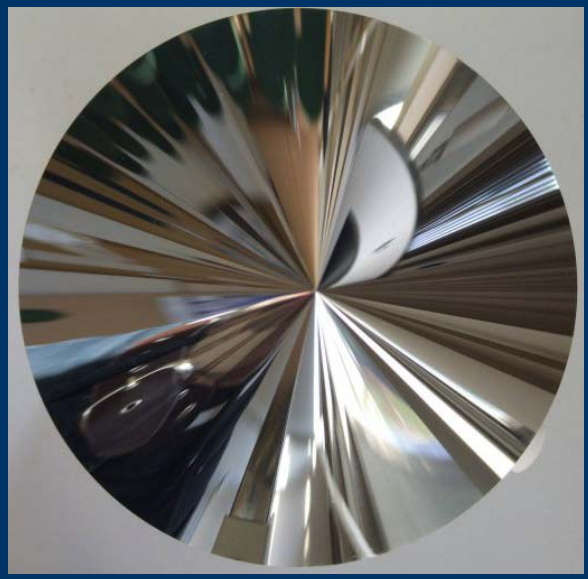
# PANORAMIC SYSTEMS



8

**8-** *Hand with a sphere.* Drawing by M.C. Escher (1898-1972).

# PANORAMIC SYSTEMS



Conical mirror

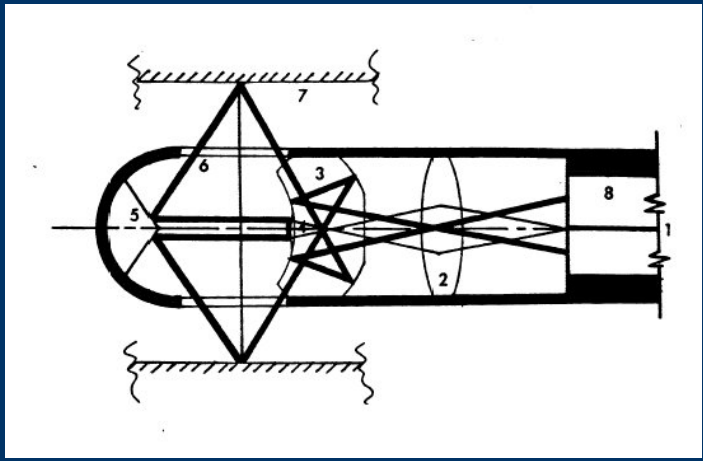
Panoramic view

Unwarped view



**9-** http://cswww.essex.ac.uk/mv/

# Panoramic Systems for measurements in Engineering



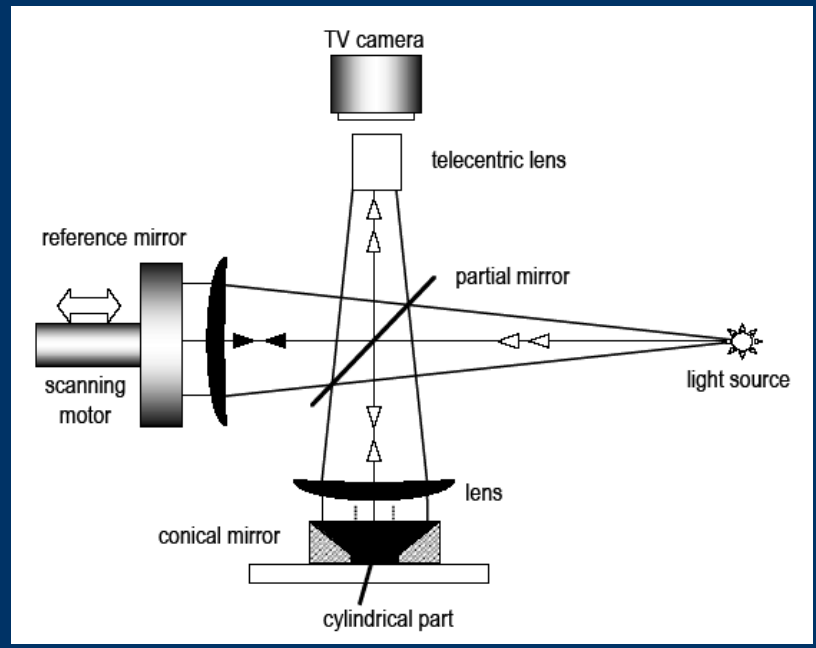

## Endoscopic probes using panoramic lenses

**10-** Matthys DR, Gilbert JA, Greguss P. *Endoscopic measurement using radial metrology with digital correlation*. Opt Eng 1991;30(19): 1400–55.

10

## Radial interferometry

**11-** Albertazzi GA, Melao I, Devece E. *Measurement of thermal deformation of an engine piston using a conical mirror and ESPI*. In: Pryputniewicz RJ, Brown GM, Jueptner WP, editors. Proceedings of the 1998 SPIE, laser interferometry IX: applications, vol. 3479, 1998. p. 274–83.

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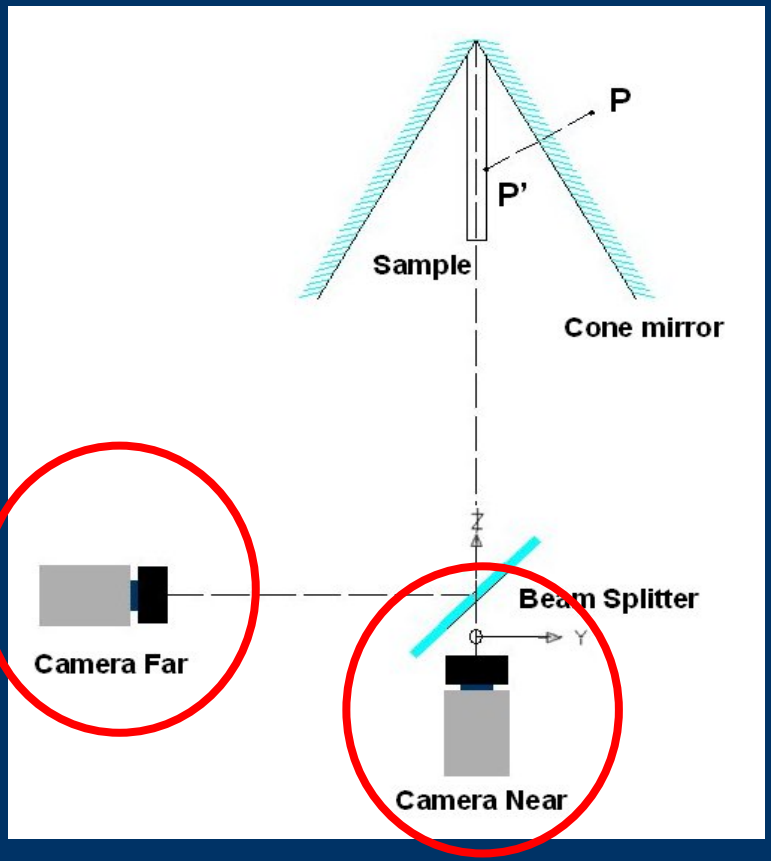
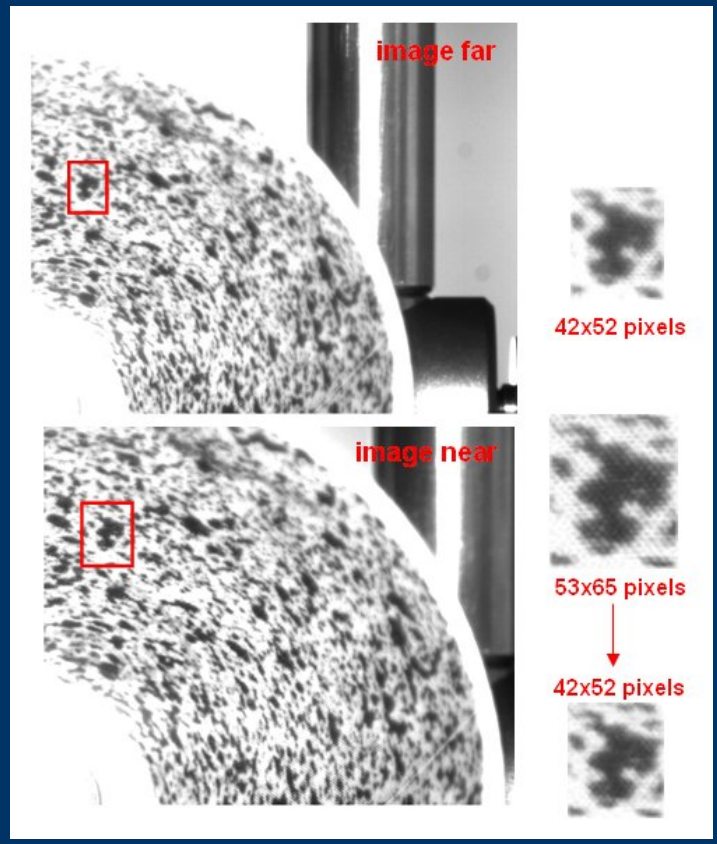
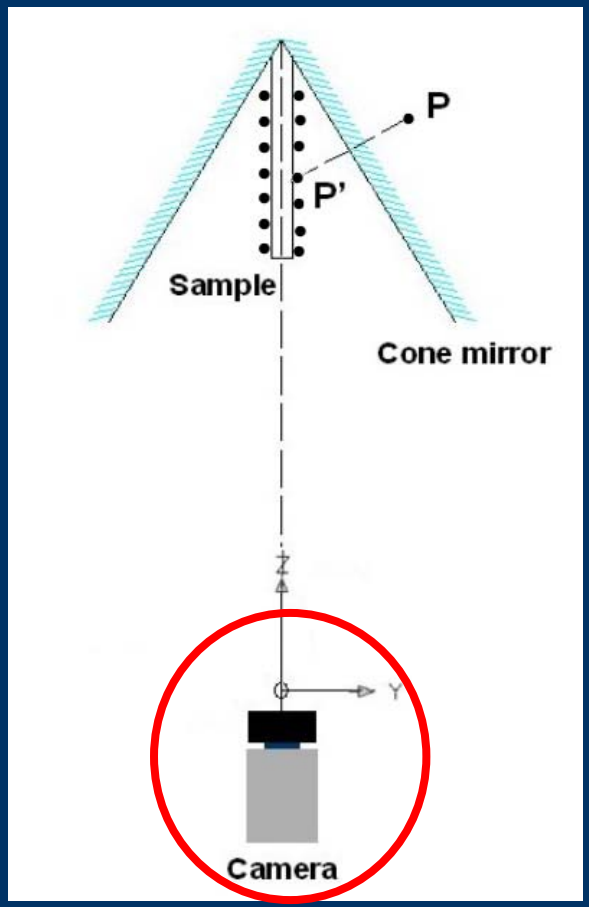
# Stereo-DIC/360° measurement

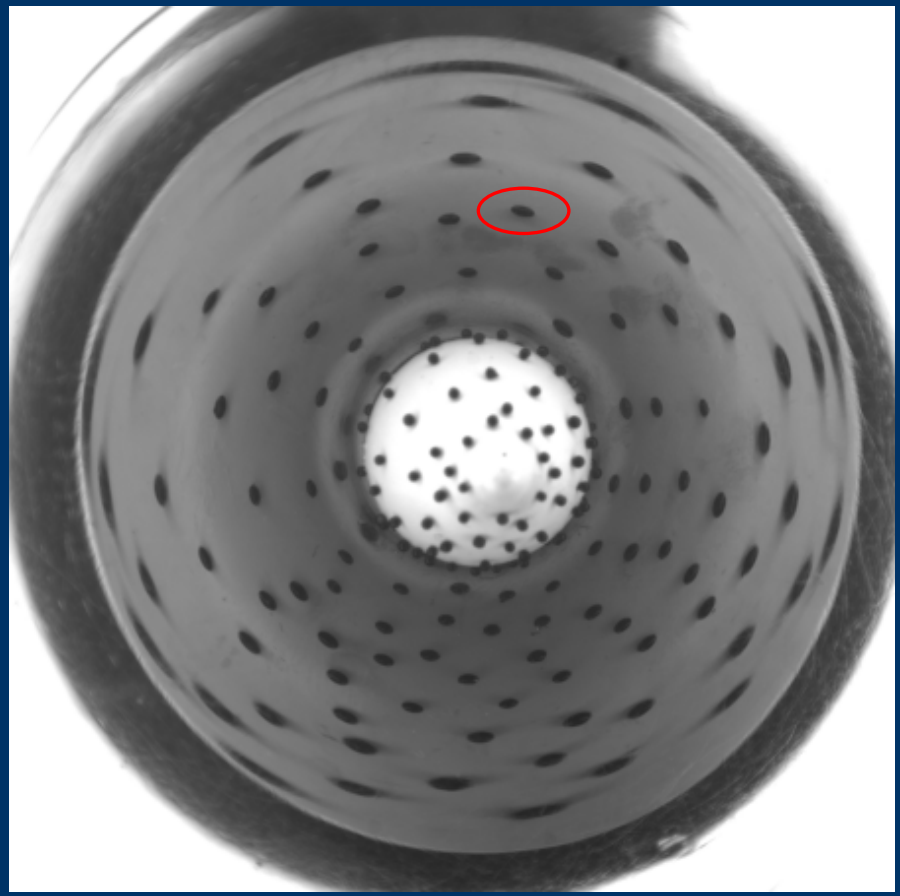



Genovese K, Pappalettere C., *Axial Stereo-Photogrammetry for 360-deg measurement on tubular samples*, Optics and Laser in Engineering, 45/5, 637-650, 2007.

# Single camera/360° measurement

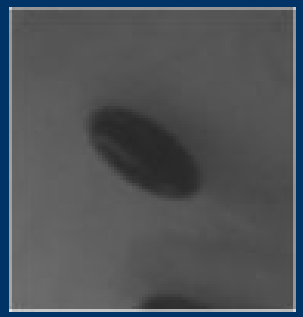


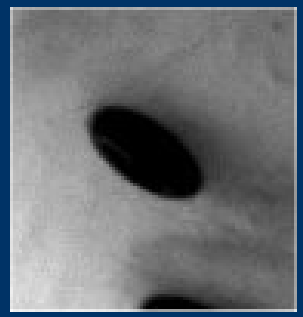
(x,y) centroid coordinates
S major axis
s minor axis

→ $P=(r,\theta,z)$

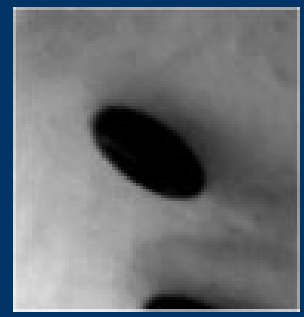
# Digital image processing



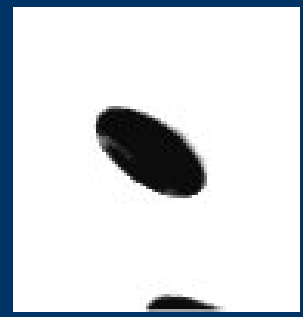
Original



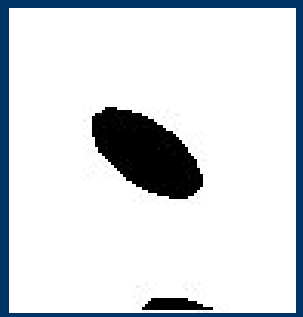
Histogram adjustment



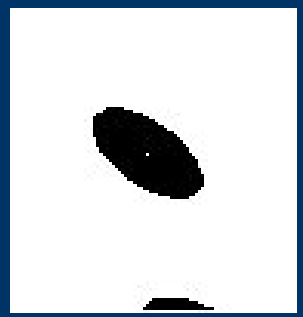
Median filter



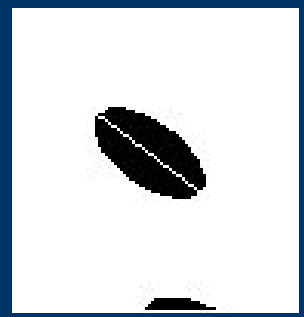
Contrast enhancement



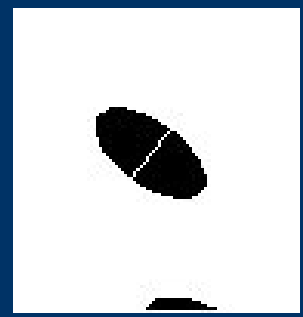
Binarization



Centroid (x,y)



Arc length S



Radial dimension s

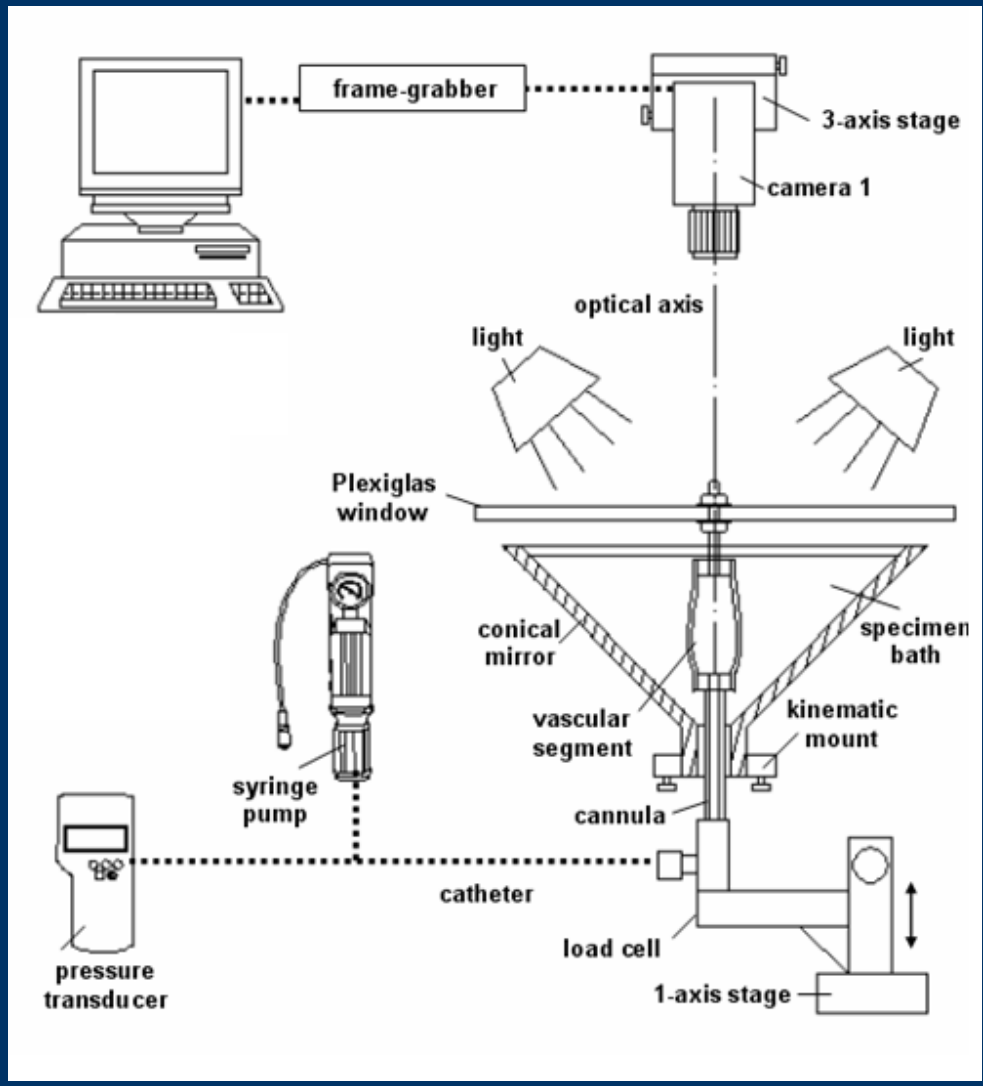
$\lambda = \sqrt{x^2+y^2} = z/MF$

$\theta = \arctan(y/x)$

$r = \lambda\, s\, MF/S$

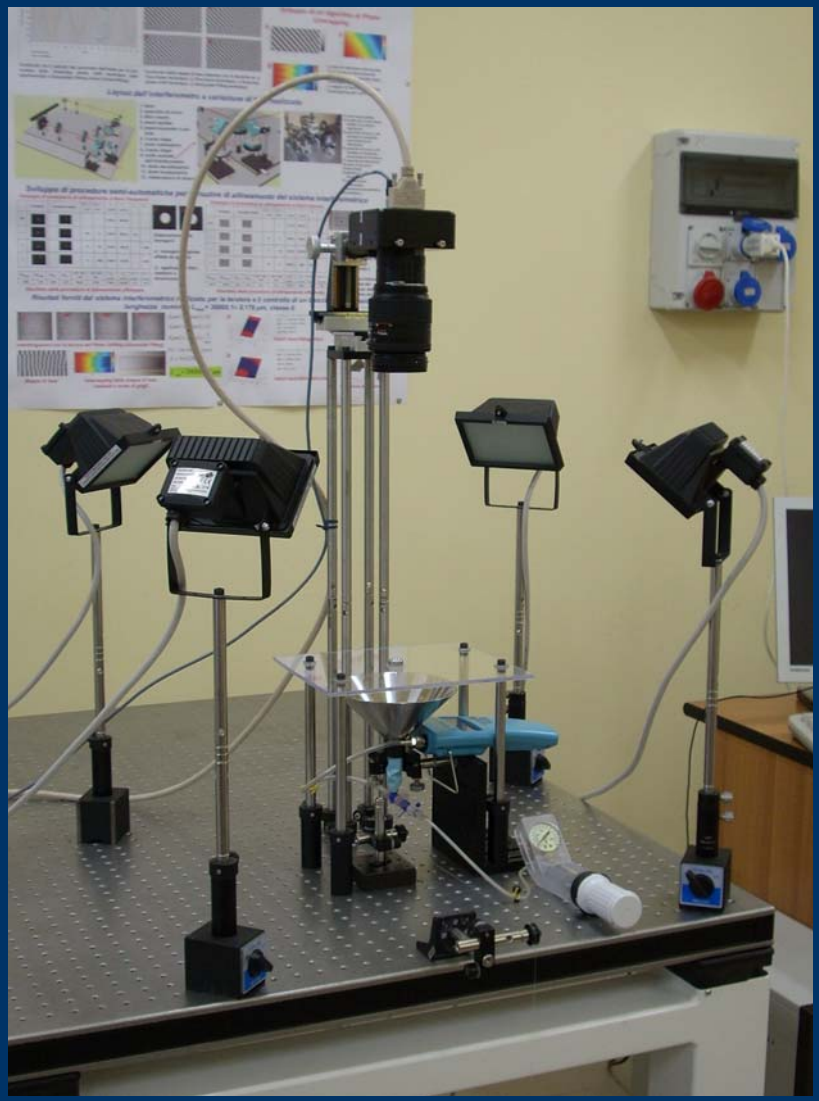
$\longrightarrow$ $P=(r,\theta,z)$

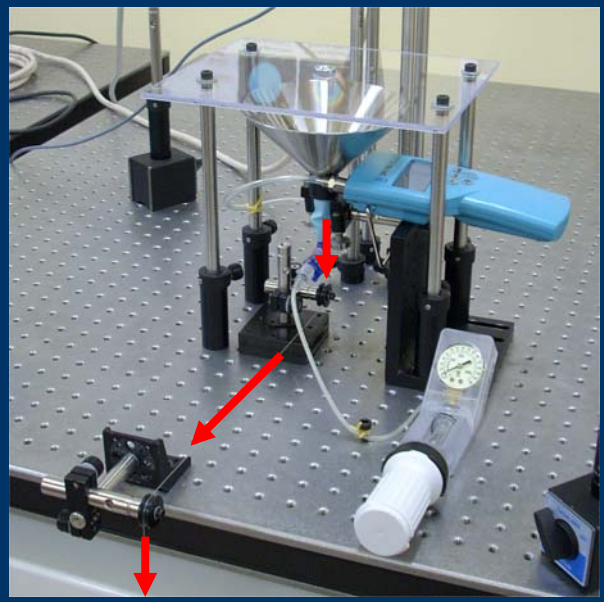
# CM set-up for in-vitro experimentation

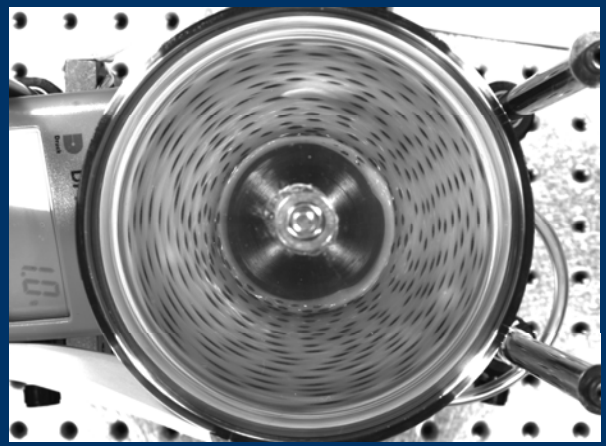



Genovese K. *A video-optical system for time-resolved whole-body measurement on vascular segments*, Optics and Laser in Engineering, in press.

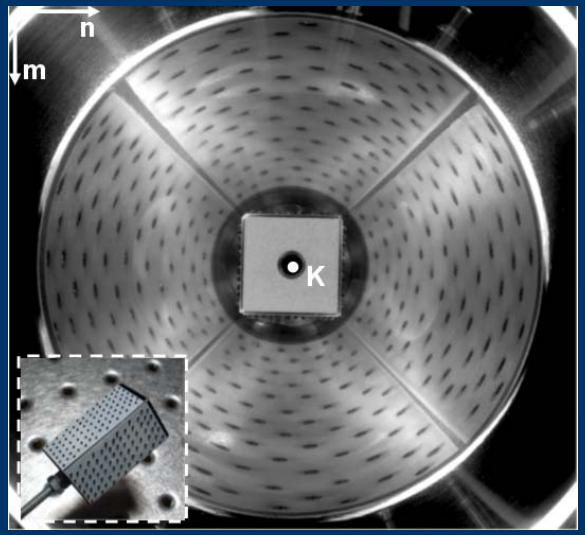
# CM set-up for in-vitro experimentation

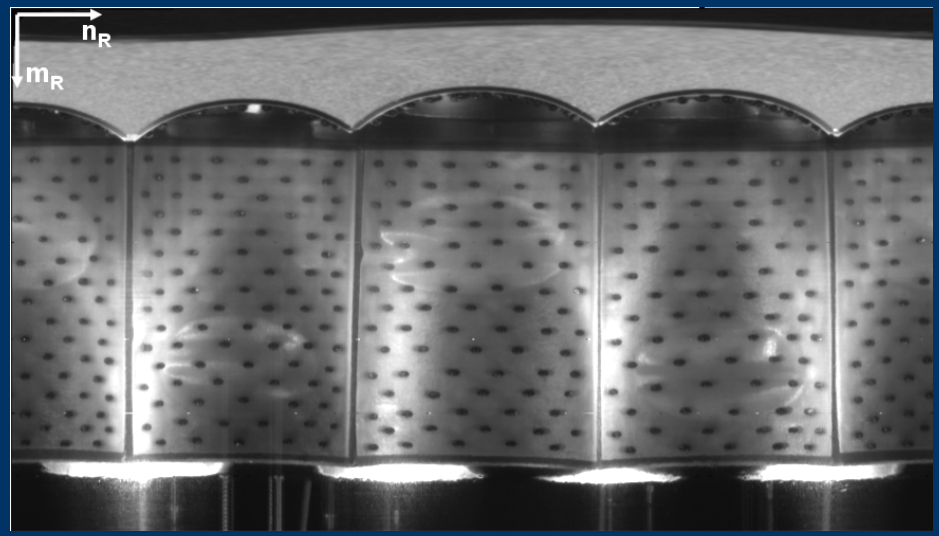


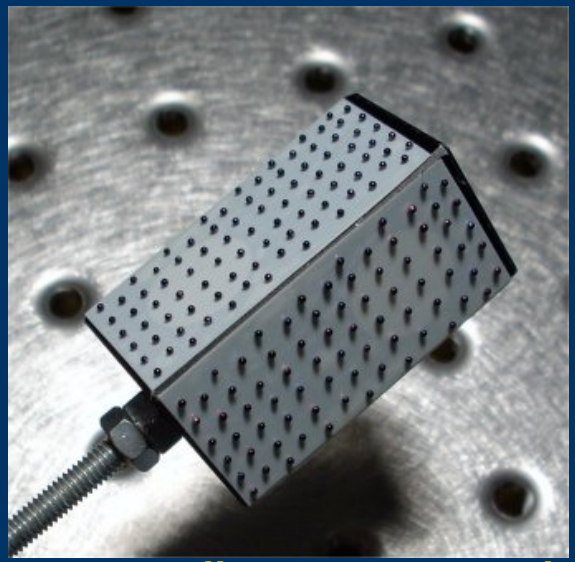


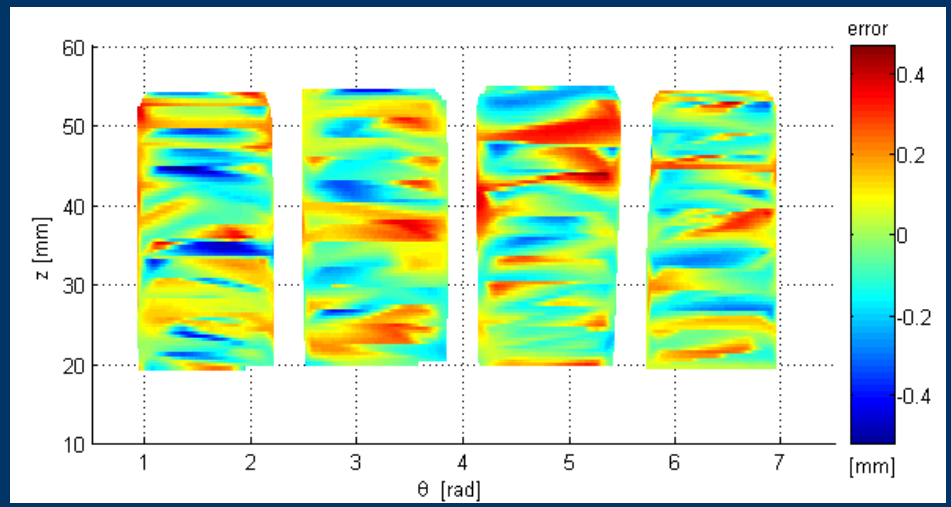


# Calibration



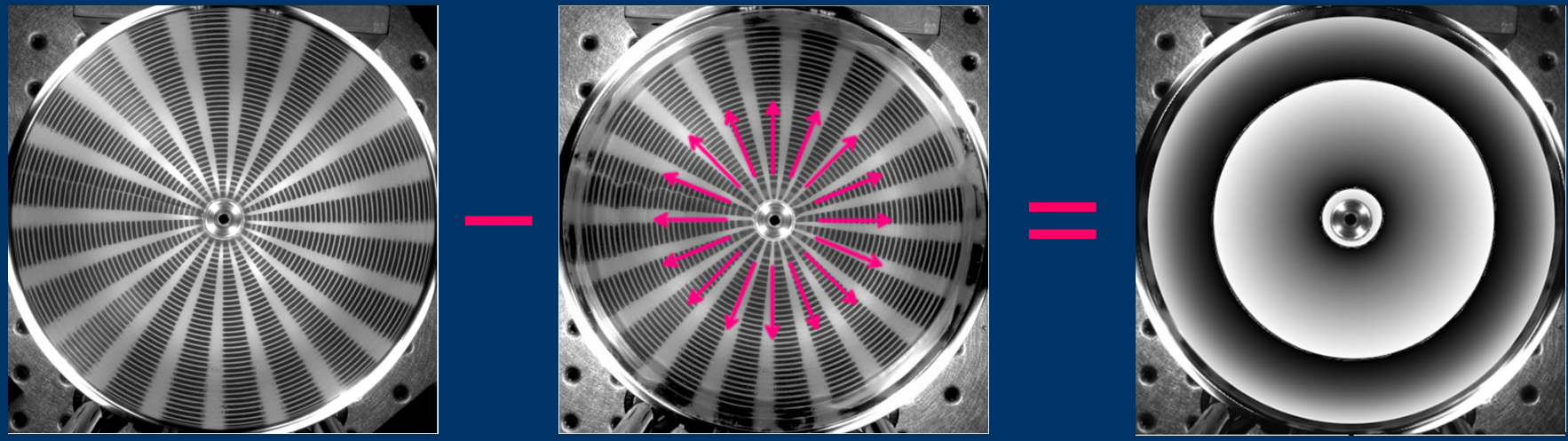



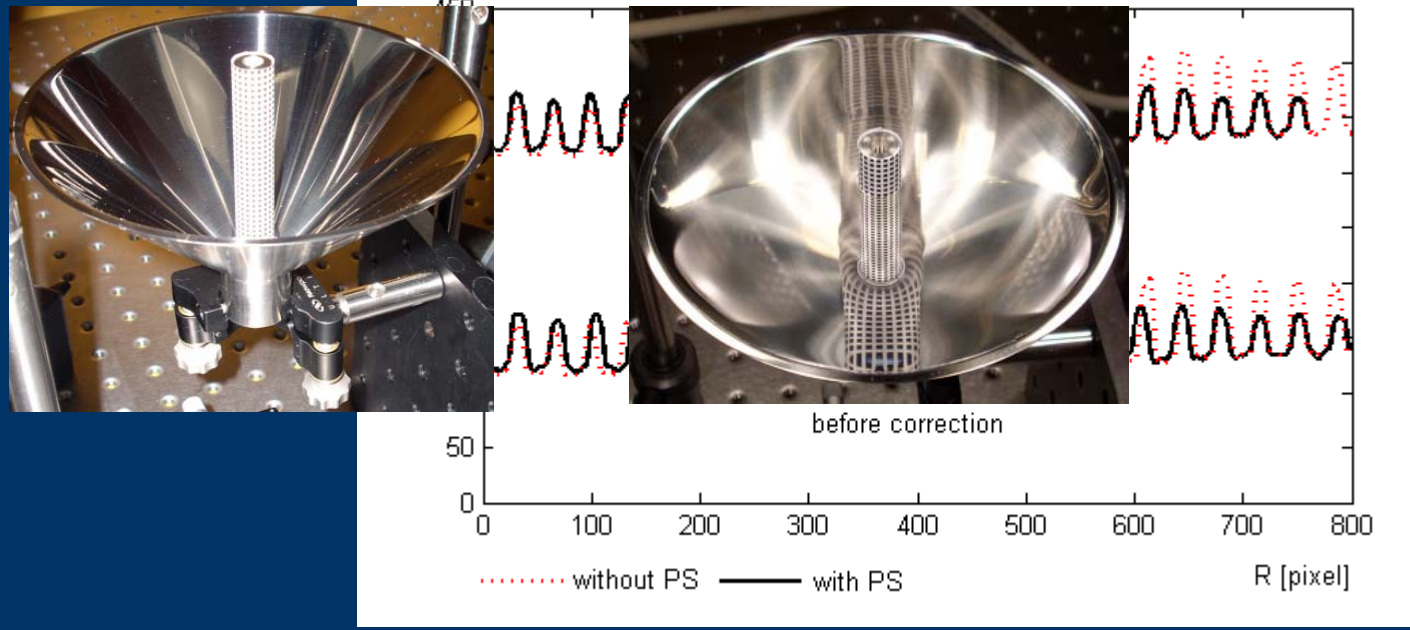






**Error on radius SD 0.17mm, largest 0.55 mm (5% of the sample mean radius)**

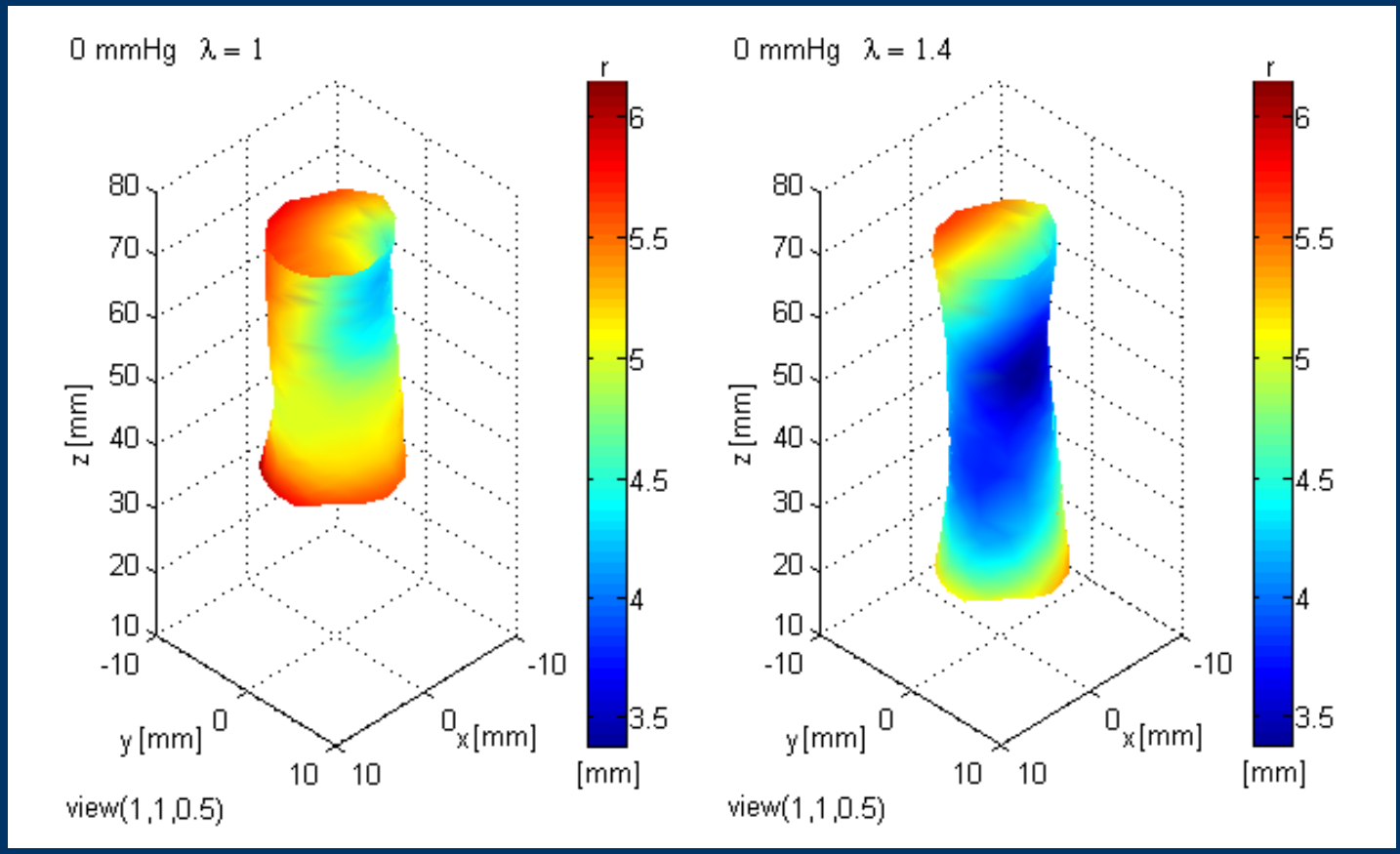
# Calibration with physiological solution





# Shape: examples

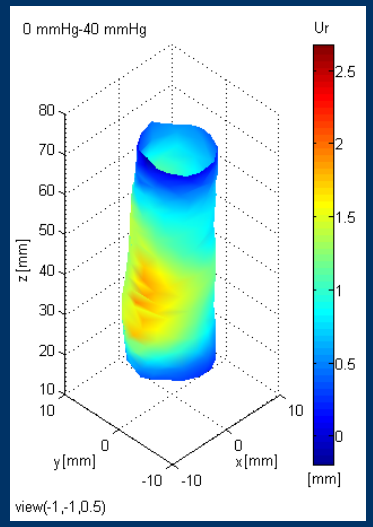
**Sample: porcine vascular segment**

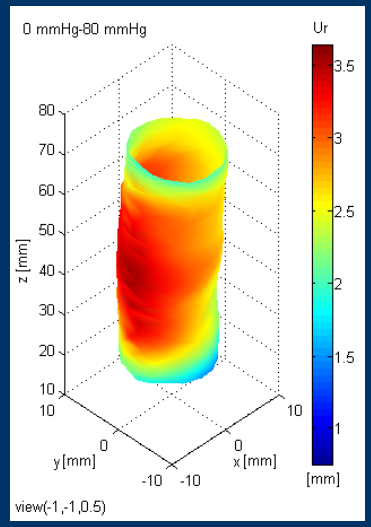


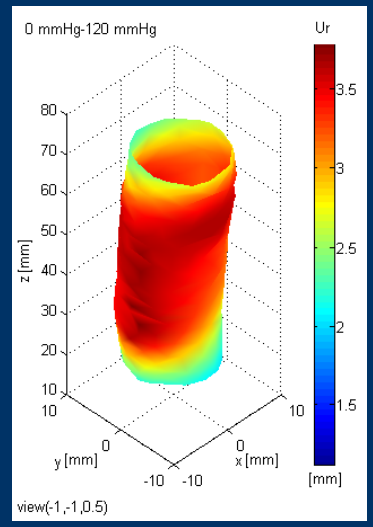

**Strength point: *3D whole-body data for each frame of the load sequence***

# Deformation maps: examples

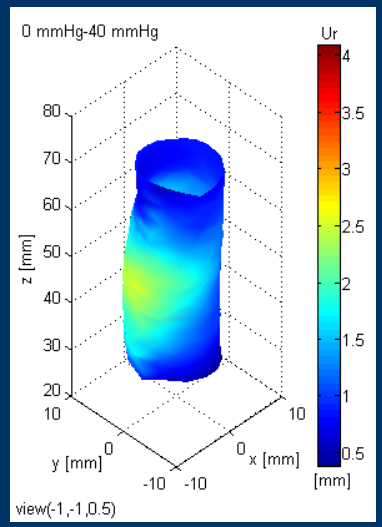
$\lambda_z = 1.4$

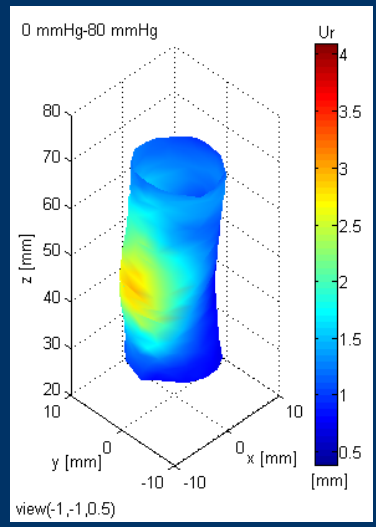


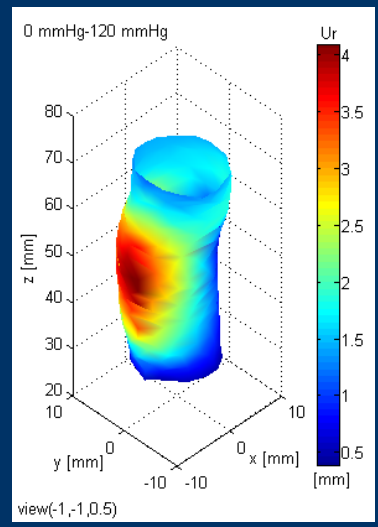




$\lambda_z = 1.1$

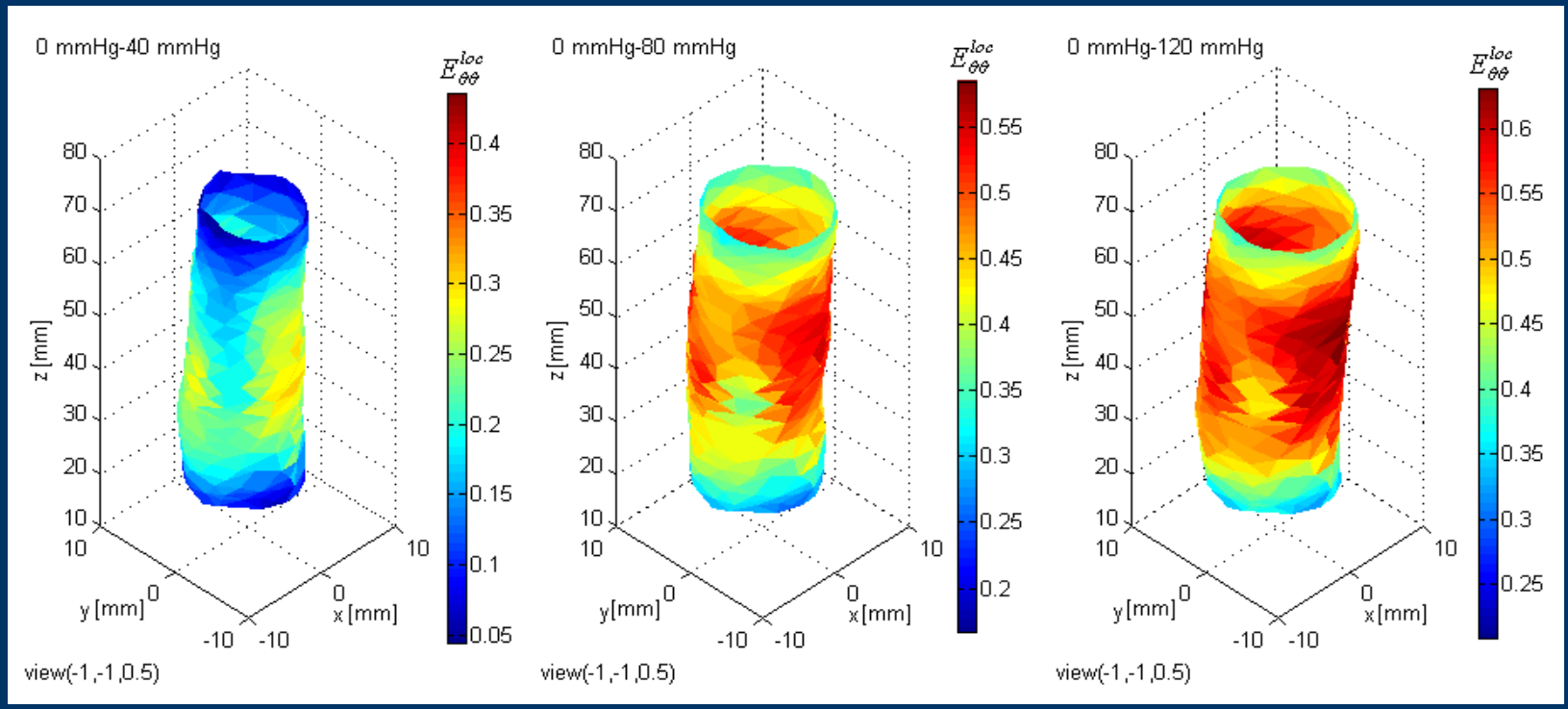



**Strength point: *High capability to capture in-homogeneity of deformation***

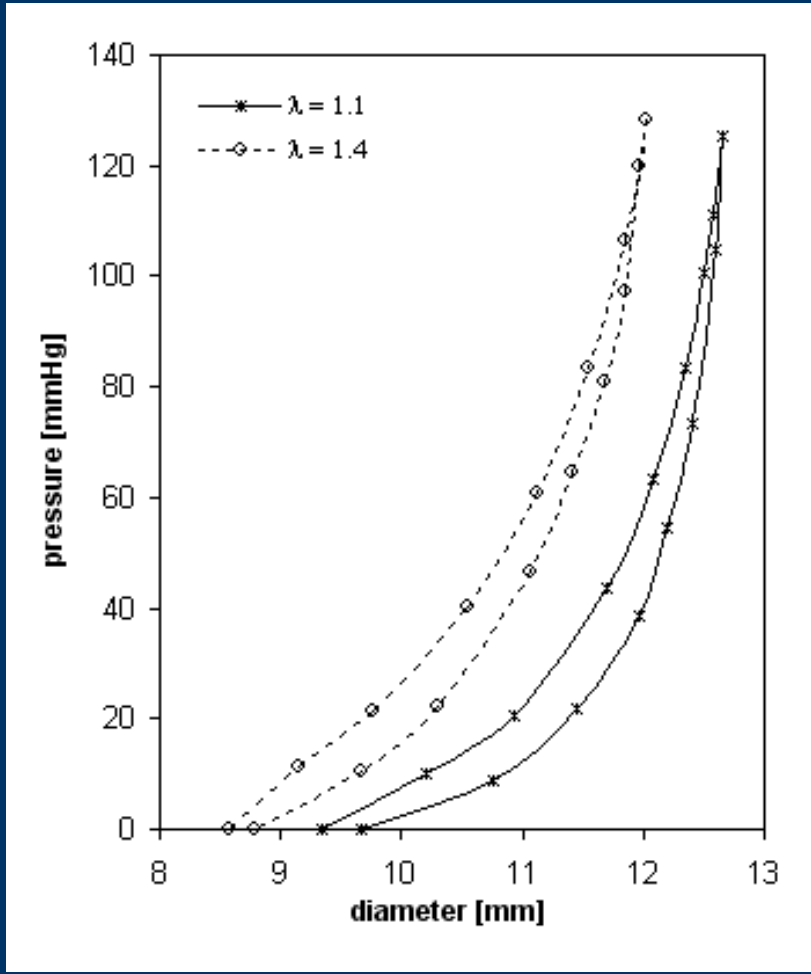
# Strain maps: examples

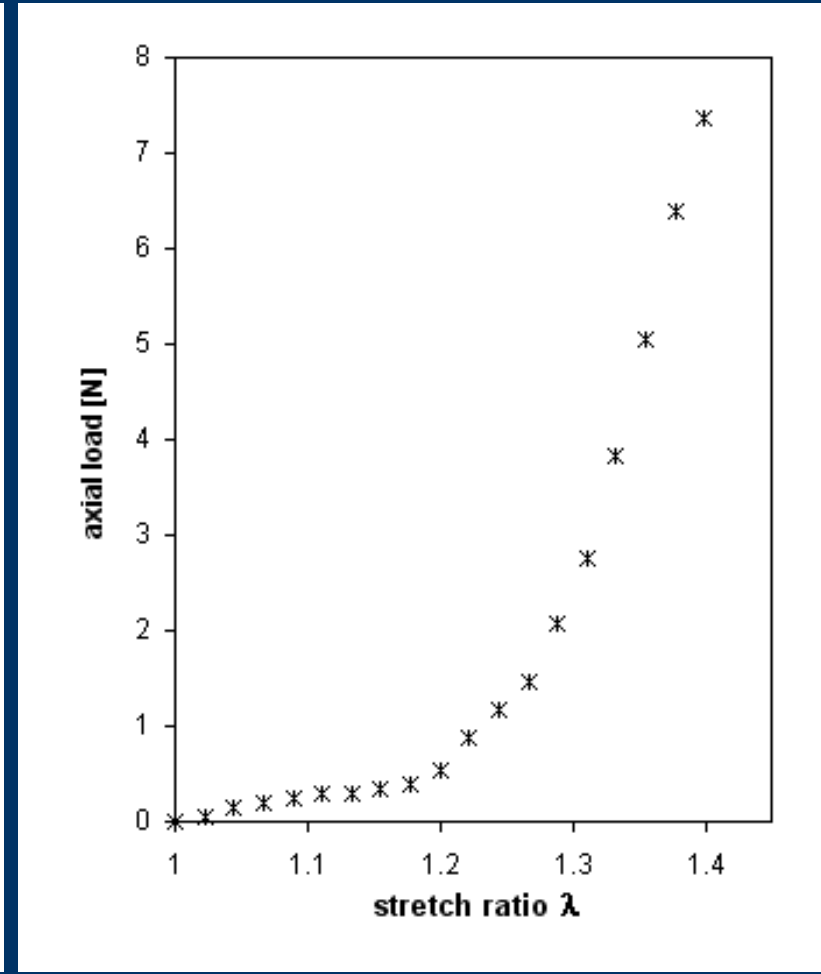



$\lambda_z = 1.4$

**Strength point:** ***easy coupling with FEM analyses***

# Pressure-diameter/Force-length curves



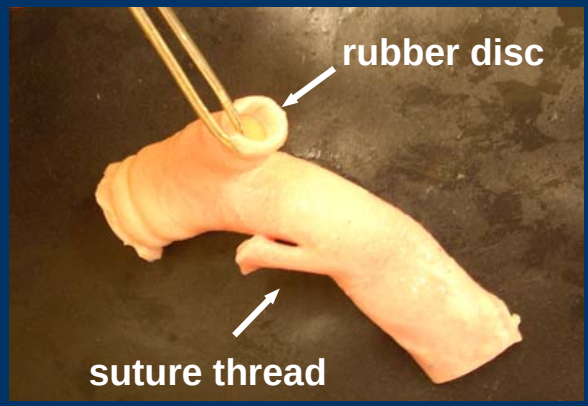




## Limitation: *No feed-back control*

**12-** Humphrey JD, Kang T, Sakarda P, Anjanappa M, *Computer-aided vascular experimentation: a new electro-mechanical test system*. Annals of Biomedical Engineering 1993; 21:33-43.

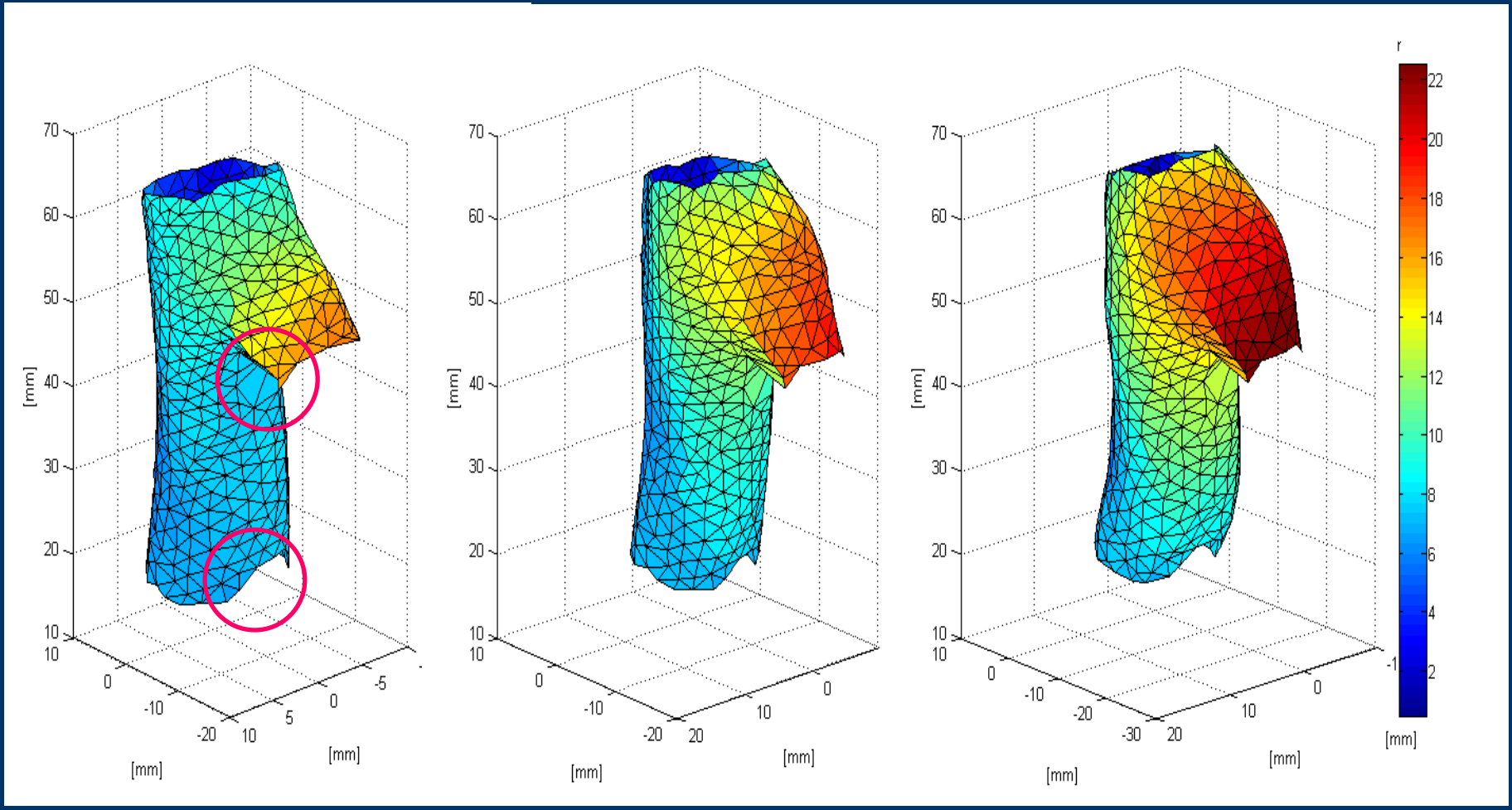
# Complex shaped vascular segments

Sample: lamb ascending aorta





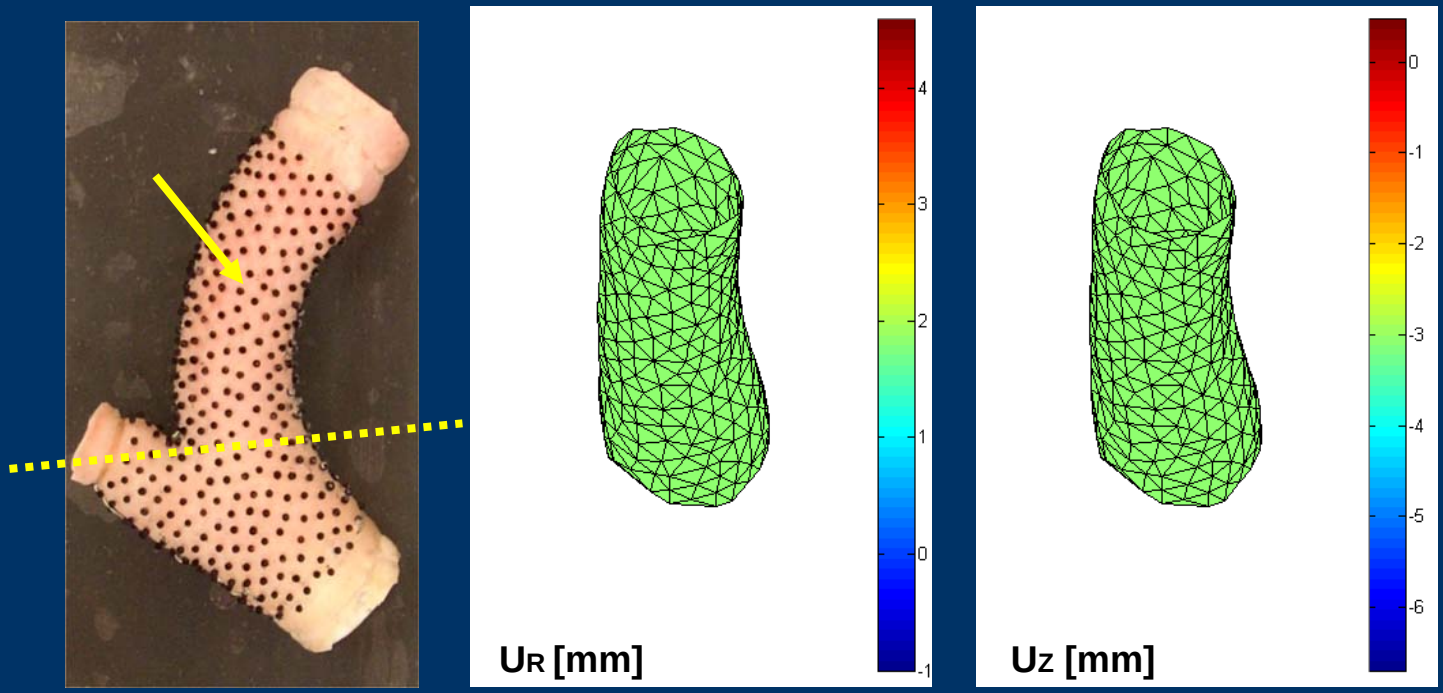
# Complex shaped vascular segments




**0 mmHg – λ =1.1** **27.8 mmHg – λ =1.1** **50.8 mmHg – λ =1.1**

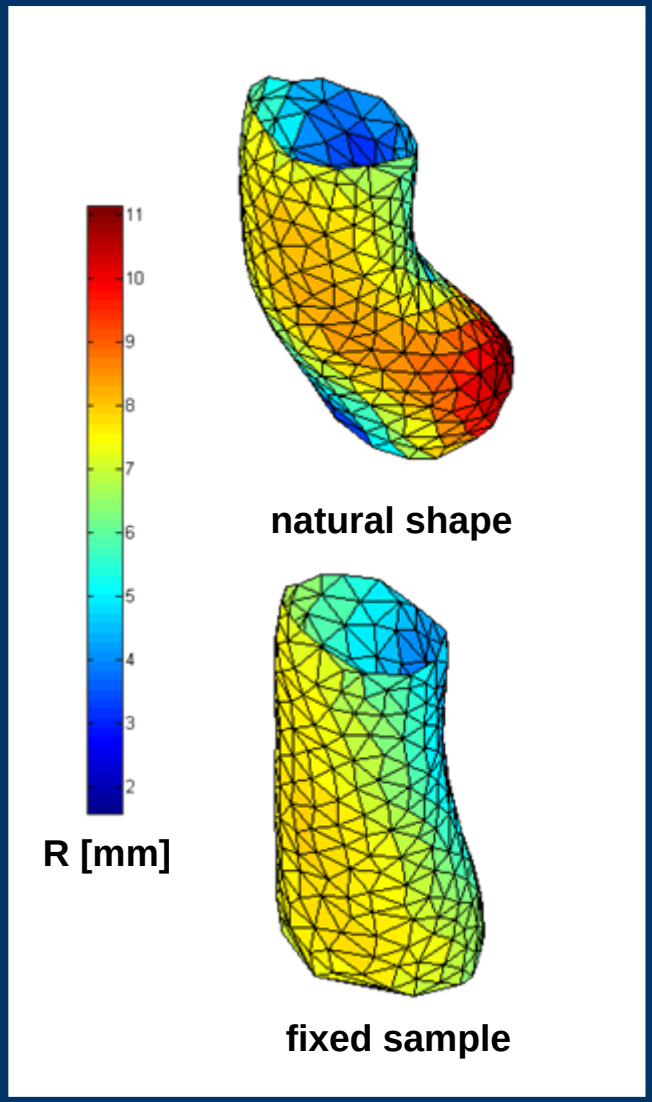
***Specific software for the simple and relatively complex geometries***

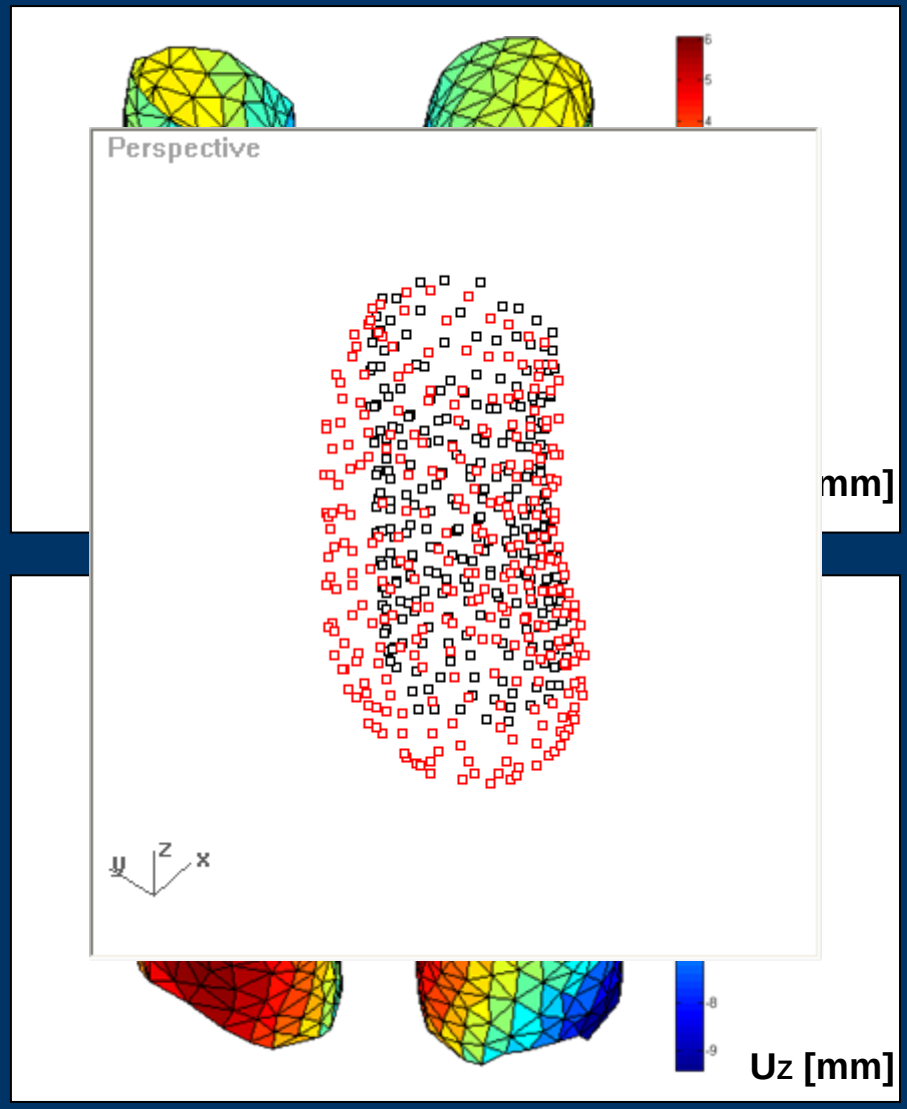
# Curved vascular segment



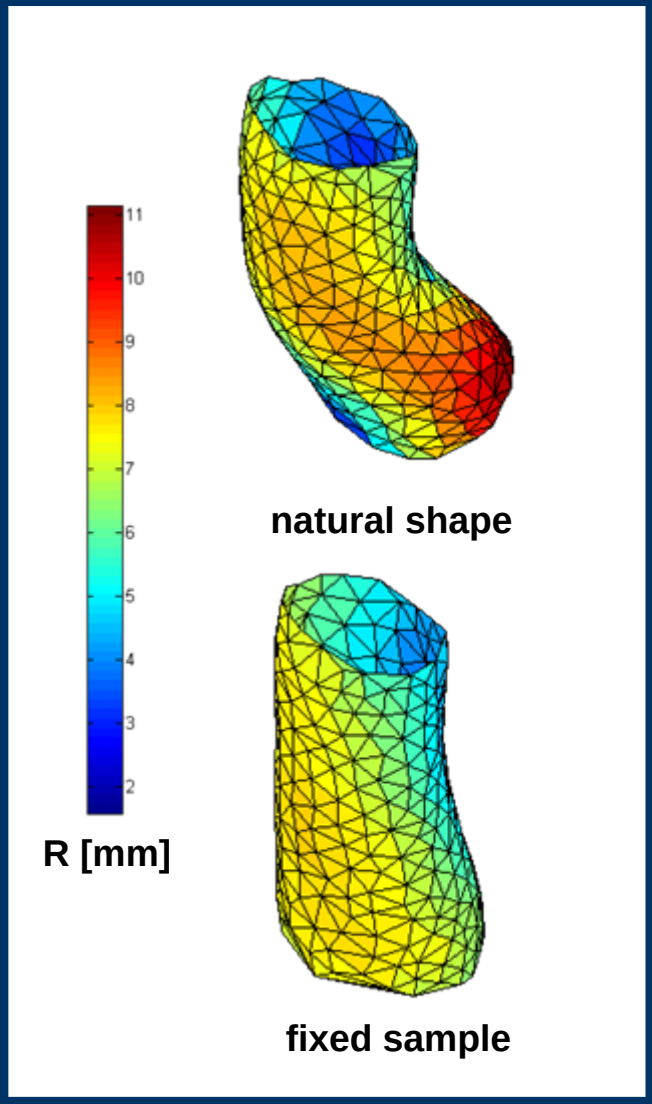

p = 0 → 120 mmHg – F = 10 g

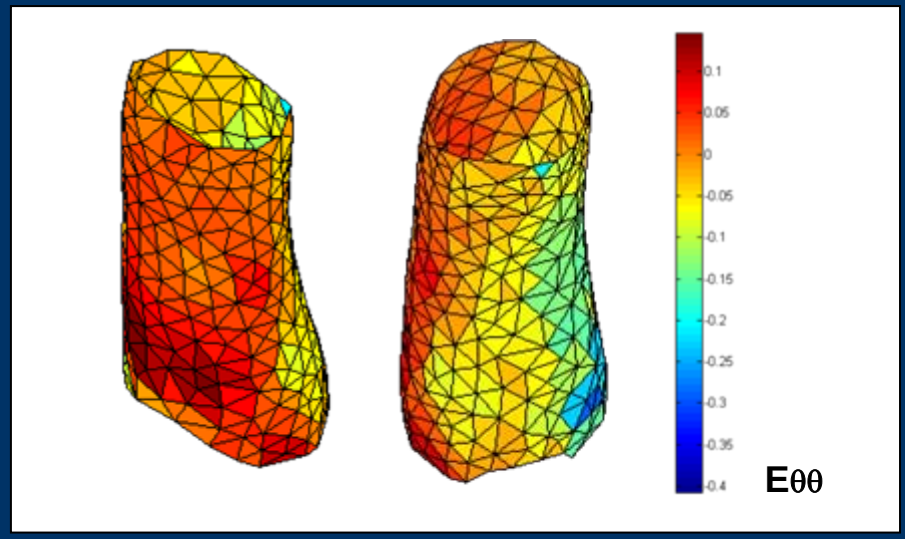
# Effect of sample fixation: deformation maps

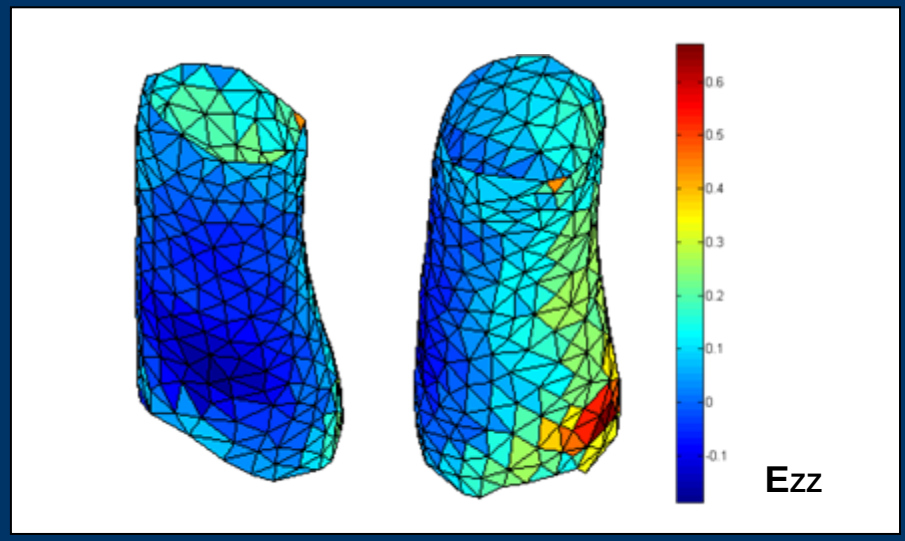


# Effect of sample fixation: strain maps



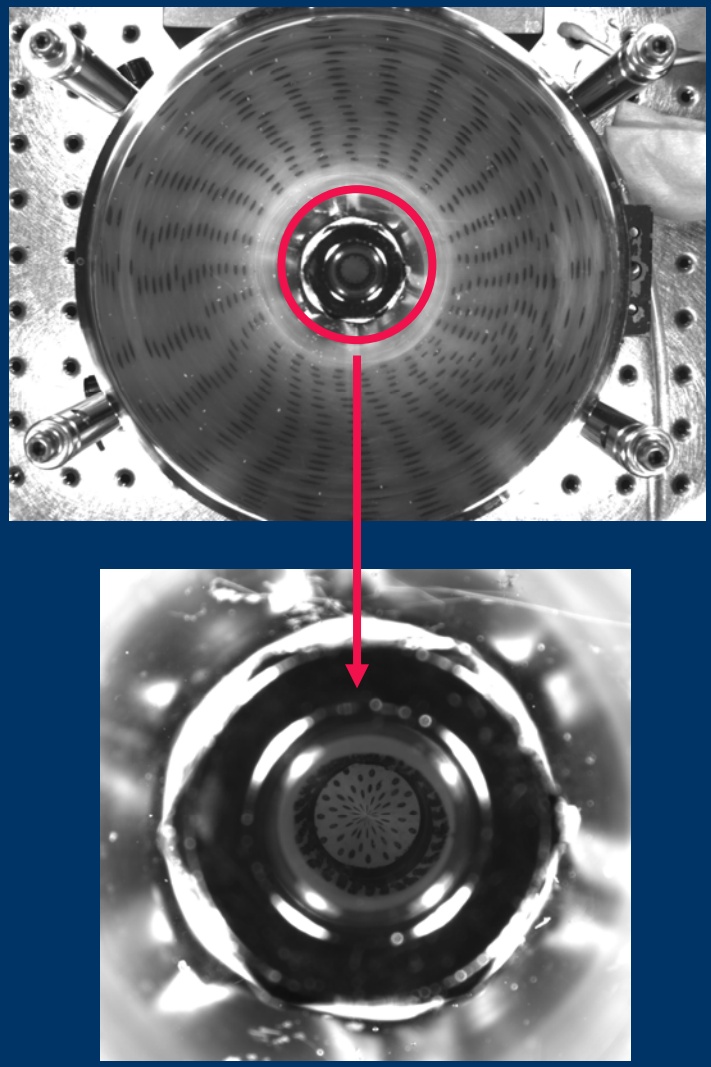



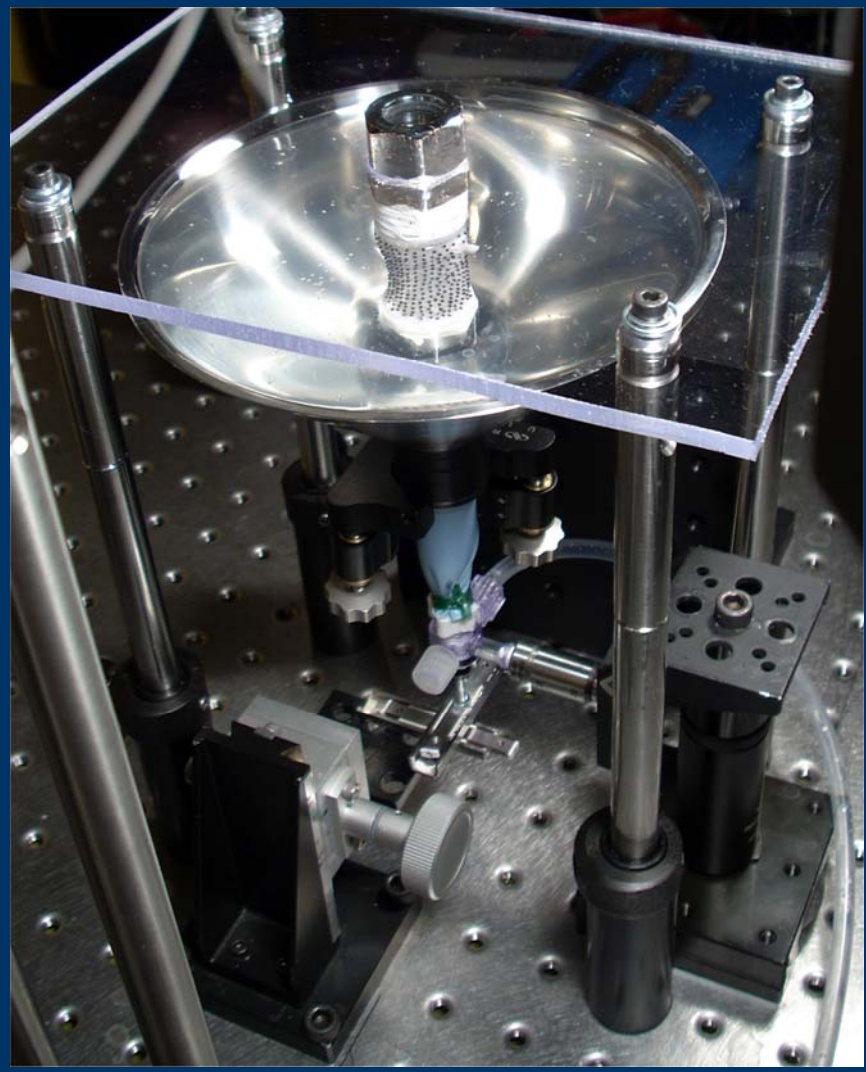
# IN-OUT CM SET-UP - *Work in progress*



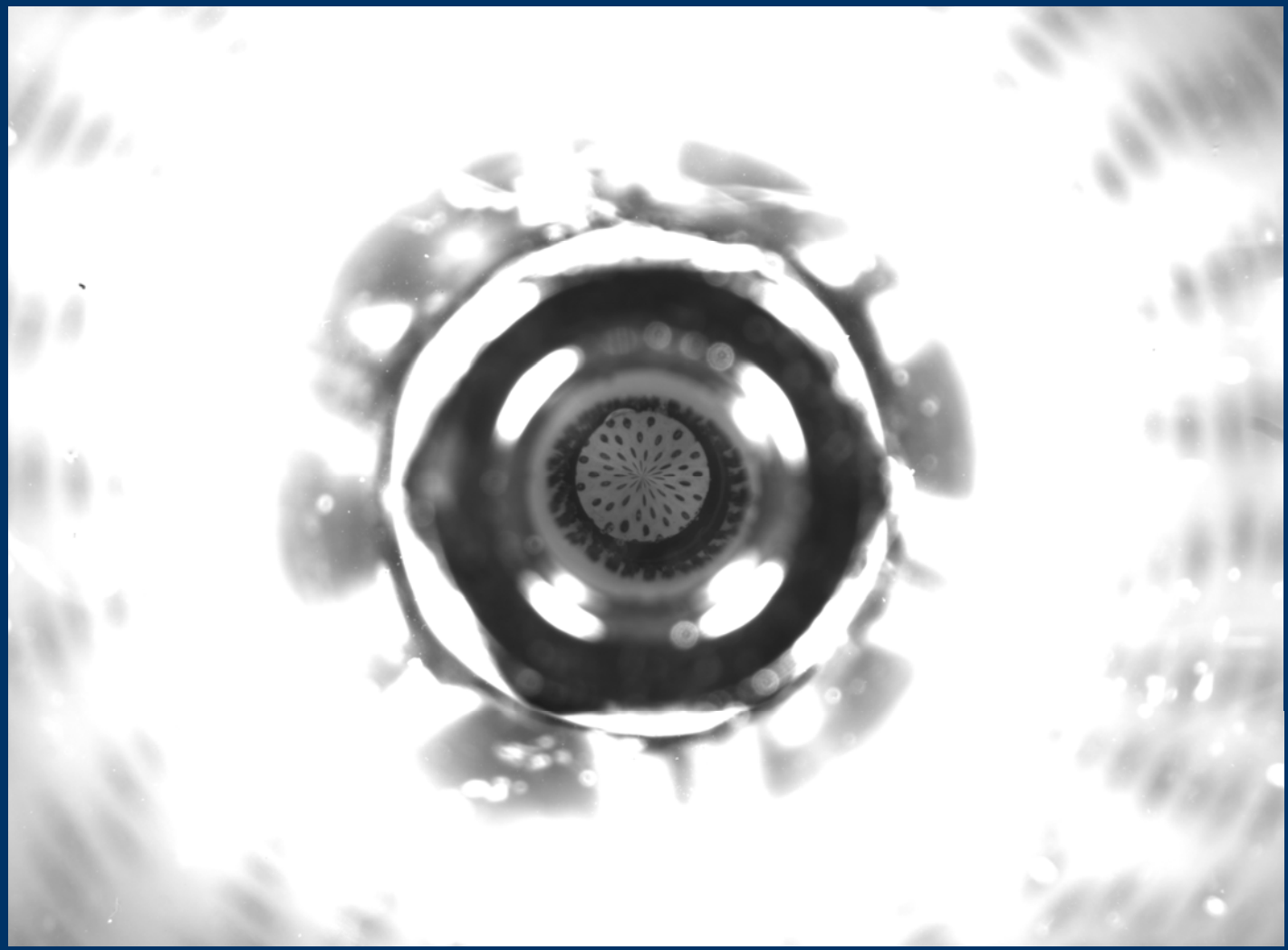

**Sample: porcine thoracic aorta**

# IN-OUT CM SET-UP - *Work in progress*



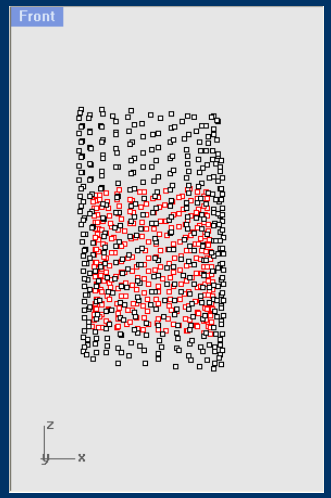


## Inner/outer surfaces measurement - *preliminary results*

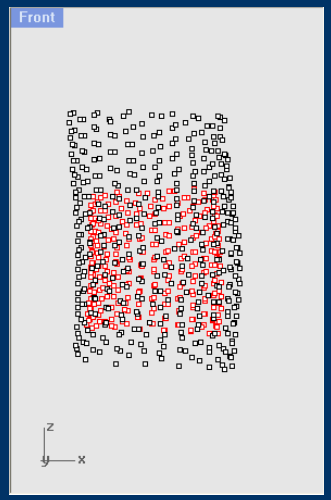


**Limitation:** ***Only incremental pressure tests***

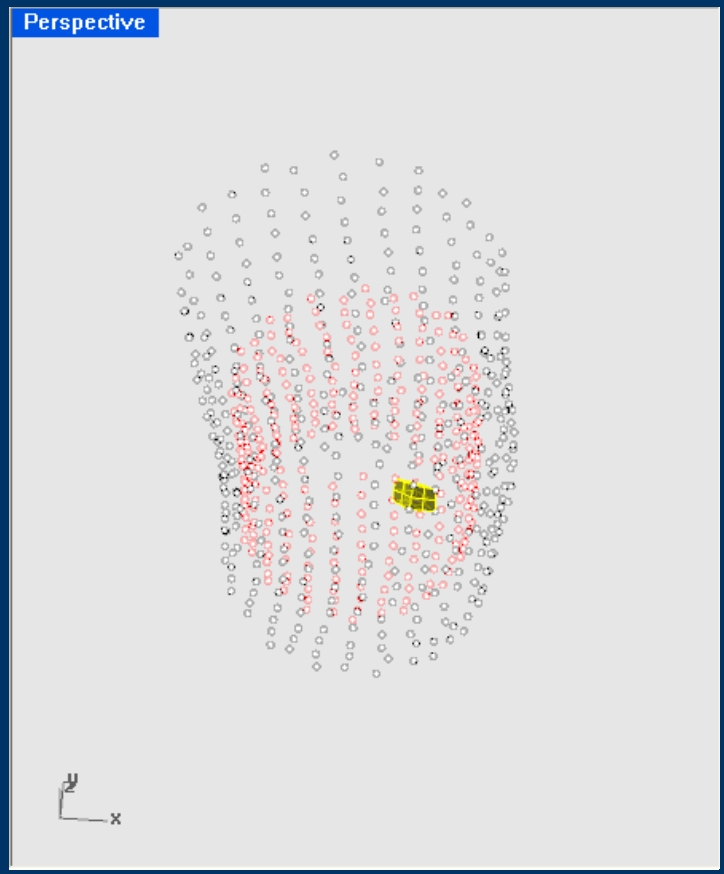
# 360° measurement on inner/outer surfaces- *preliminary results*




0 mmHg



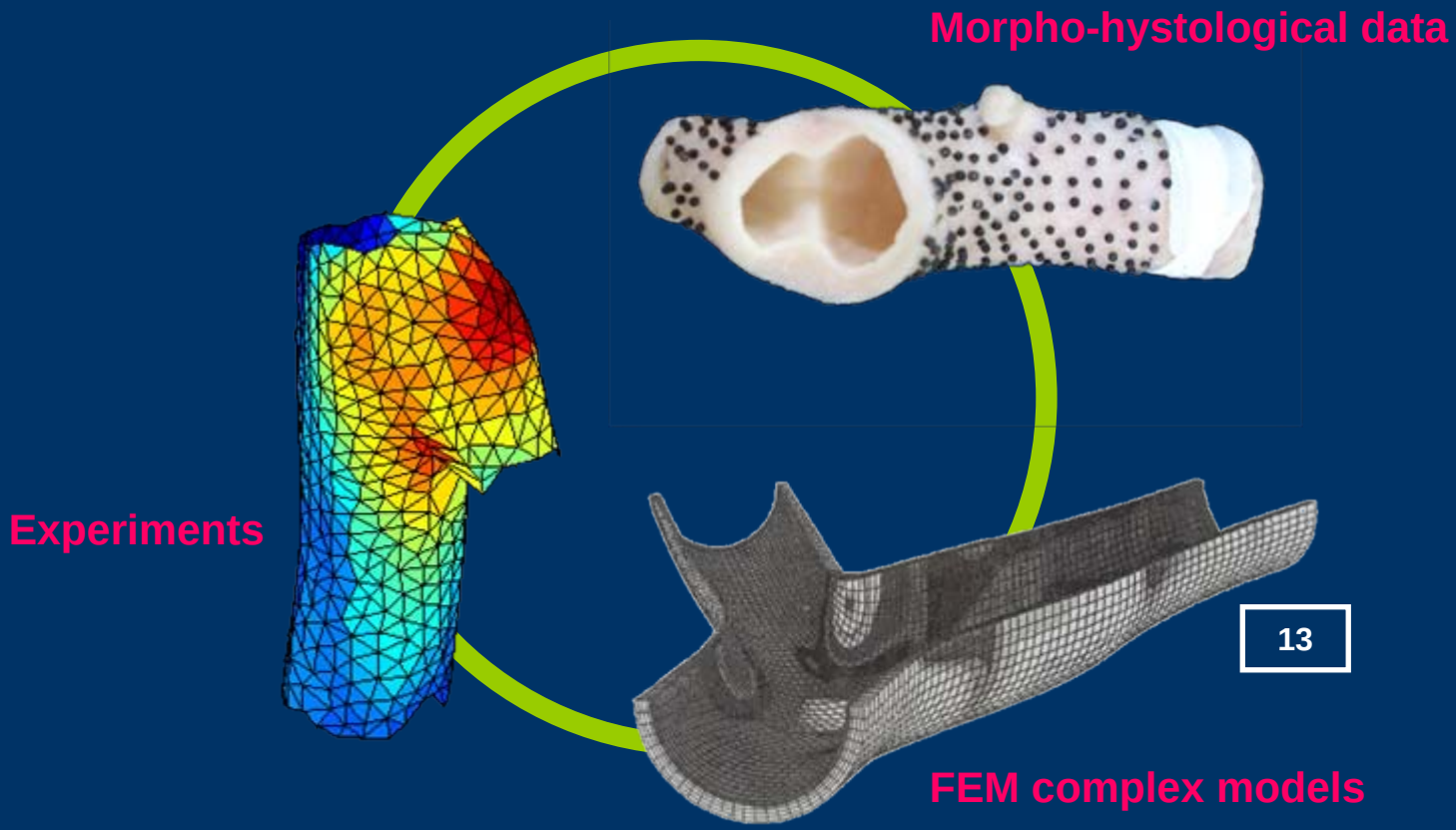

80 mmHg




Limitations: Very critical calibration procedure

Do we measure the tissue properties?

# Hybrid framework
# for mechanical characterization of vascular tissue




**13-** Delfino A, Stergiopulos N, Moore JE, Meister JJ. *Residual strain effects on the stress field in a thick wall finite element model of the human carotid bifurcation*. Journal of Biomechanics 30:777-786.

***Thank you and***

***thanks to my friends and colleagues* Dr Uccio Cosola *and* Dr Luciano Lamberti *for technical support and fruitful discussions.***