PIV and Digital Holography for measuring blood flows and vessel wall dynamics

Laura Arévalo, Eva Roche, Virginia Palero, Miguel Ángel Martínez and Mª Pilar Arroyo

larevalo@unizar.es

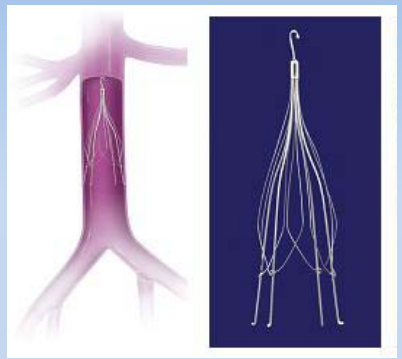
Instituto de Investigación en Ingeniería de Aragón (I3A)-Universidad de Zaragoza
Zaragoza, Spain.

COST Action MP1106: "Multiphase flows with/without phase change"
Zaragoza 2013

Flow-filter interaction

Experimental data (blood velocity) → validate → Numerical Models → design →

Antithrombotic filter

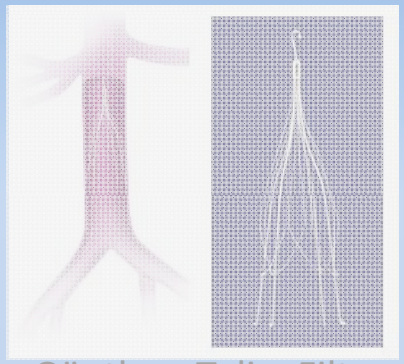


Günther Tulip Filter

Universidad Zaragoza
Instituto Universitario de Investigación en Ingeniería de Aragón
Universidad Zaragoza

Flow-filter interaction

Experimental data (blood velocity) → validate → Numerical Models → design → Antithrombotic filter



Günther Tulip Filter

Current experimental techniques →

- Magnetic resonance.
- Ultrasonic methods.

→

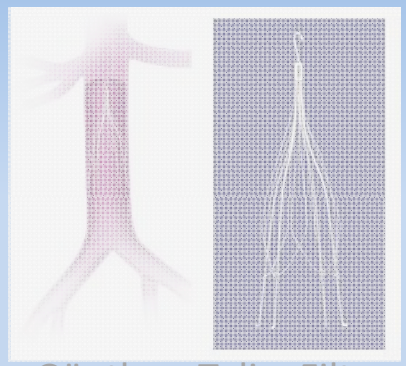
- ❖ Limited by temporal and spatial resolution.
- ❖ Incomplete measurement (1C)

Universidad Zaragoza
Instituto Universitario de Investigación en Ingeniería de Aragón
Universidad Zaragoza

Flow-filter interaction

Experimental data (blood velocity) → validate → Numerical Models → design →

Antithrombotic filter



Günther Tulip Filter

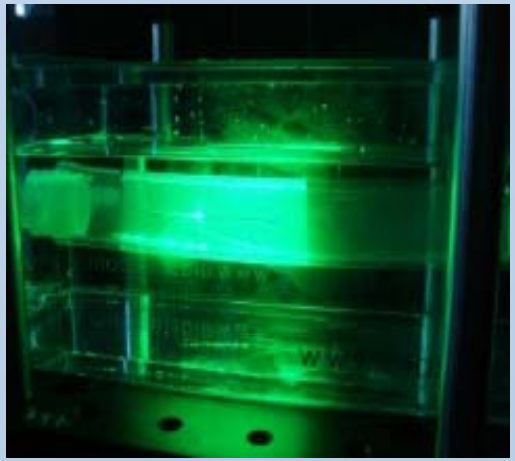
Current experimental techniques →

- Magnetic resonance.
- Ultrasonic methods.

→

- ❖ Limited by temporal and spatial resolution.
- ❖ Incomplete measurement (1C)

Particle Image Velocimetry (PIV) →



- Flow velocity measurement in a vena cava model with a filter inside.
- Constant and pulsatile flow.

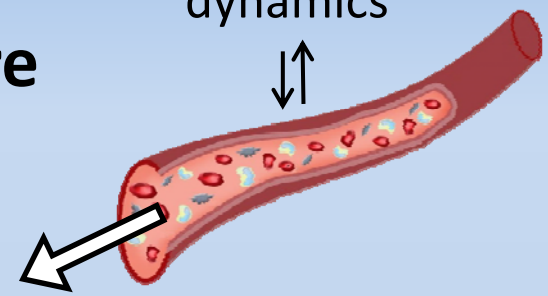
Universidad Zaragoza
Instituto Universitario de Investigación en Ingeniería de Aragón Universidad Zaragoza

Fluid-wall interaction

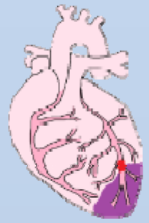
Research
Treatment
Diagnosis
Prevention

Fluid-Structure Interaction

Vessel wall dynamics



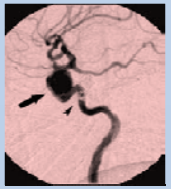
Blood Flow



HEART ATTACK

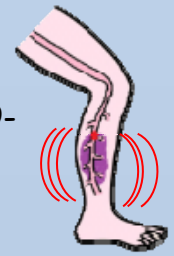
STROKE

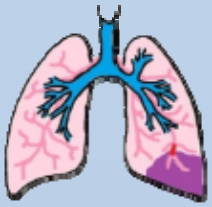
CARDIOVASCULAR DISEASES



ANEURYSM

VENOUS THROMBO-EMBOLISM





PULMONARY EMBOLISM

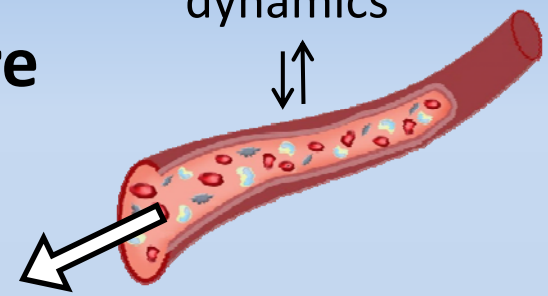
Universidad Zaragoza

Instituto Universitario de Investigación en Ingeniería de Aragón Universidad Zaragoza

Fluid-wall interaction

Research
Treatment
Diagnosis
Prevention

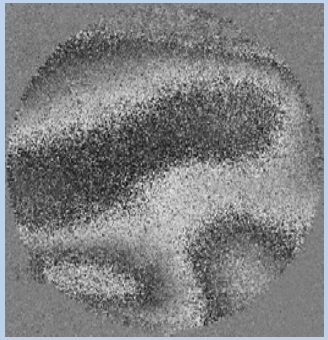
Fluid-Structure Interaction



Digital Image Plane Holography (DIPH)

Endoscopic illumination and imaging

Endoscopic DIPH



Vein wall deformation (lamb aorta)

Universidad Zaragoza
Instituto Universitario de Investigación en Ingeniería de Aragón Universidad Zaragoza

Outline

PIV technique:

Velocity Measurement

Endoscopic DIPH technique:

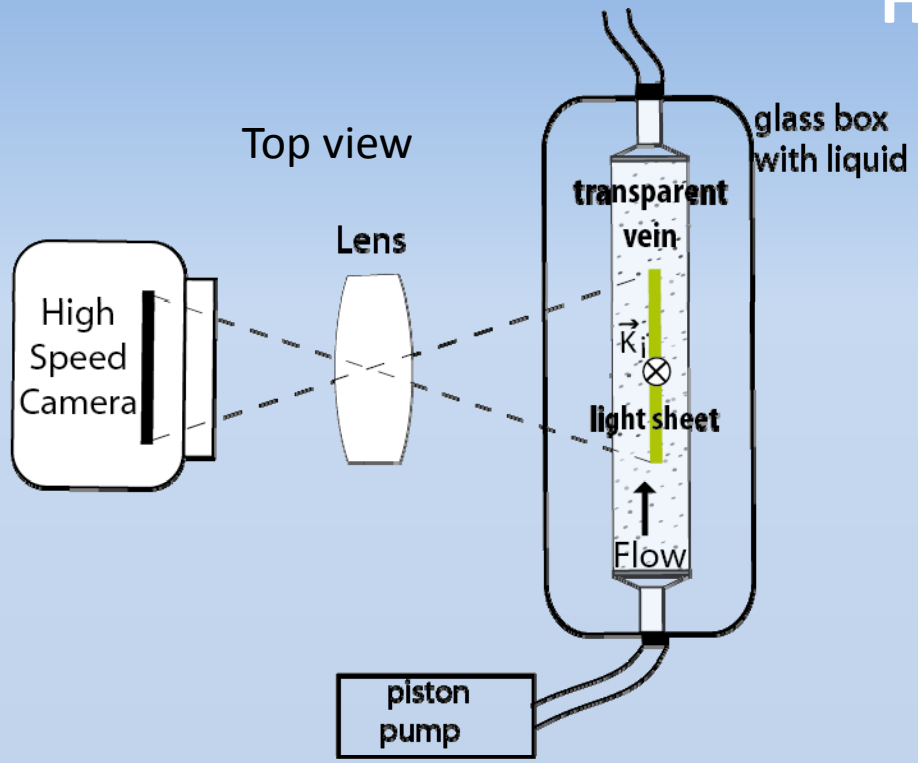
Deformation Measurement

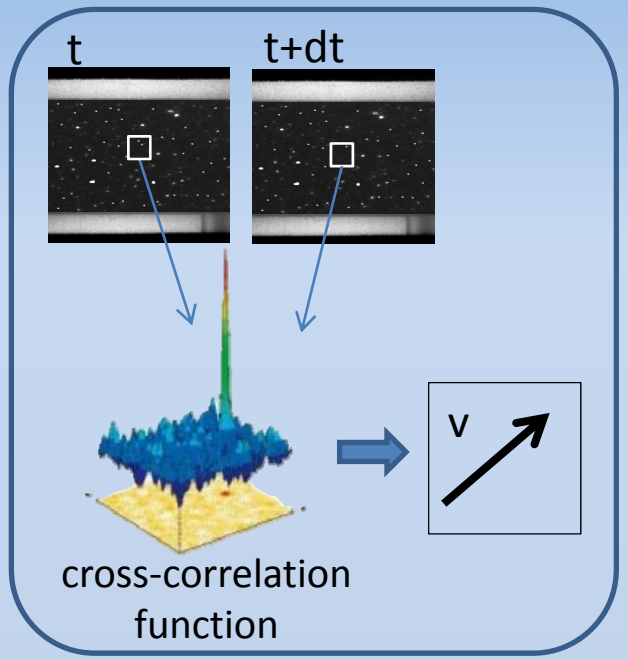
Conclusions

Universidad Zaragoza
1542
Instituto Universitario de Investigación en Ingeniería de Aragón
Universidad Zaragoza

Flow-filter interaction

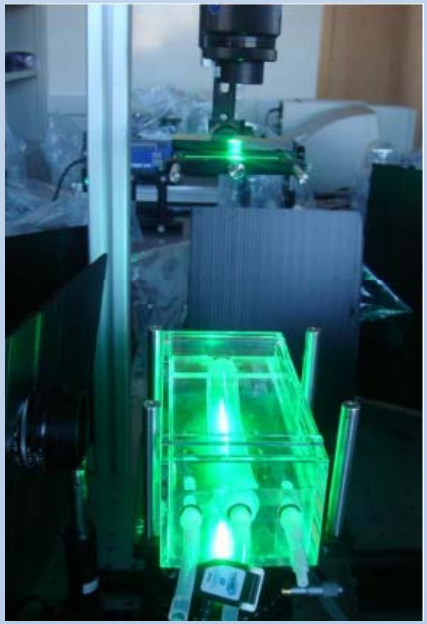
High Speed PIV technique



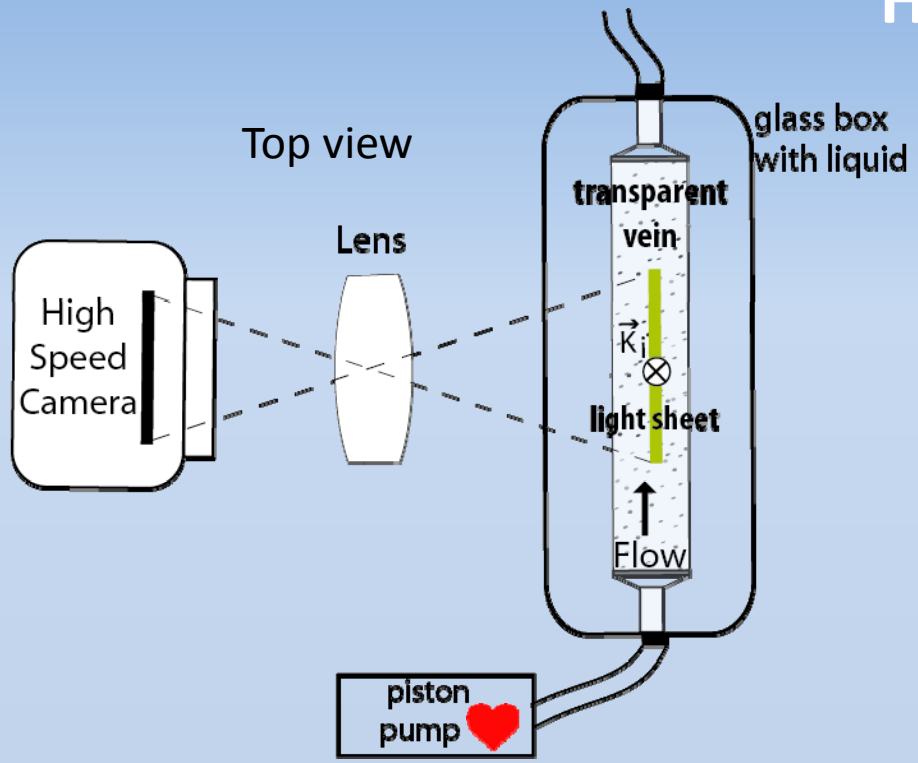


Experimental Set-up:

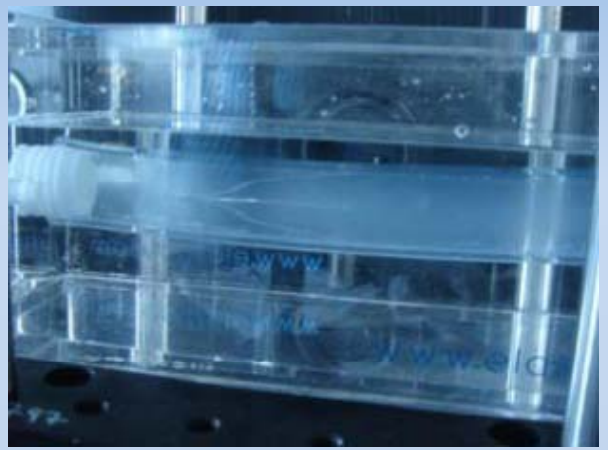
- High Speed two-cavity New Wave Pegasus laser (λ=527nm, energy per pulse=10mJ at 1000Hz).
- High Speed camera (Fastcam SA2, sensor size of 2048x2048 pixels, pixel size of 10µm x 10µm).
- 16-bit images at 1000frames/s.
- Nikon AF-S VR Micro-Nikkor 105mm f/2.8D Lens.
- A cylindrical lens (f'=1000mm) produces a light sheet.



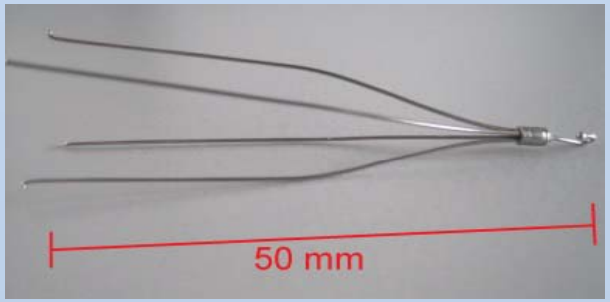
High Speed PIV technique



Vein Model



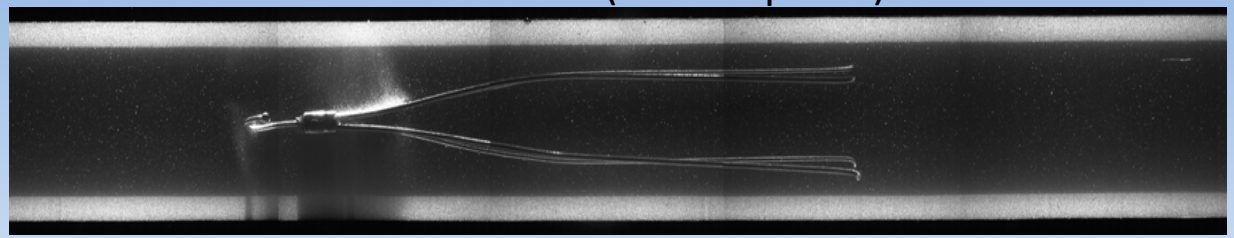
Antithrombotic filter



- Vena cava model: Piece of elastic transparent silicone tube of inlet diameter 12mm.
- Blood model: Mixture of glycerin (60%) and water (40%).
- Tracers: 4-7µm diameter latex particles.
- Pump that produces constant and steady physiological pulsatile flows.

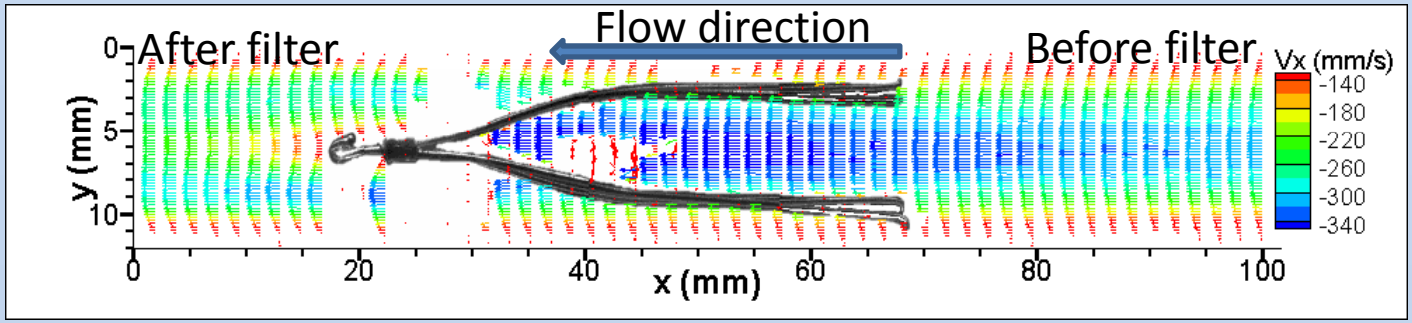
Velocity Measurements

Vein model with a filter inside (central plane)



ΔT_{PIV}=0.004ms
T_{exp}=0.001ms

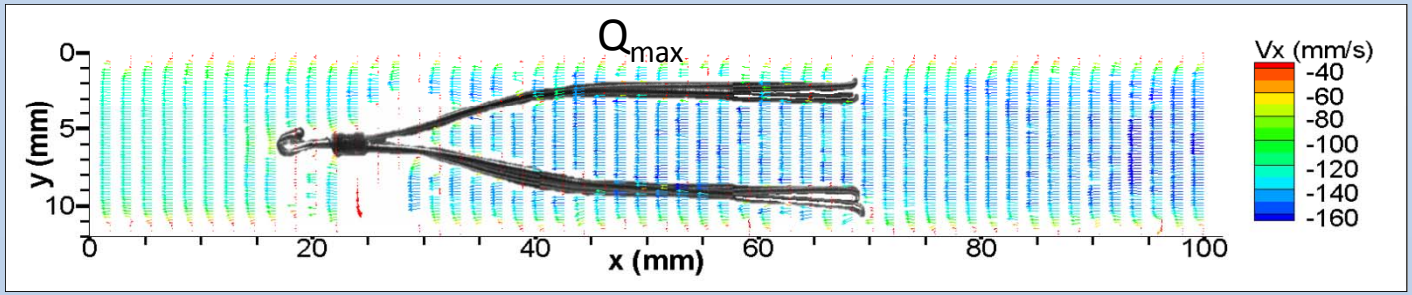
Constant Flow

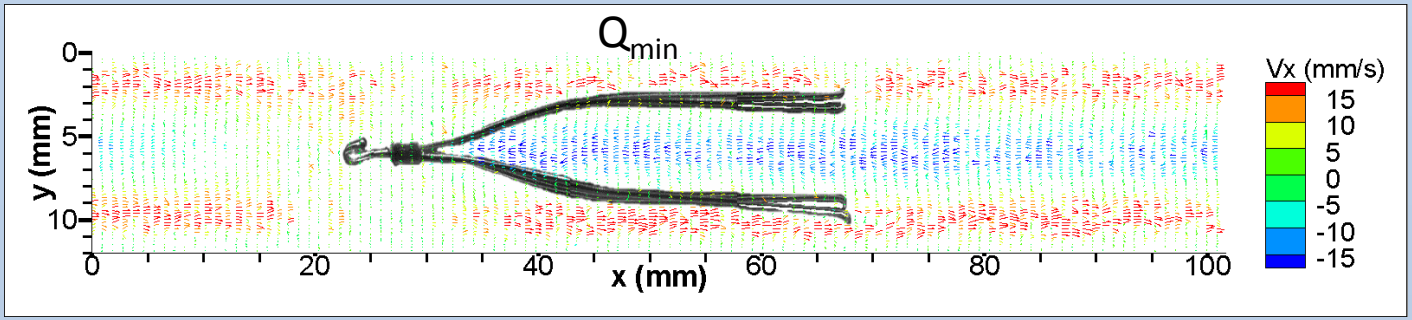


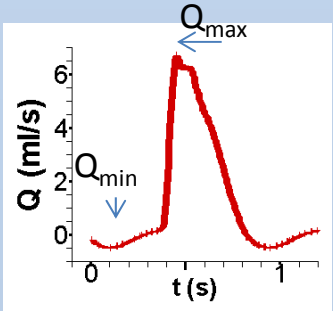
Average from 100 images !

v_{max} =311.4mm/s
Q=16mL/s

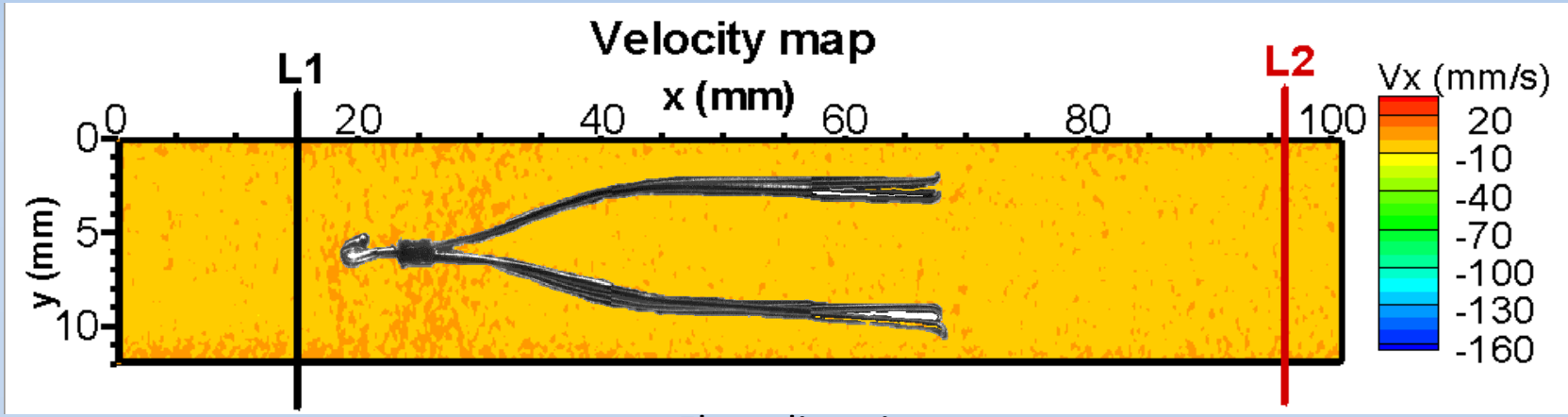
Pulsatile Flow







Vein model with a filter inside: Femoral waveform

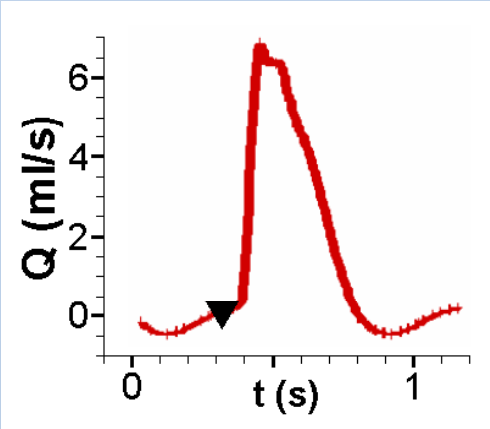


Line 1: After Filter

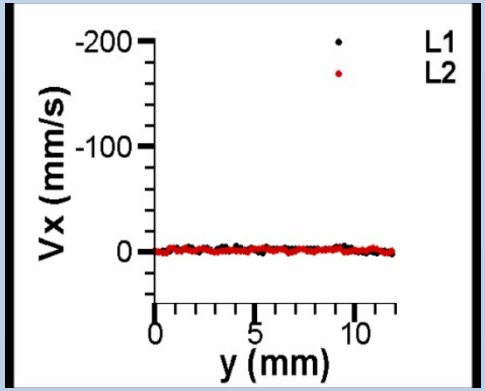
Flow direction

Line 2: Before Filter

Flow Rate



Velocity profile line **1** & line **2**

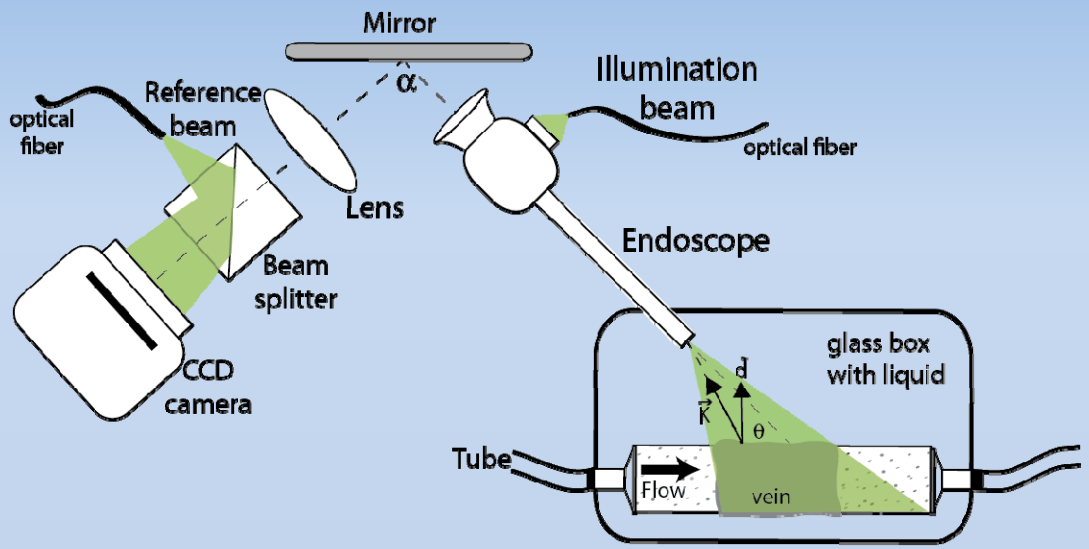


Instituto Universitario de Investigación
en Ingeniería de Aragón
Universidad Zaragoza

Universidad Zaragoza

Wall deformation measurement

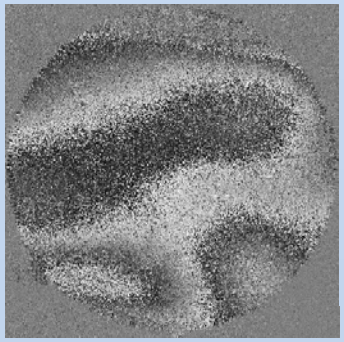
Endoscopic Digital Holography



Interferometric analysis

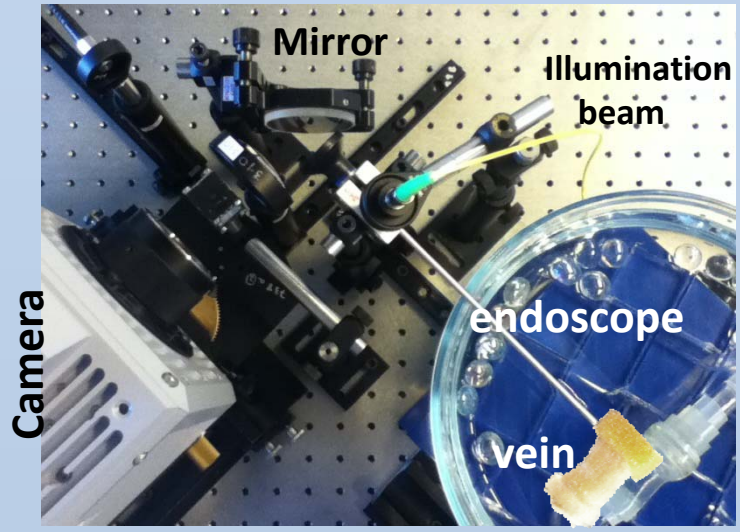
Sensitivity vector $\vec{K} = \frac{2\pi}{\lambda}[\vec{u}_o - \vec{u}_i]$

Phase difference $\Delta\phi = \vec{K} \cdot \vec{d}$



Experimental Set-up:

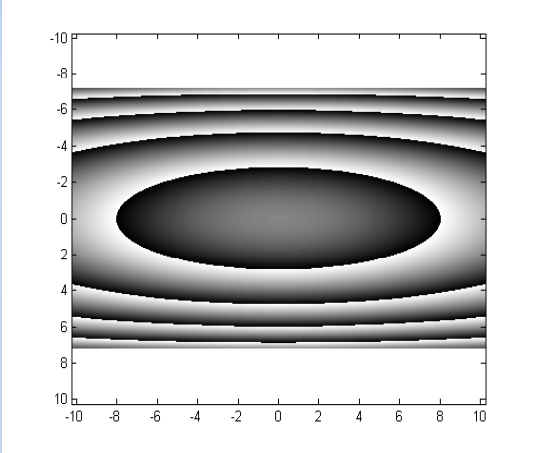
- Laparoscope
- A diode-pumped solid-state laser (532.4nm, 317mW)
- *100 mm* focal length lens.
- High Speed camera (Fastcam SA2, sensor size of 2048x2048 pixels, pixel size of 10µm x 10µm).
- 16-bit images at 1000frames/s.



Deformation measurment

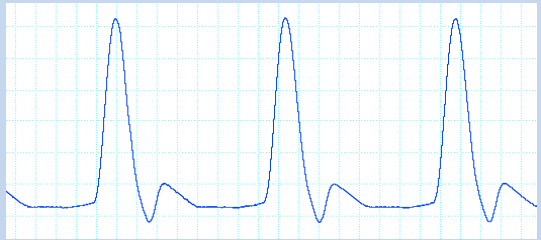
- Finge -> displacement: $\lambda/2=266nm$

Simulated radial displacement

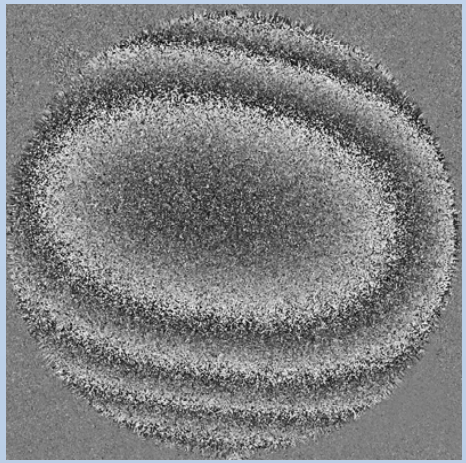


Pulsatile Flow

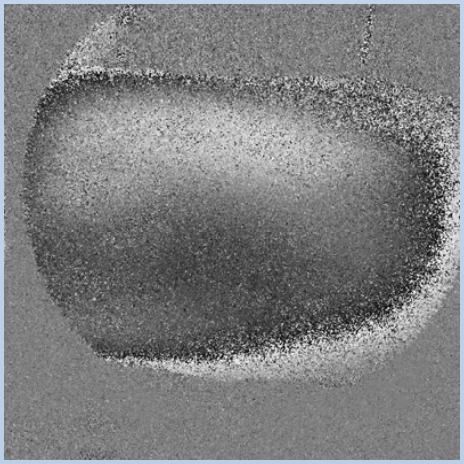
Q_{max}=1 *mL/s*
Q_{prom}=0,199 *mL/s*
T=840 *ms*



Silicon Tube



Sheep Aorta



Diameter: 12 *mm*

CONCLUSIONS

- Endoscopy has been combined with High Speed PIV and holographic interferometry for flow velocity and wall deformation measurement.
- Different velocity vector maps have been obtained for constant and pulsatile flows in a vena cava model.
- Endoscopes have been used for illumination and recording of digital holograms. In holographic interferometry, the sensitivity will be maximum (half the wavelength per fringe).
- Endoscopes allow an easy change of the sensitivity vector direction and of the recorded region size.
- Qualitative wall deformation has been obtained using digital holography in a vein model and in a real sheep aorta.

Universidad Zaragoza
Instituto Universitario de Investigación en Ingeniería de Aragón Universidad Zaragoza

Thank you

for your attention!

Acknowledgments:

TOL Laser Optical Technologies

Universidad Zaragoza 1542

instituto de investigación en ingeniería de Aragón Universidad de Zaragoza

GOBIERNO DE ARAGON