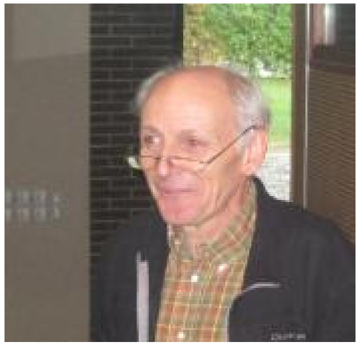
2012 :15th SESSION of ESMP

Lecture presented in Archamps (Salève Building) by :

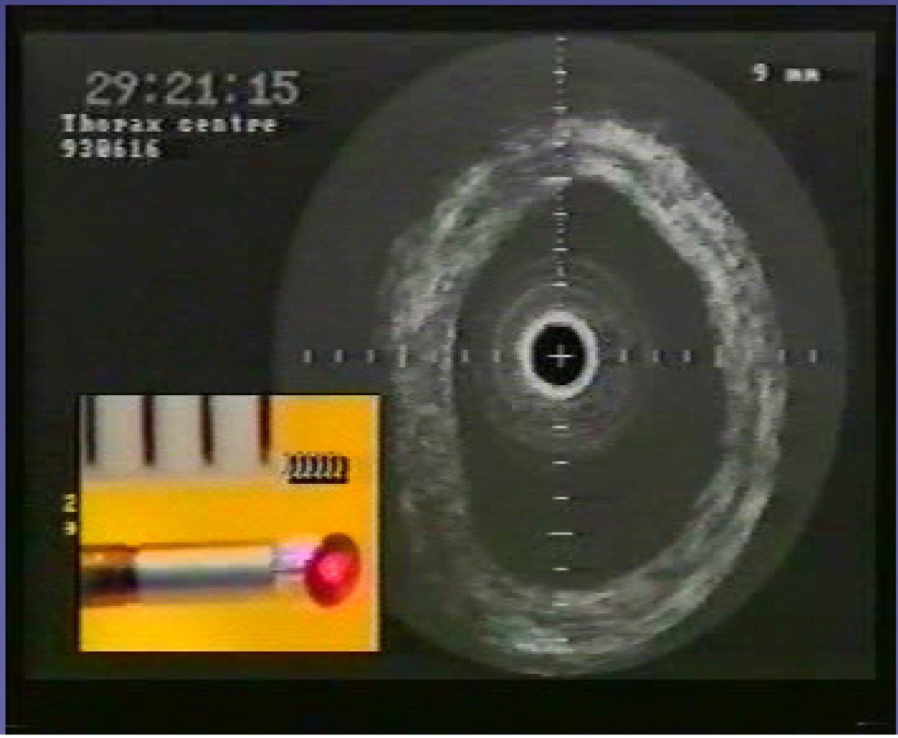
Christian CACHARD (CREATIS Lyon)



Intravascular imaging

Nico de Jong

Presented (and adapted) by
Christian Cachard

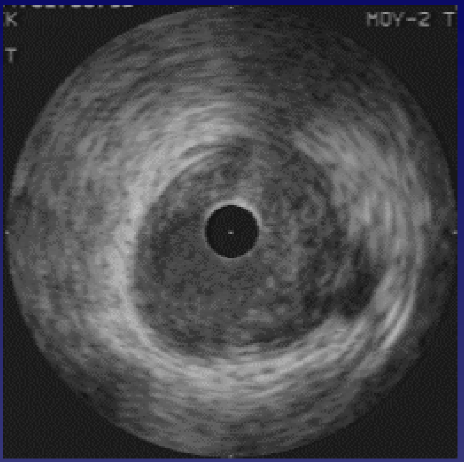


Outline

- General presentation
  - principal features, contributions to diagnosis
- Image formation
  - Image formation
  - catheter technologies
  - Geometric artefacts
- IVUS in the clinic

- IVUS diagnostic modality under investigation

General presentation

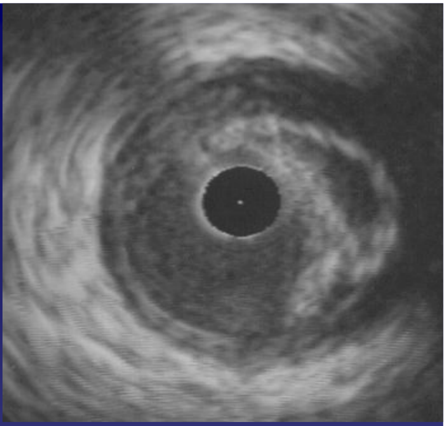


- Usefulness in cardiology
  - diagnosis of atherosclerotic coronary artery disease
  - guiding therapeutic procedures (balloon angioplasty, stenting)
- High resolution cross-sectional images of vessel walls in real time
- Frequency: 30-40 MHz, depth < 10 mm

General Presentation

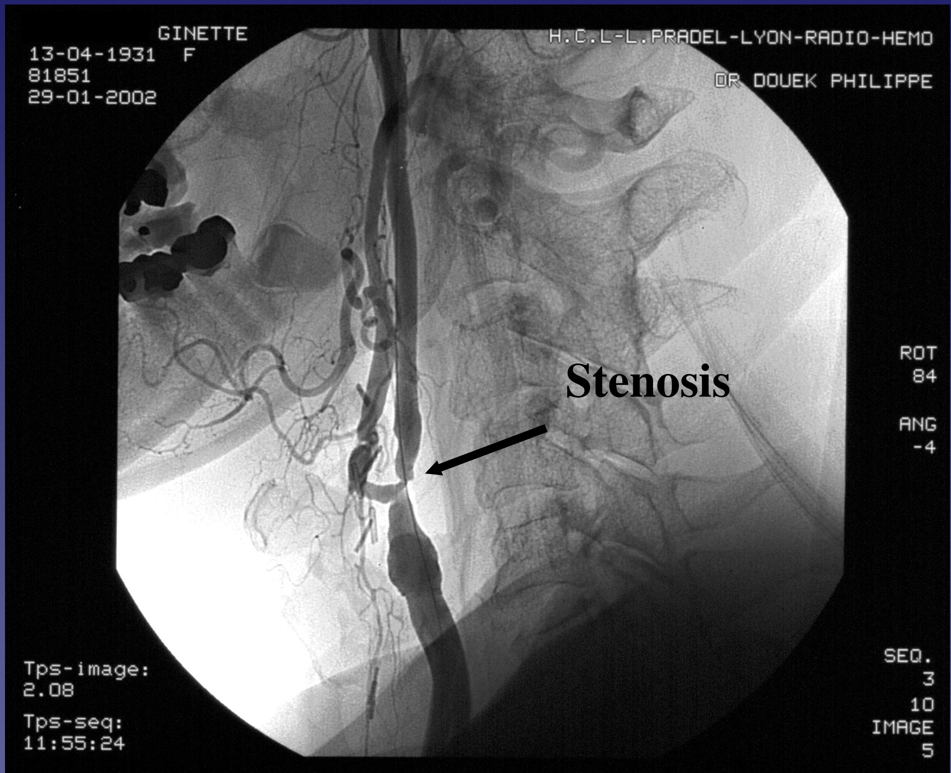
- Well spread in the middle of interventional cardiology
  - ex: in France, among 135 centres of angioplasty 30 have intravascular ultrasound imaging
- Time of examination : 5 to 10 mn
- Cost : 800 € (depends on the catheter used)
- Operating room

- Main advantages



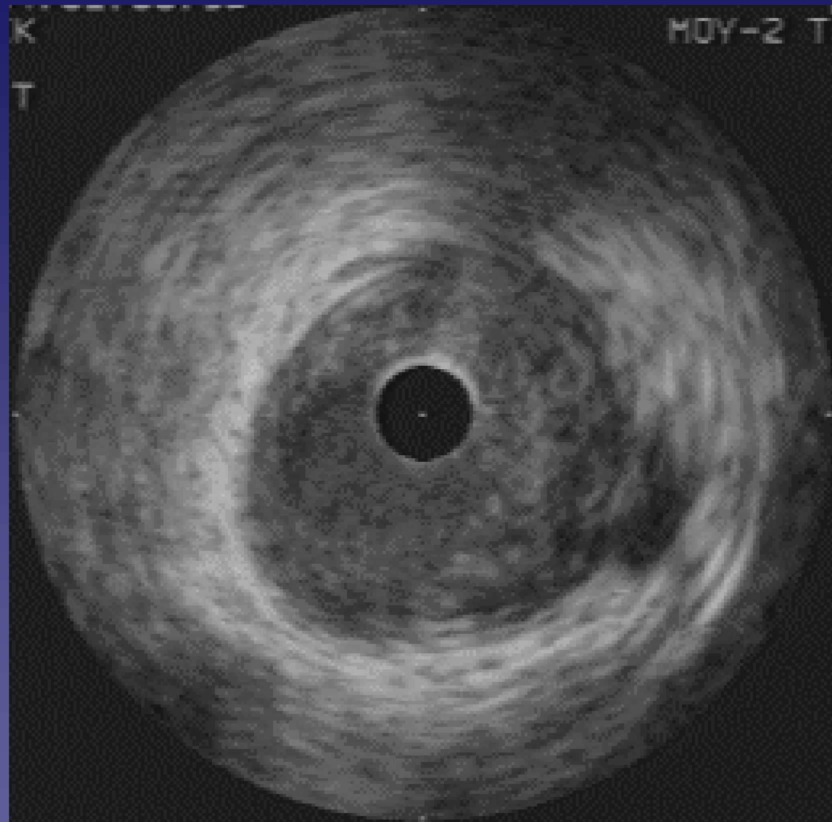
  - qualitative analysis by characterising *roughly* plaque components, plaque rupture or acute thrombosis
  - depicting atherosclerotic plaque morphology and remodeling
  - 2D and 3D quantitative analyses by precise measurements
    - arterial dimensions (diameter and area)
    - % stenosis
    - plaque volume

Imaging of the vessels



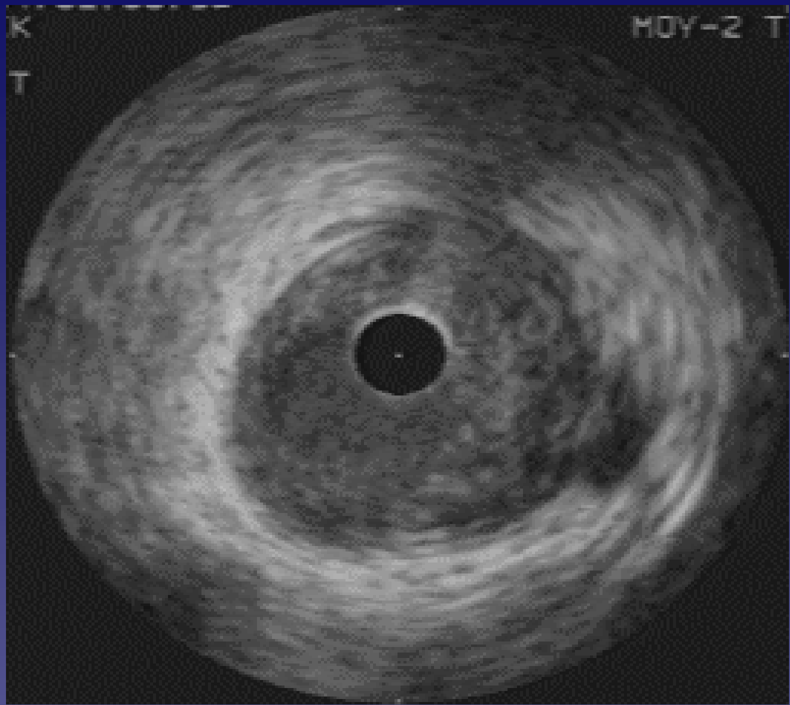
X-ray angiography

skeleton image of artery



Intravascular Ultrasound (IVUS)

cross-sectional image of artery



Intravascular Ultrasound (IVUS)

●IVUS provides **real time cross-sectional** images *in vivo* of vessels.

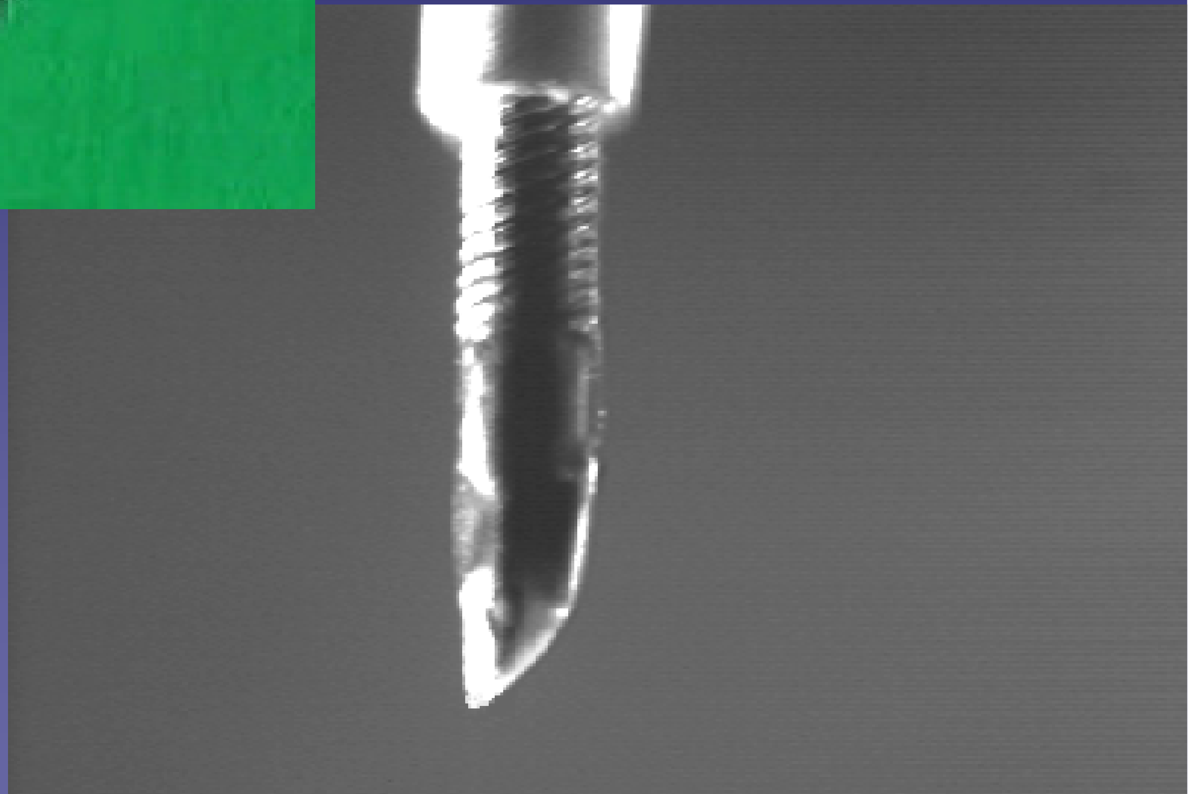
IVUS provides specific diagnostic information and guides interventional techniques for treatment of atherosclerotic luminal narrowing

IVUS is used for studying the mechanisms for restenosis .

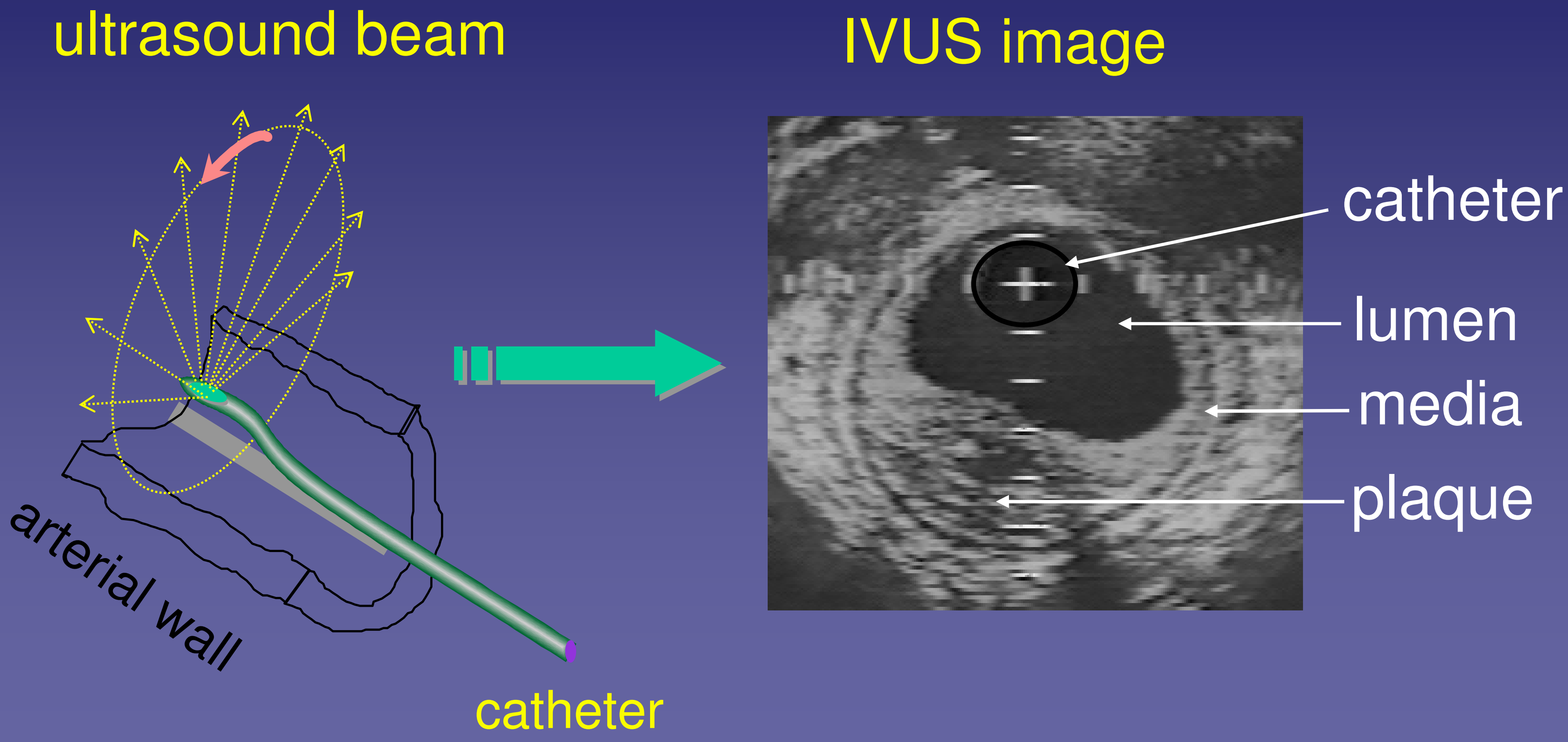
Image formation

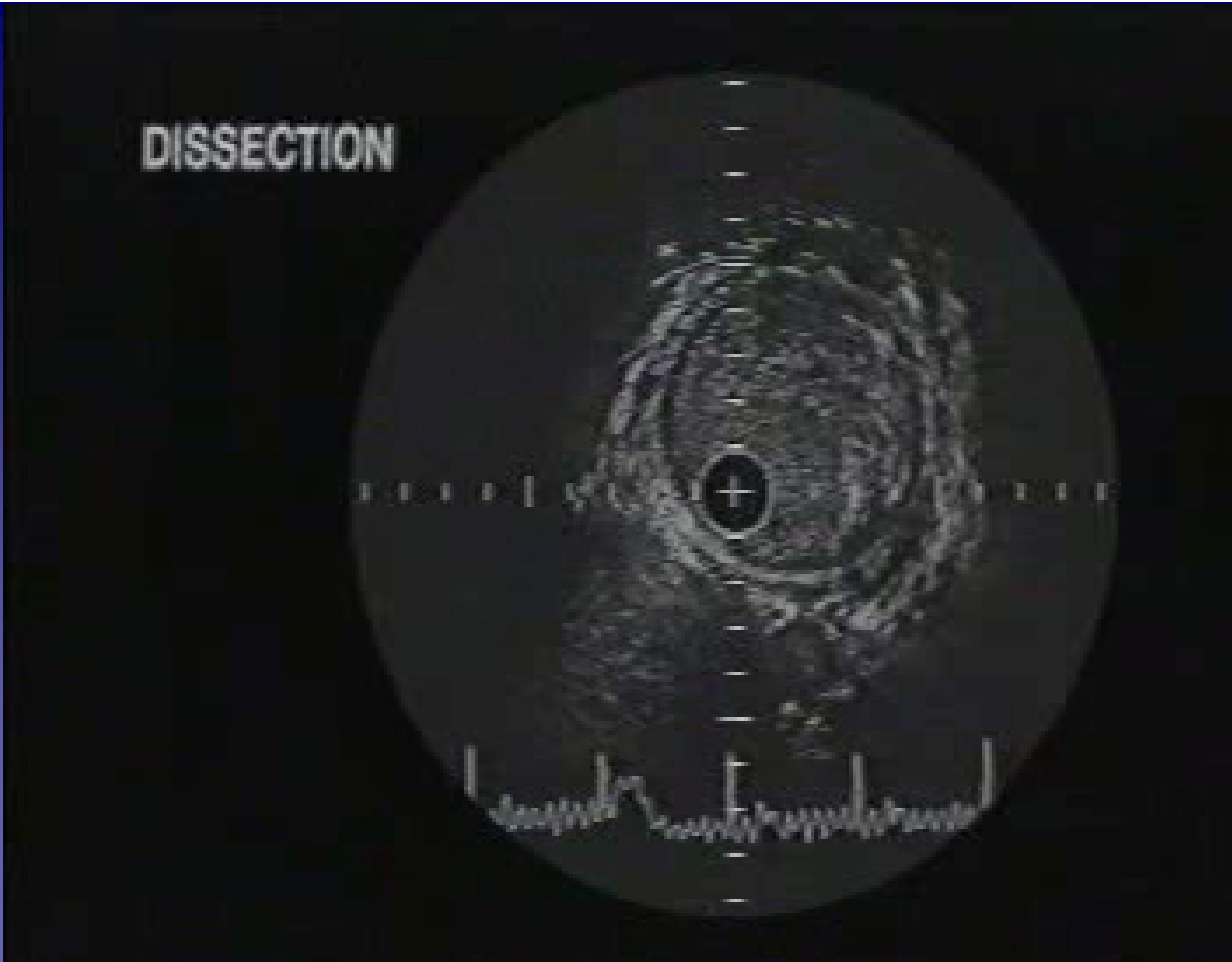
Catheter diameter ≅ 1mm

IVUS is an **invasive** imaging modality



Intravascular Ultrasound (IVUS) Imaging




DISSECTION

IVUS compare to classic probe

Advantages of IVUS

- Frequency: **30 MHz**
  - High frequency: **better resolution** and more attenuation
- Vessel size: some millimeters
- Wavelength: $\lambda = c/f = 50\ \mu m$
- Axial resolution : 150 µm at 30 MHz
- Lateral resolution : 250 µm at 30 MHz

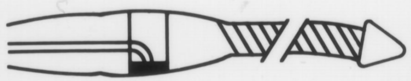
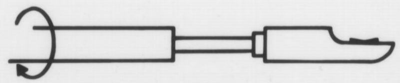
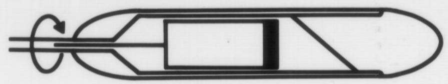
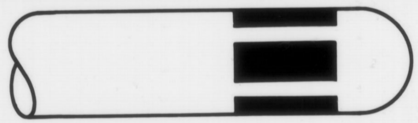
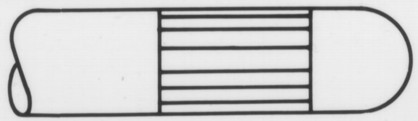
Drawback

- **Invasive technique** (operating room)

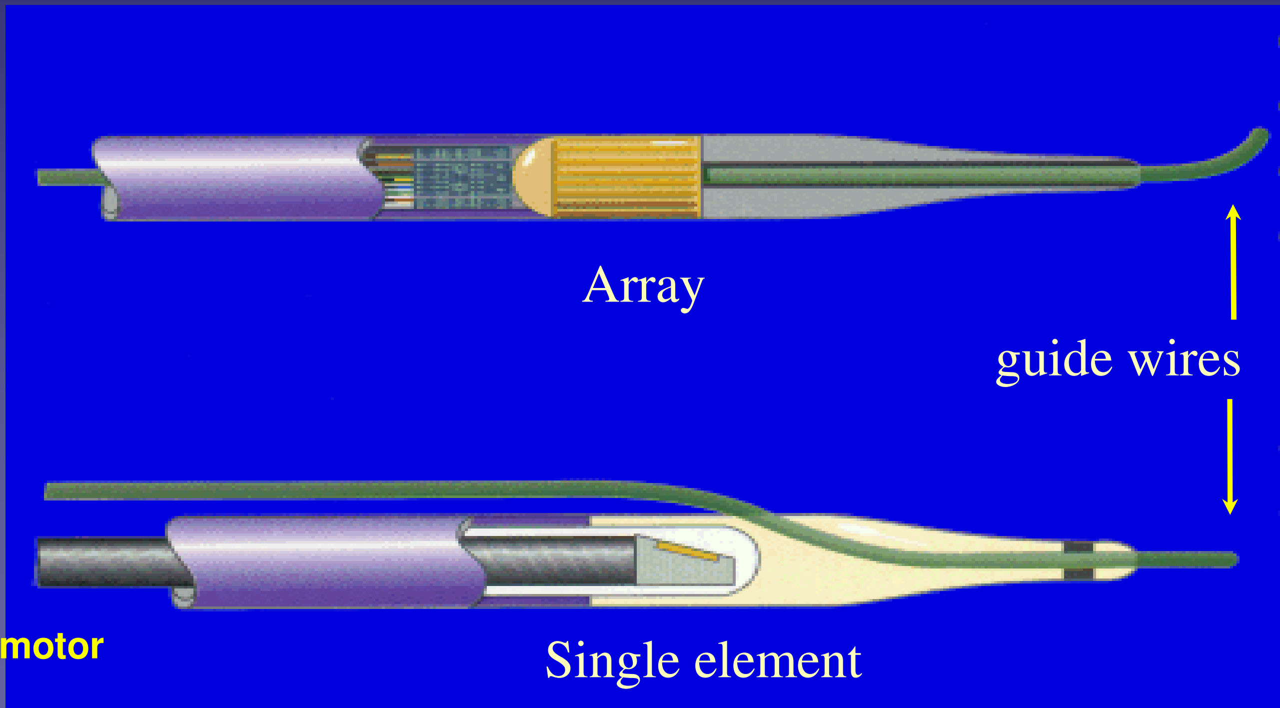
Construction of an IVUS catheter

- Catheter based imaging technique

INTRALUMINAL IMAGING

Wild	1955	echo-endoscope		rectal tumour location
Omoto	1962	rotating probe C-scan		intracardiac tomography
Ebina	1964	transesophageal P.P.I. scanning		heart and vessels
Wells	1965	rotating mirror		intravenous
Eggleton	1969	4-elements e.c.g. triggered		heart
Bom	1971	32-elements cylindrical phased array		intracardiac tomography

Intravascular Ultrasound Catheters

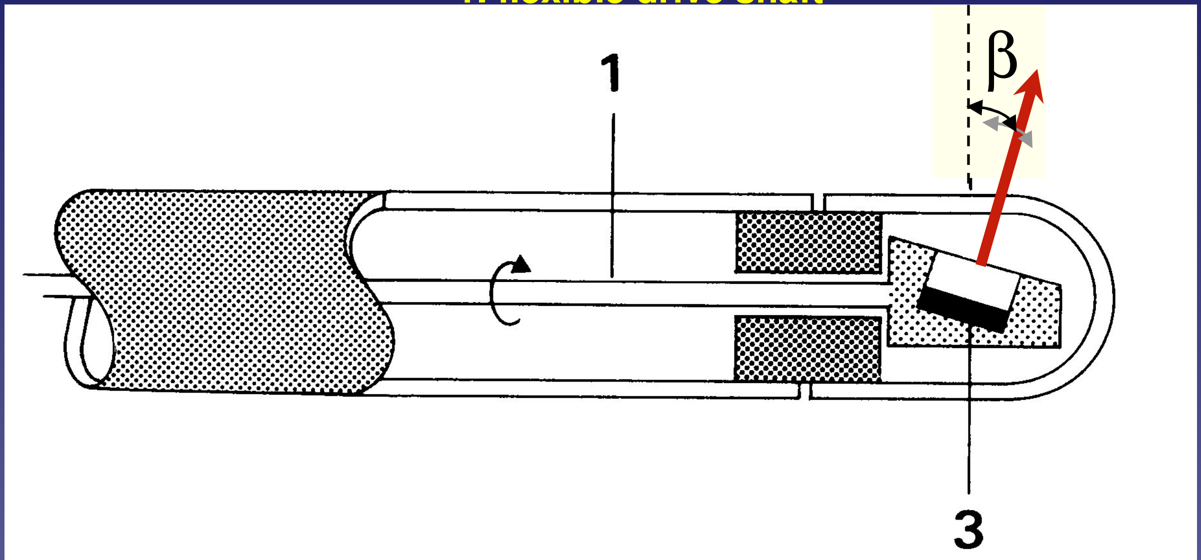


Electronic probe

Mechanical probe

rotating motor

- Mechanical rotating single element catheter



Typical features

catheter diameter : 0.9 mm (~3 French)

aperture : 14 °

forward inclination angle : β = 10 - 15°

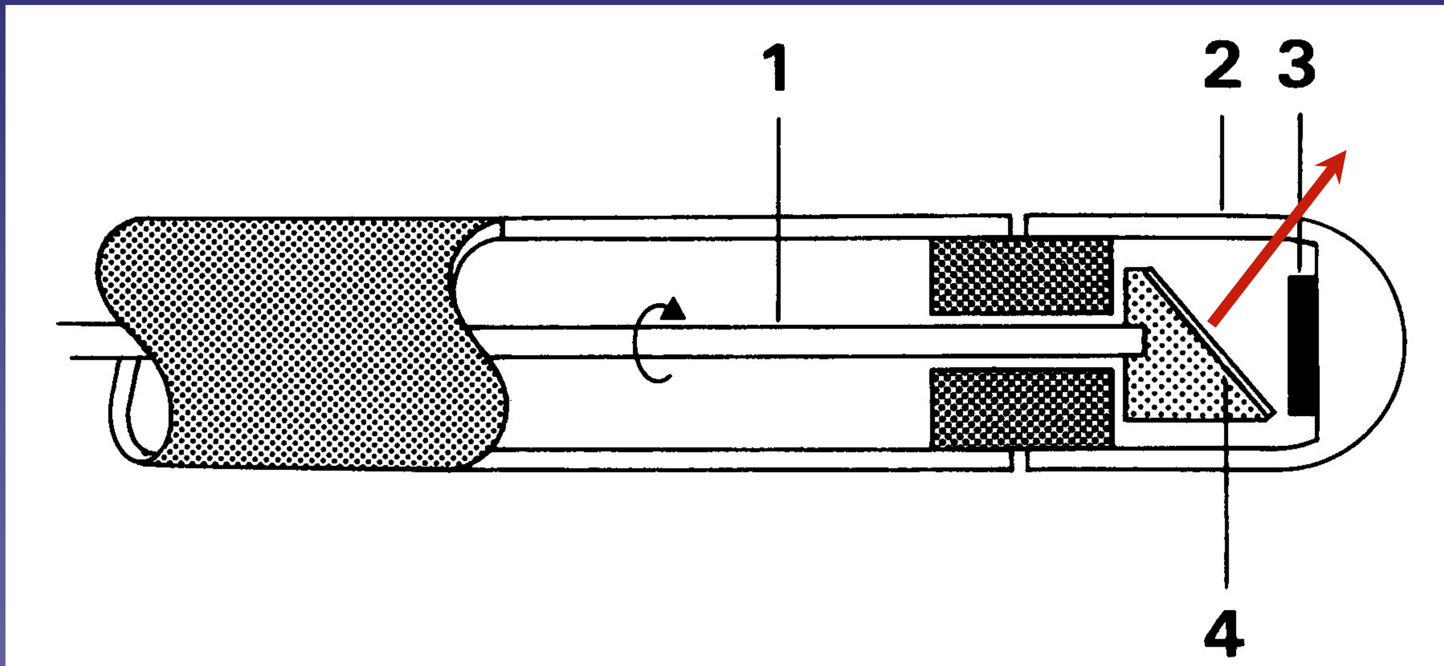
central frequency : 30 - 40 MHz

- Mechanical rotating mirror

transmitted ultrasonic beam

1. flexible drive shaft

rotating motor

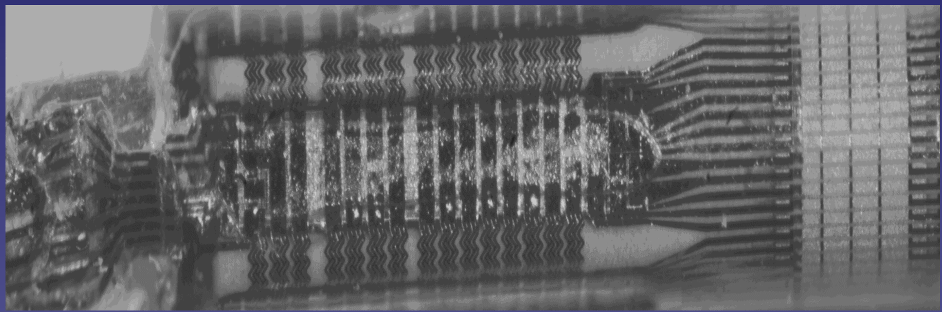


2. Transparent dome

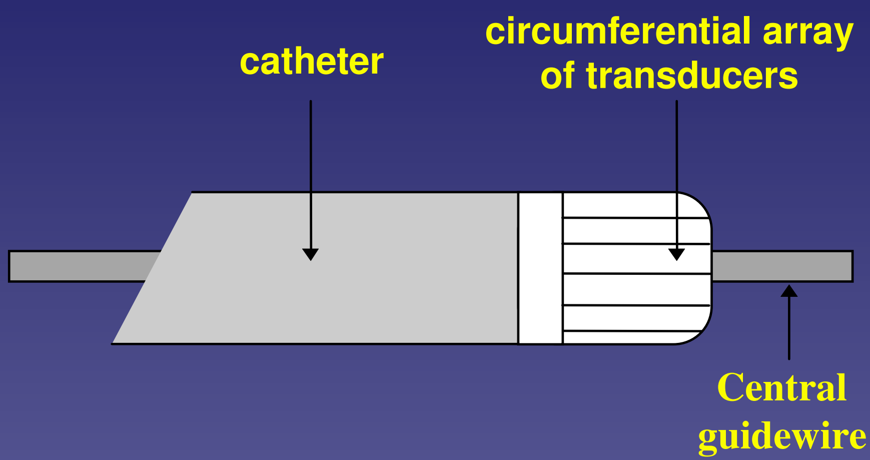
3. transducer

4. rotating mirror

- Electronically switched **phased circular array** catheter



64-element probe, Endosonics



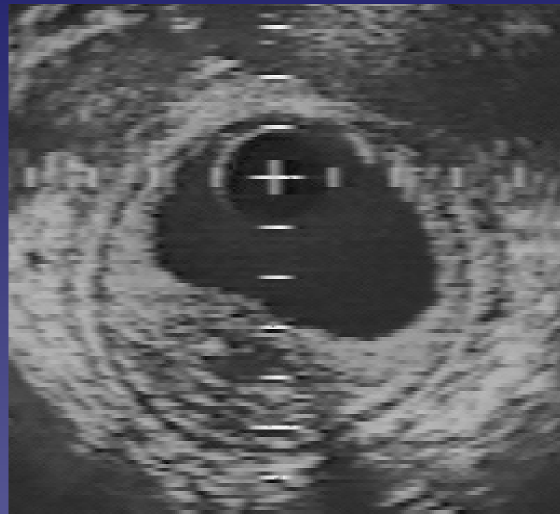
➯ ***Typical features***

catheter diameter : 1.2 mm (~4F)
elements number : 16, 32, 64 or 128

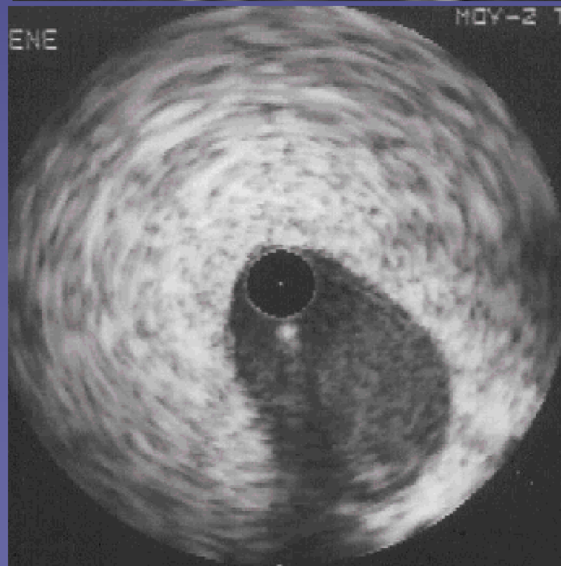
Bom N, Lancée CT, Van Egmond FC (1972) An ultrasonic intracardiac scanner. Ultrasonics 10

Geometric artefacts

- Geometric distortion are caused by the position of the ultrasound catheter within the artery

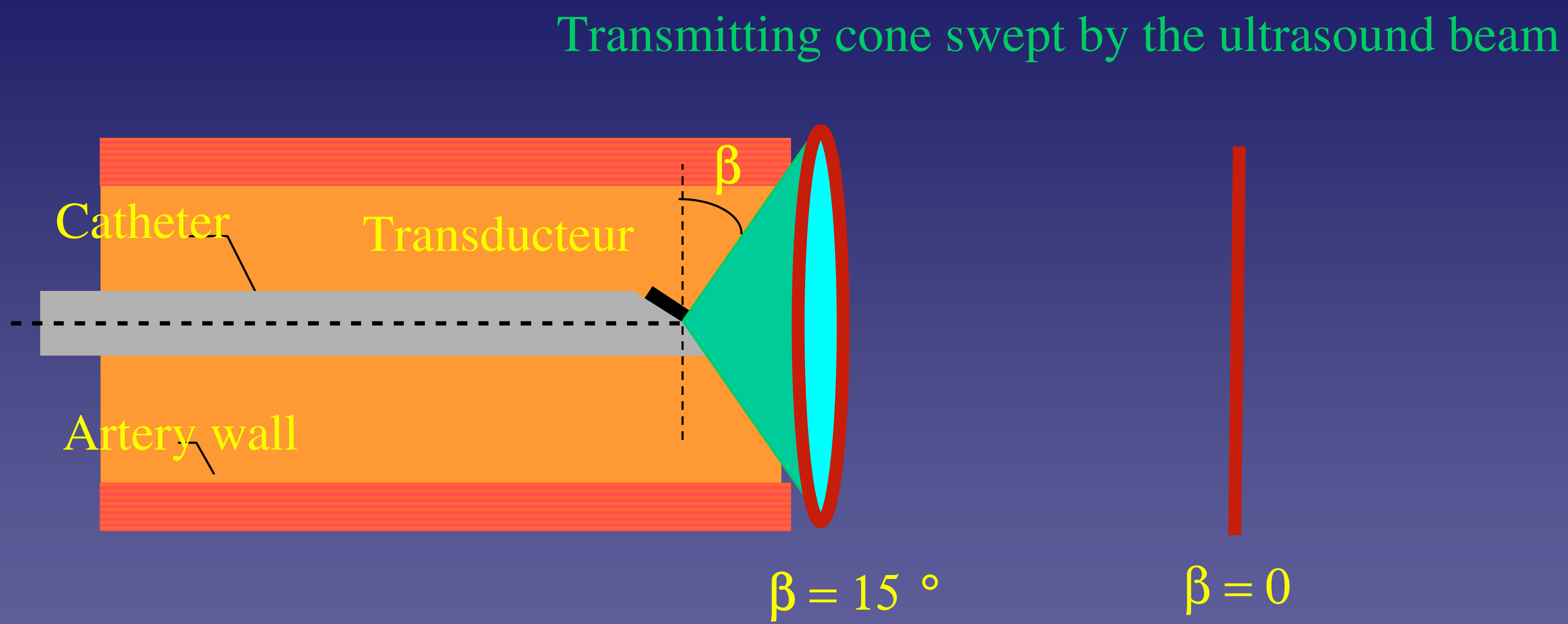


- A circular artery is seen on IVUS images as a noncircular vessel represented by more or less complex shapes



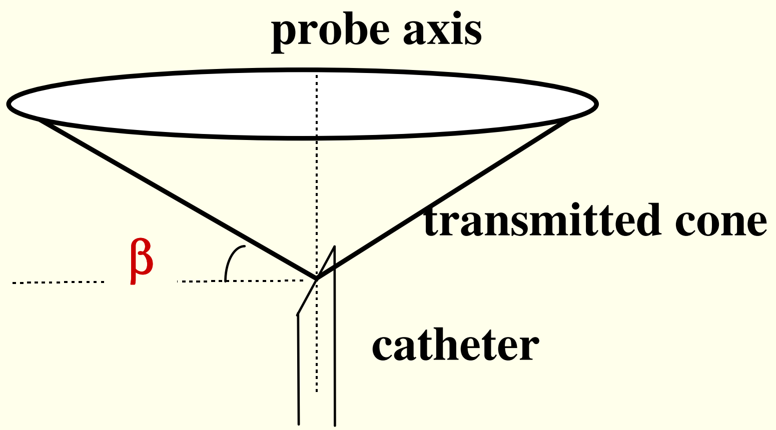
- The main distortions are due:
  - to the inclination of the catheter (its long axis is not coaxial the vessel axis), angle α
  - to the off centered position of the catheter (the axis catheter is not located on the axis of the vessel), δx and δy
- These artefacts are amplified by the geometry of the probe
  - the origin of the ultrasound beam is not the center of the catheter: ρ
  - the ultrasound beam looks forward (not perpendicular to the long axis of the catheter), angle β

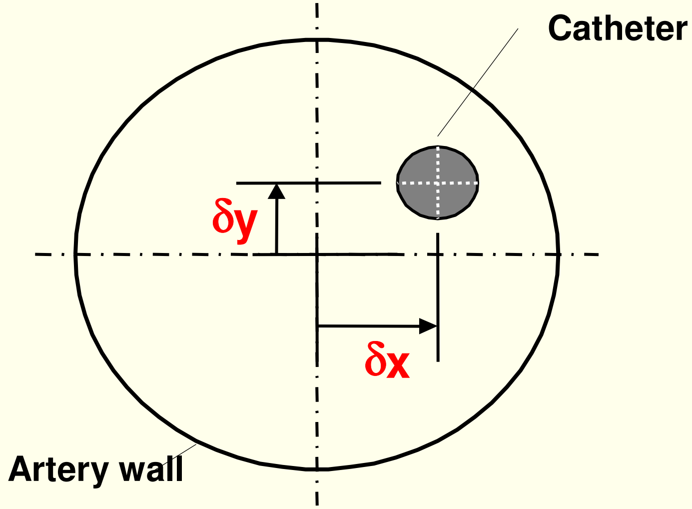
Forward inclination angle β

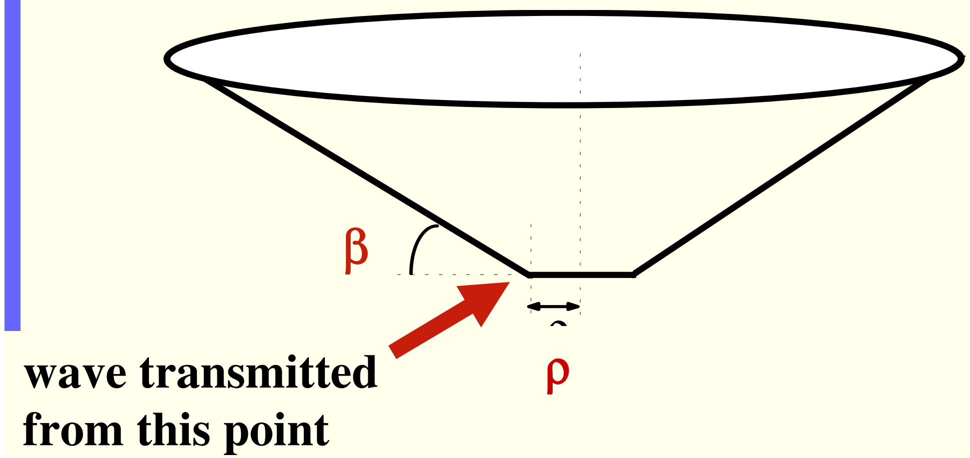


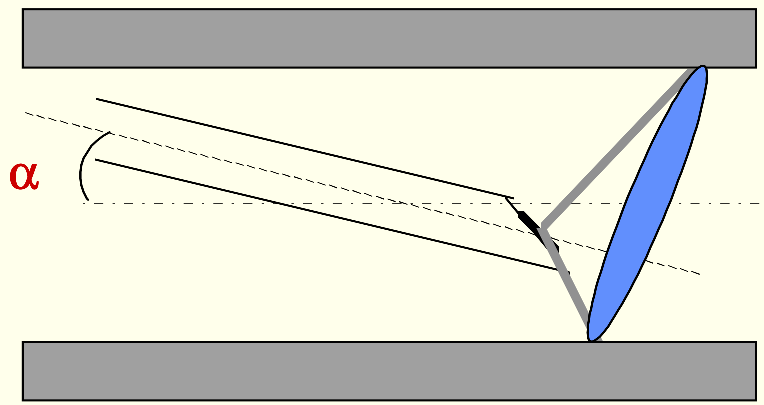
- The forward inclination of the piezoelectric element avoids direct reflection on the vessel wall and the multiple reflection. The scattering is reinforced

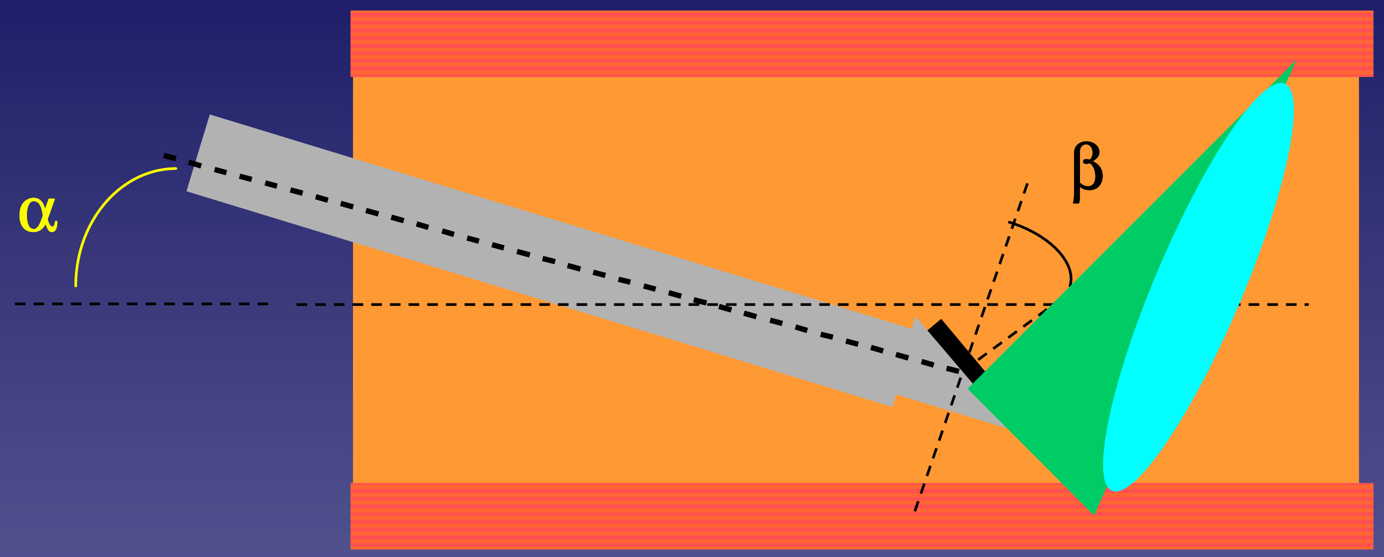
Four origins for geometric artefacts











combination:

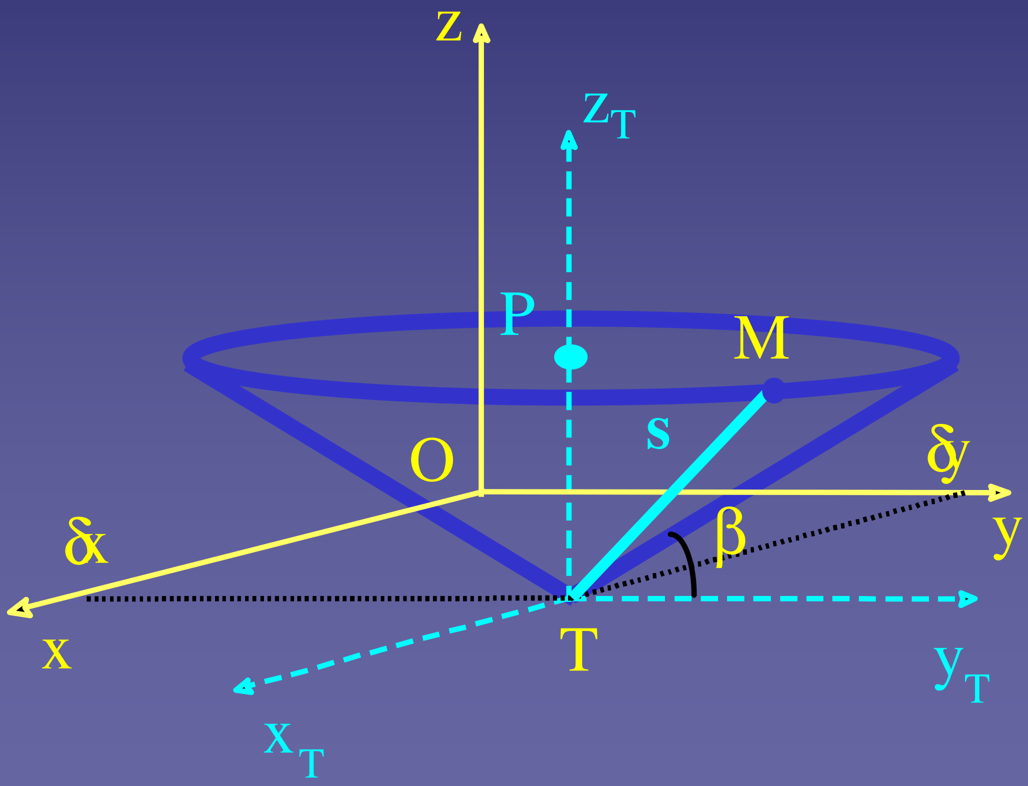
forward inclination angle β
inclination of the probe axis α,
off centered position δx et δy

Modelisation of the geometry

Reference coordinate system: R (O, x, y, z)

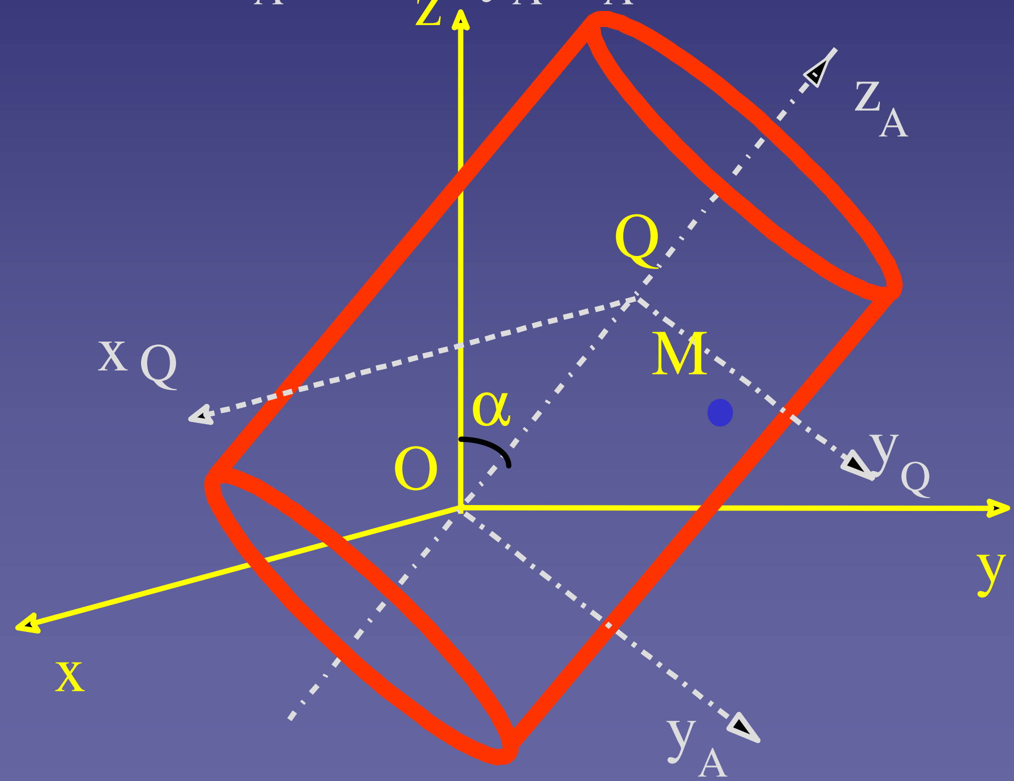
Probe coordinate système:

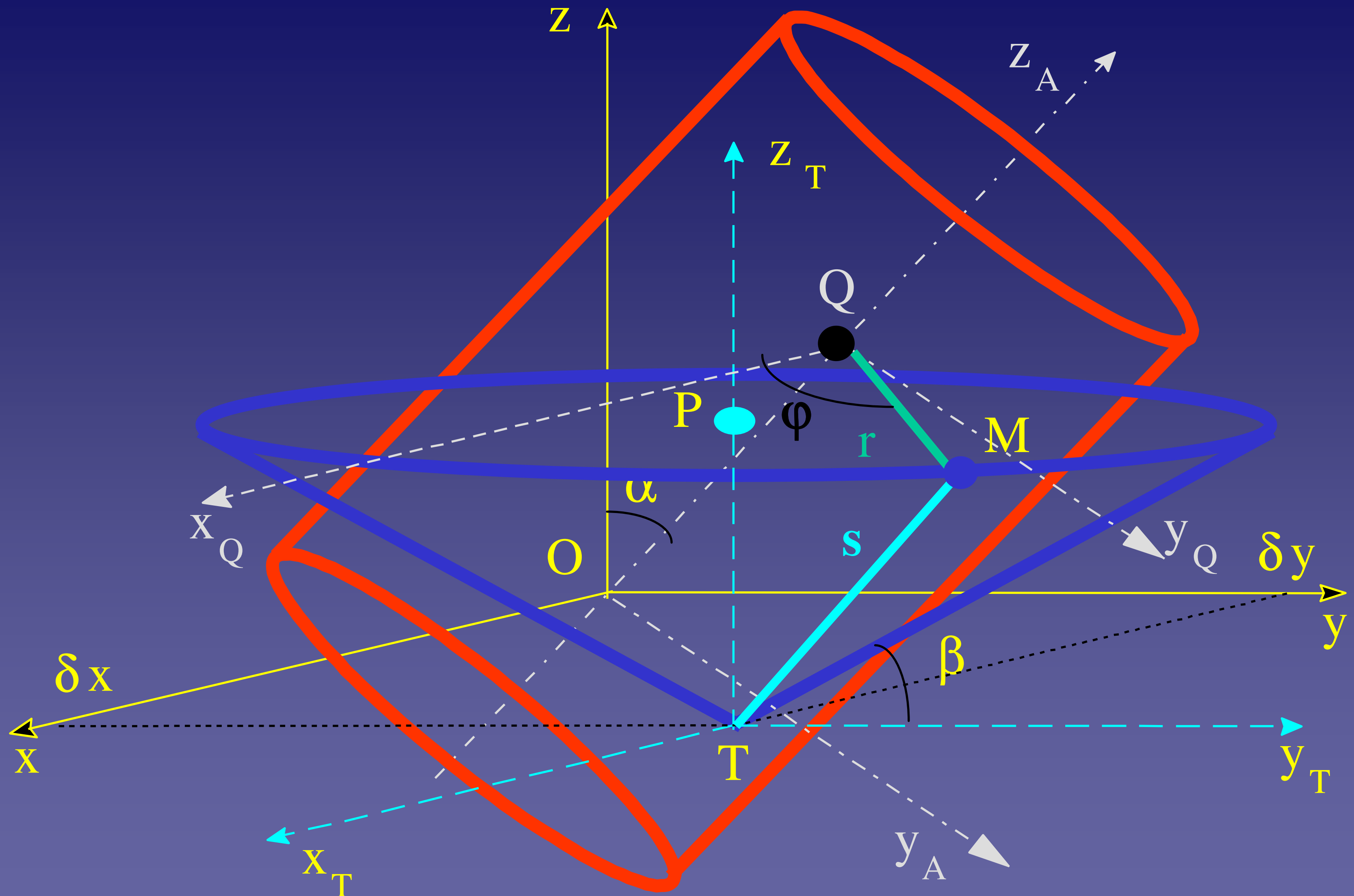
R_T (T, x_T, y_T, z_T)



Artery coordinate systeme:

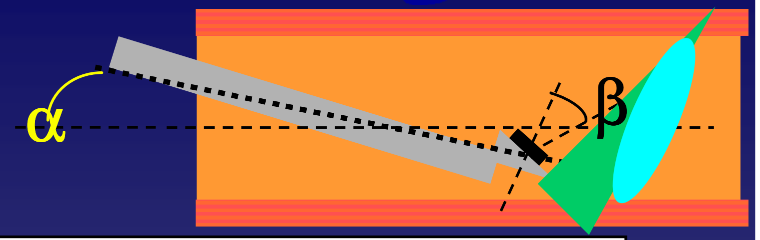
R_A (O, x, y_A, z_A)

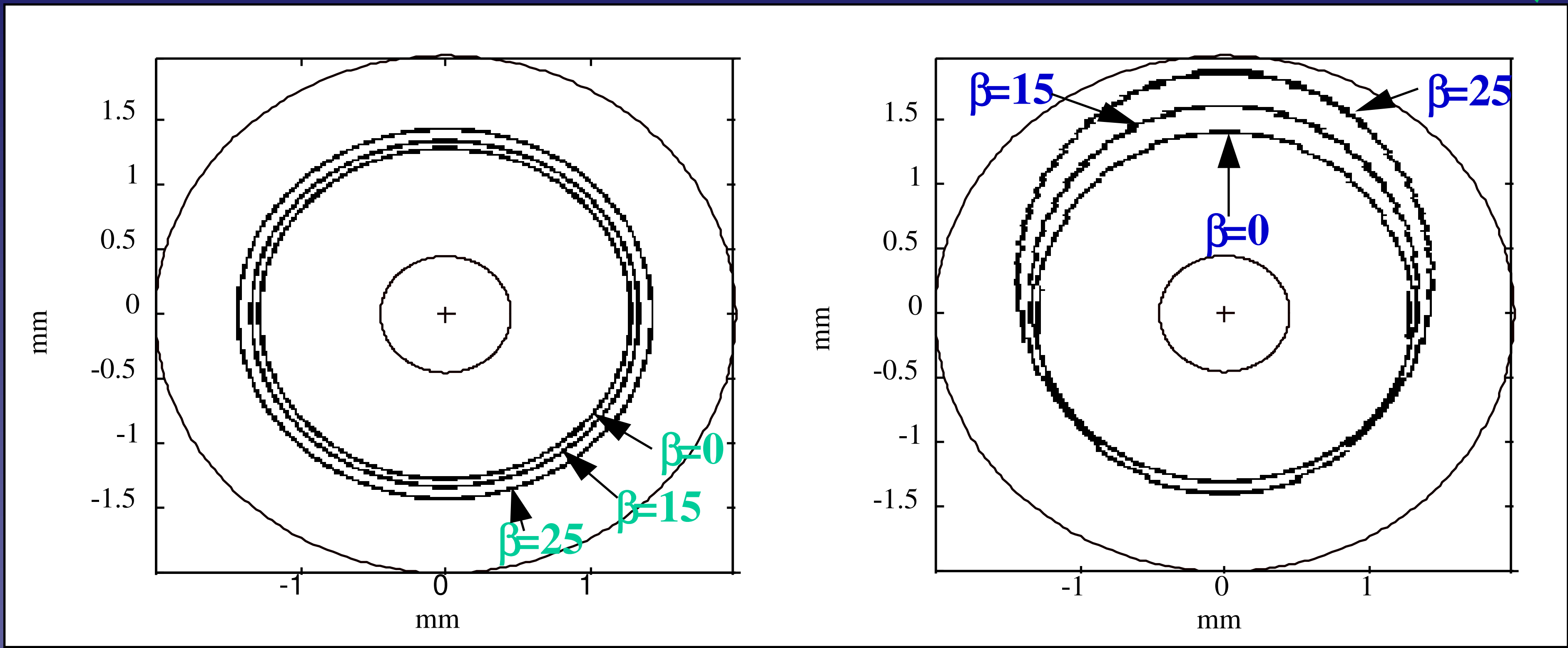




Delachartre P., Cachard C. and al., Ultrasound in Medicine and Biology, 1999, vol. 25

■forward inclination angle β





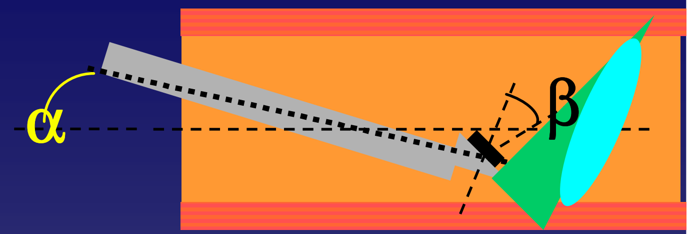
inclination $\alpha = 0$

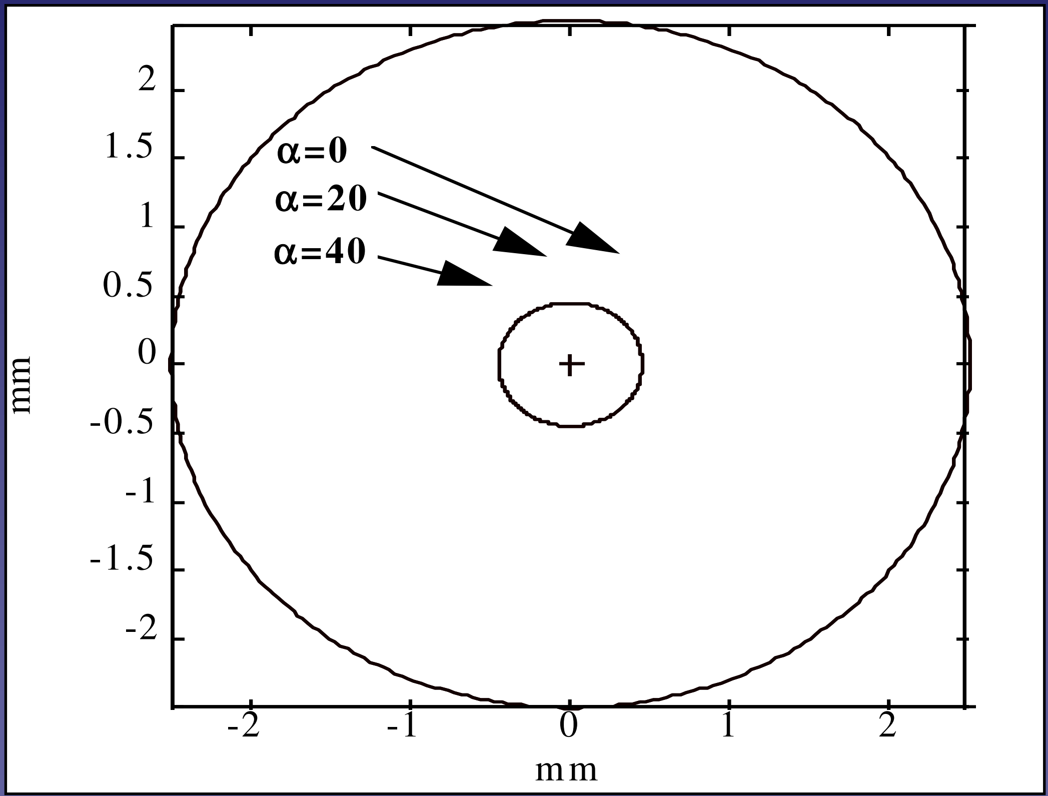
inclination $\alpha = 20°$

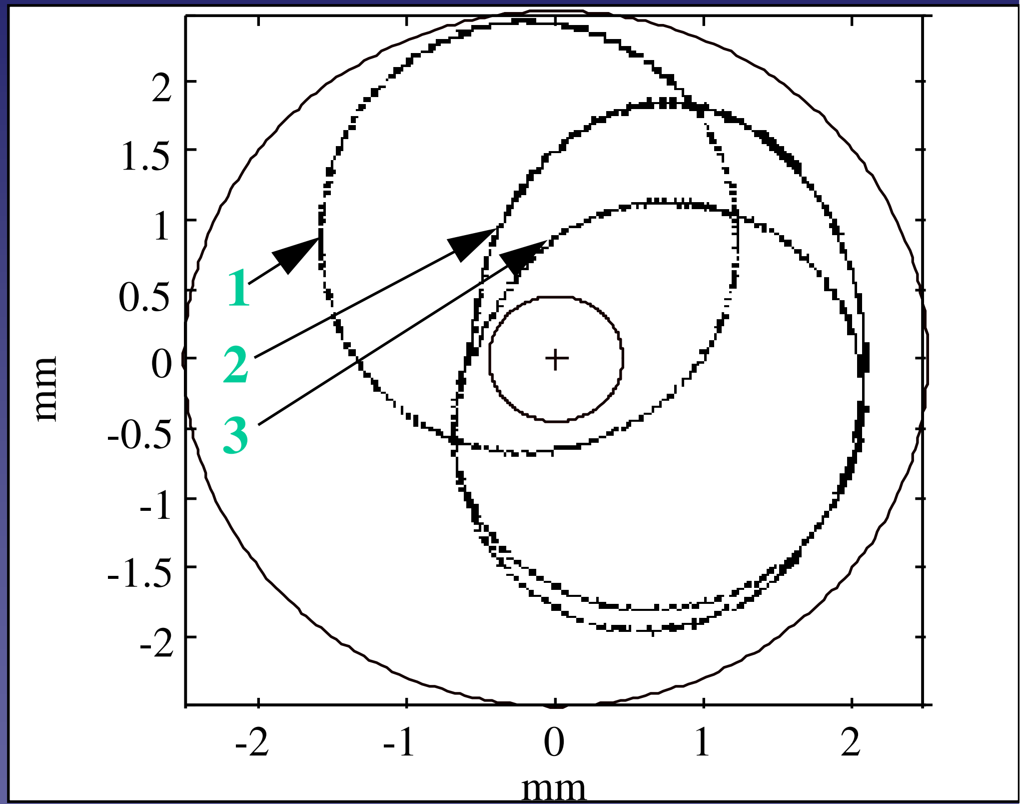
off centered position $\delta x = 0$ mm, $\delta y = 0$ mm

off axis of transmition point $\rho = 0.4$ mm

- Inclination of the catheter axis: α



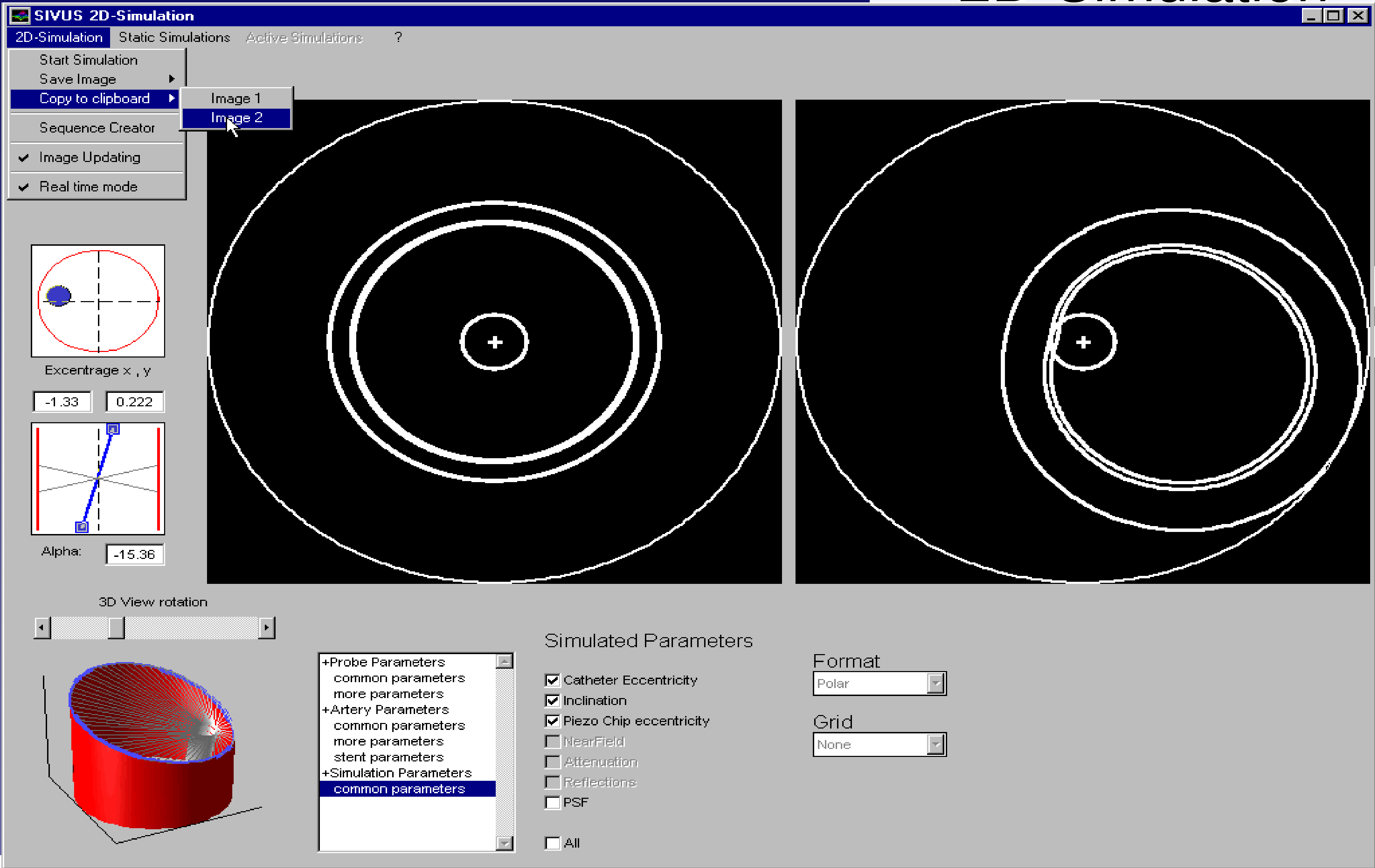




δx = - 0.7 mm, δy = 0.5 mm
β = 15°
ρ = 0.4 mm

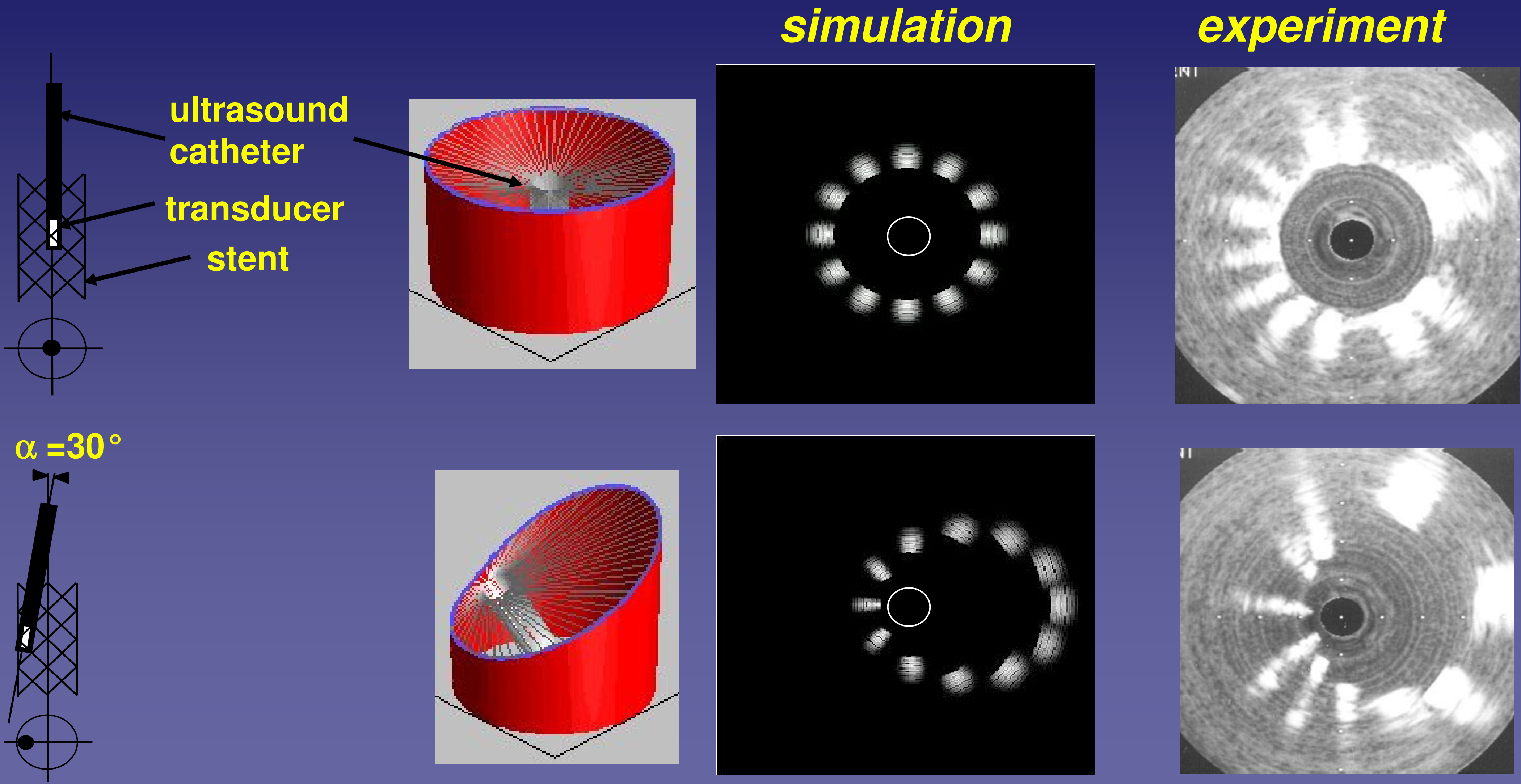
1 : α = 20°, δx = 0.2 et δy = - 0.7;
2 : α = 40°, δx = - 0.7 et δy = 0.5;
3 : α = 20°, δx = - 0.7 et δy = 0.5
(β=15° et ρ = 0.4 mm).

2D-Simulation

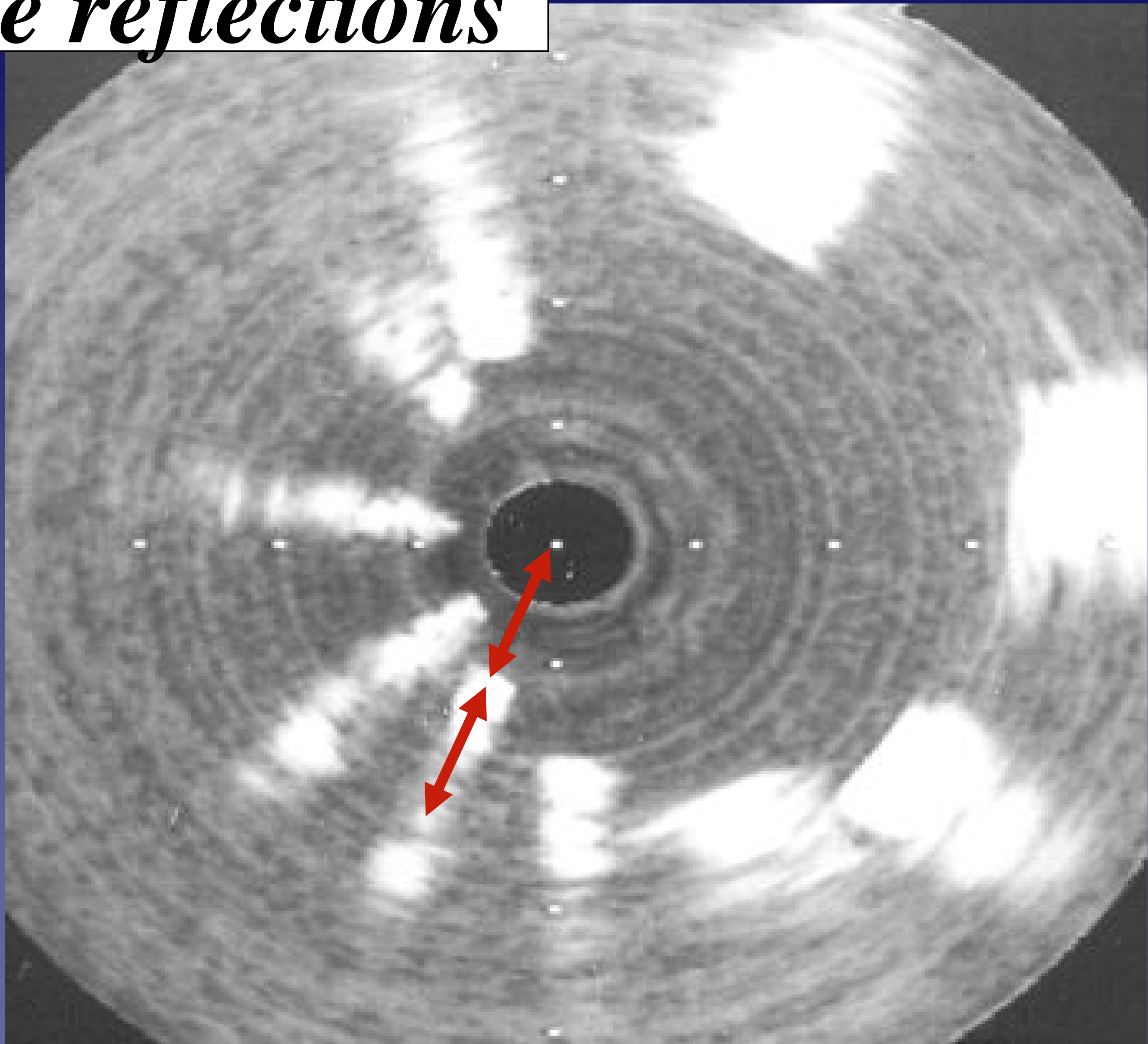


Screen capture

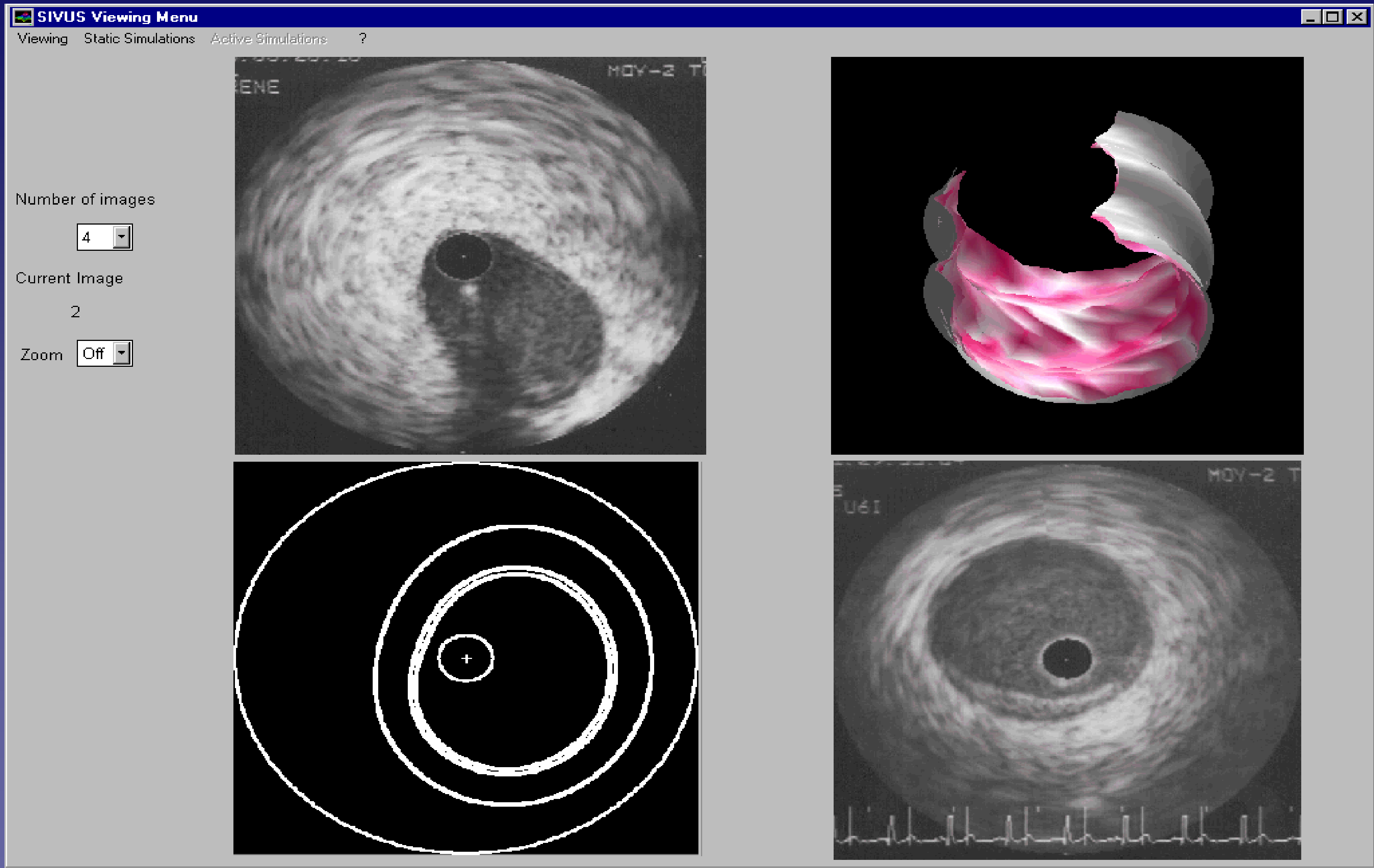
Geometric artifacts



Multiple reflections



Viewing

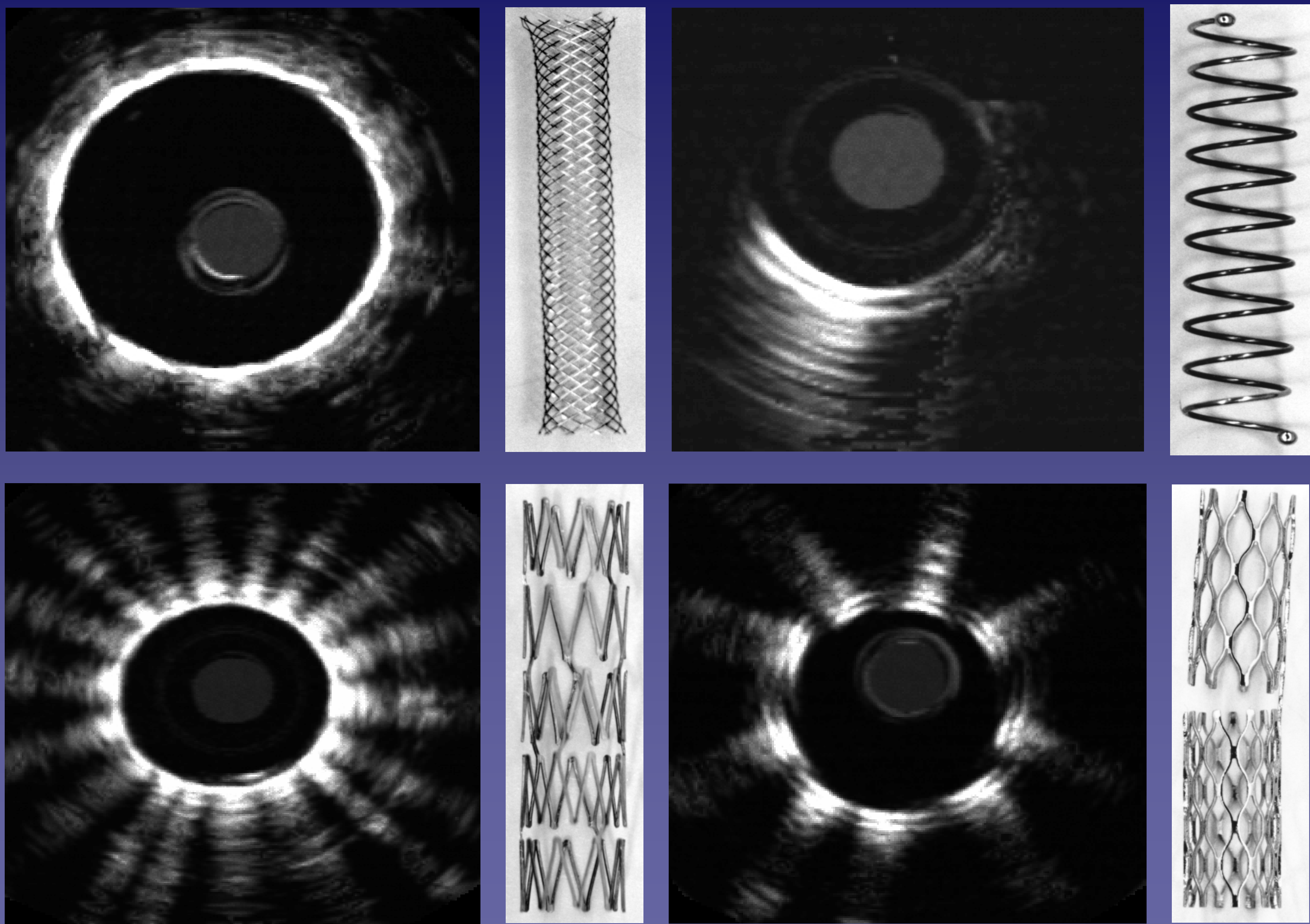


Screen capture

IVUS in the clinic

Thoraxcentre
Rotterdam

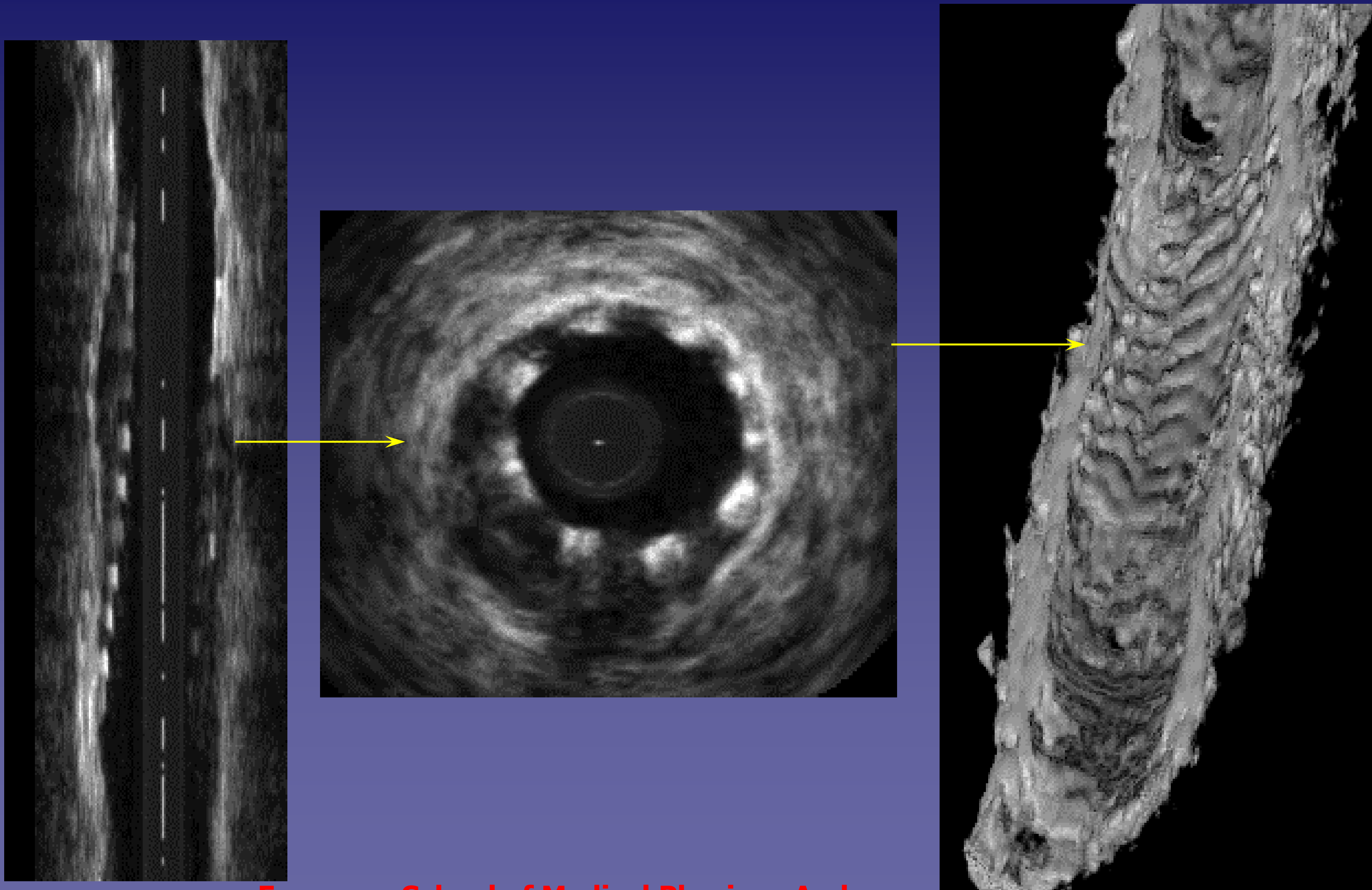
ICUS appearances of Coronary Stents



NB

Wallstent / Acute result II

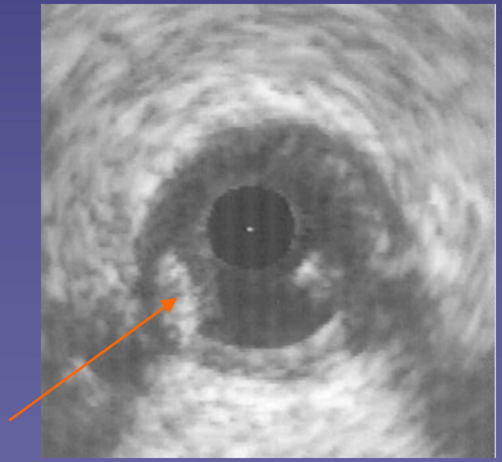
Thoraxcentre
Rotterdam



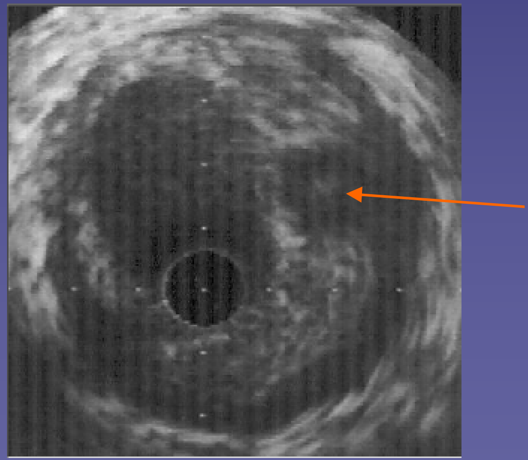
N. Bruining
Wallstent/acute II

Plaque

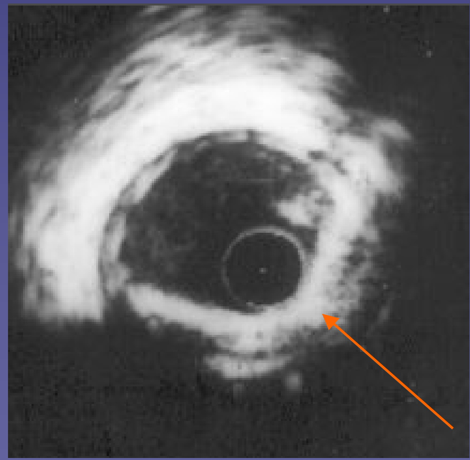
Calcified component
Hyper-reflectivity following by shadowing



Cell component
(blood, lipidic, inflammatory cells)
~ no reflectivity



Fibrous component
hypo or hyper reflec-tivity (collagen density)



Hyaline fibrosis

⚠ *Possible misinterpretations*

Quantifying plaque volume

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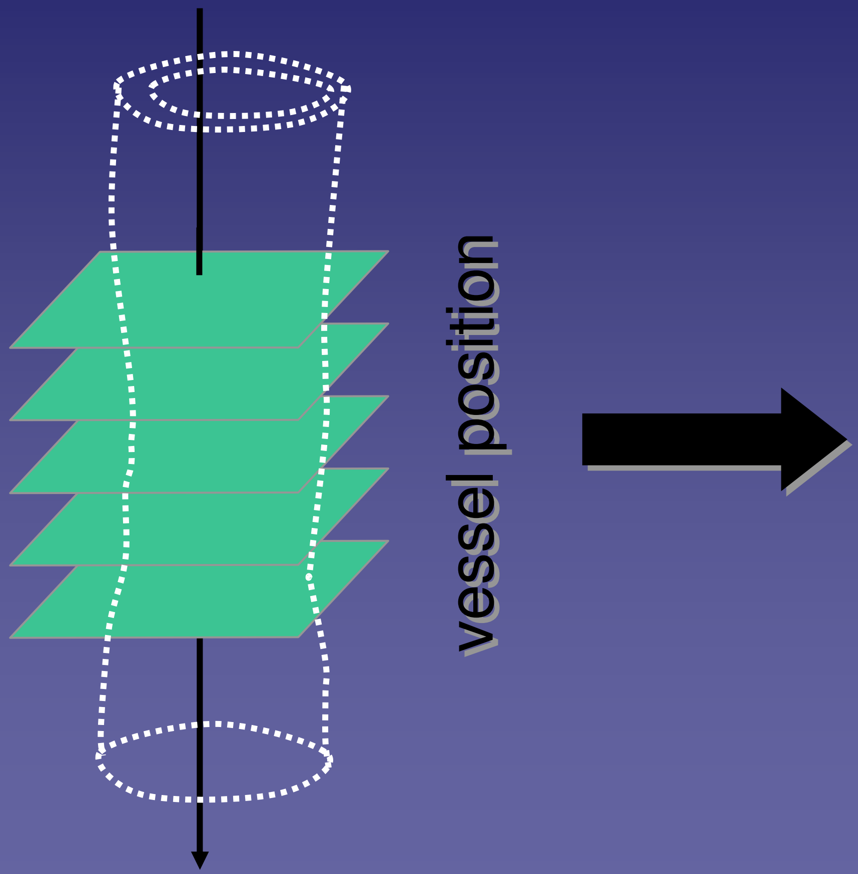
Three-Dimensional Data Acquisition



The probe is pulled out

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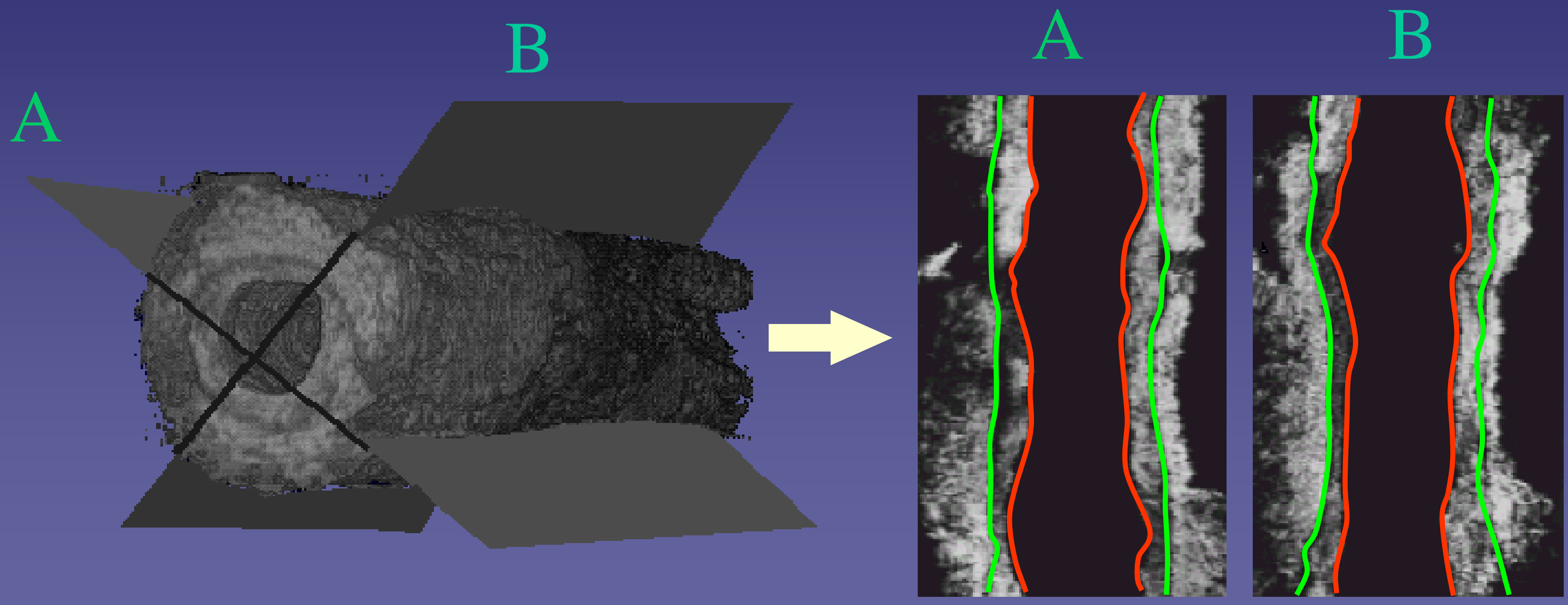
Longitudinal Contour Detection



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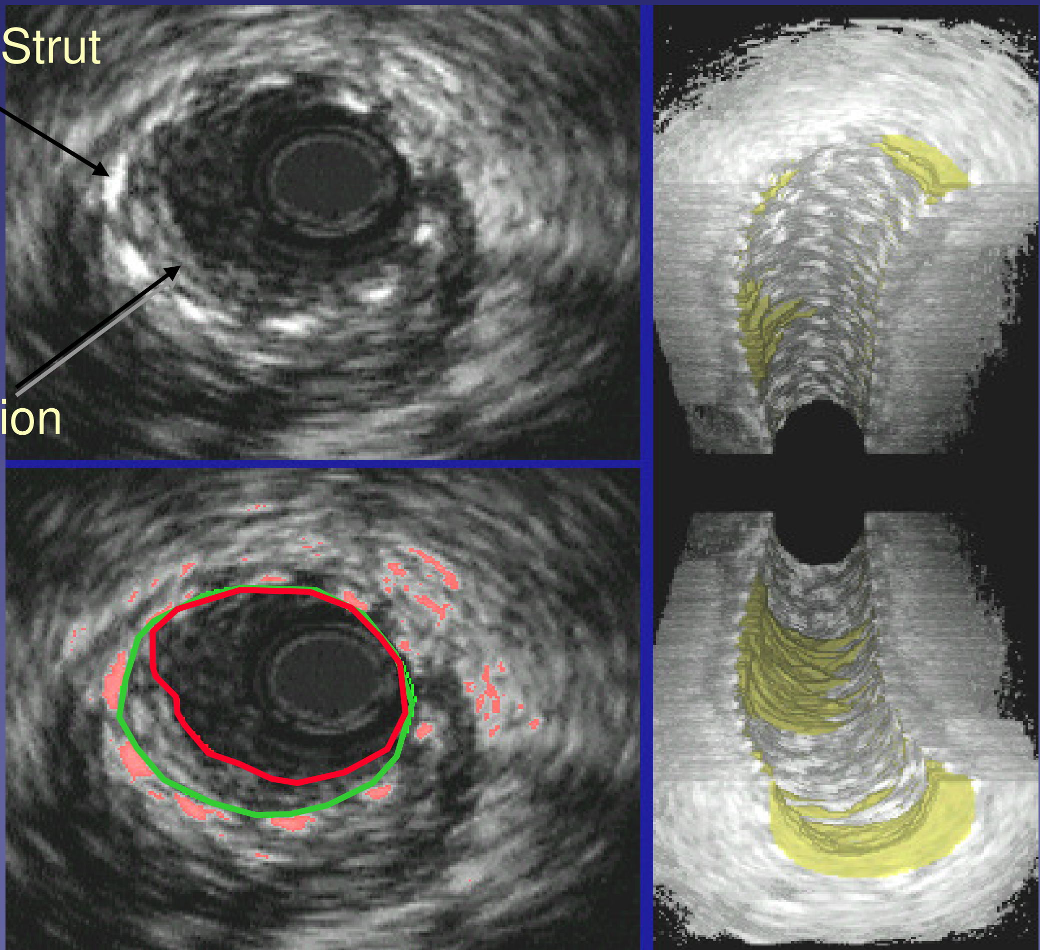
In-stent Restenosis Assessed with 3D IVUS

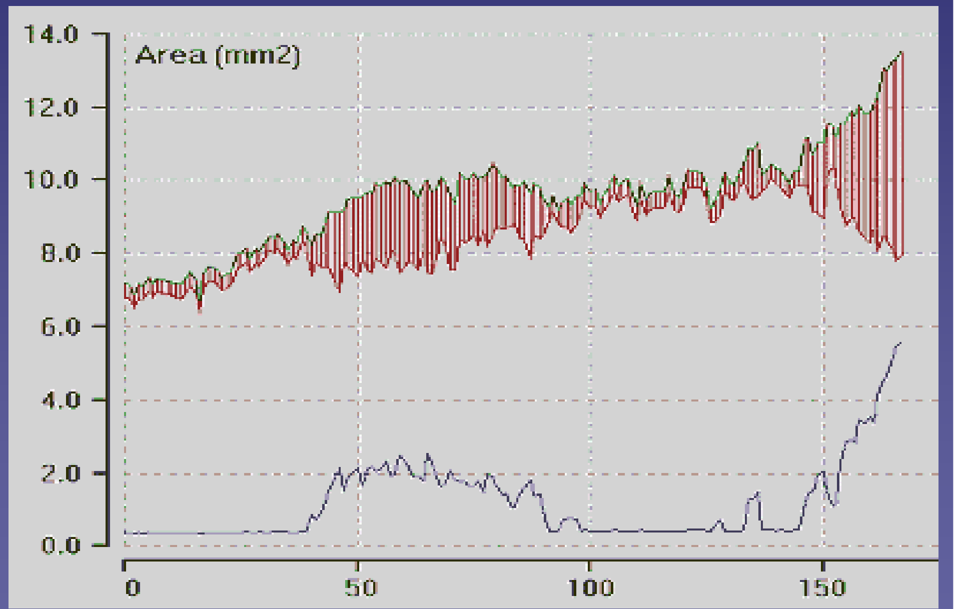
Stent Strut

Lesion



DuMed

Lumen, Stent and Lesion Areas

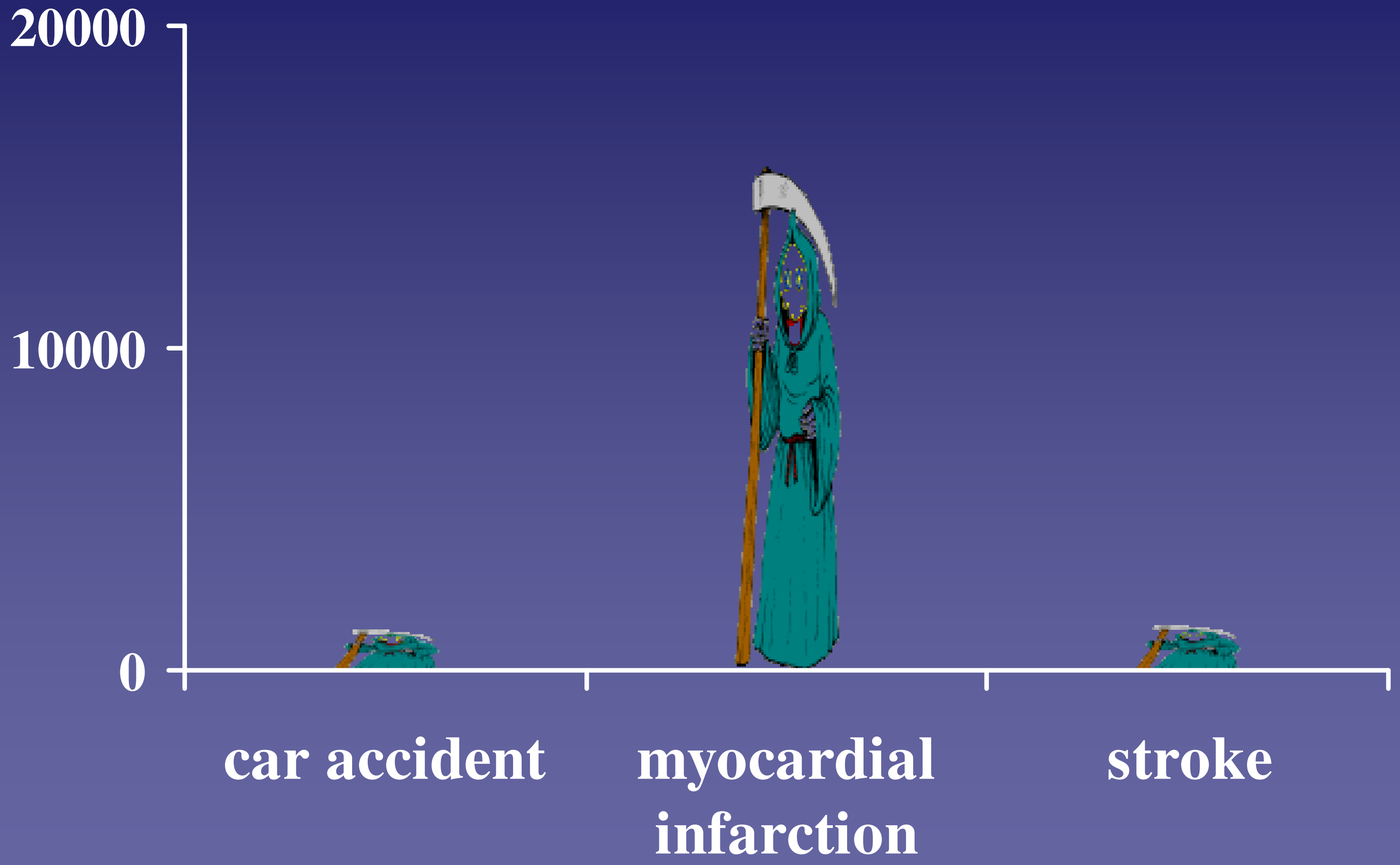


Lesion Volume: 24.85 mm^3

Li et al. 1994-1997

Vulnerabele Plaque Characterization

Mortality per annum
The Netherlands

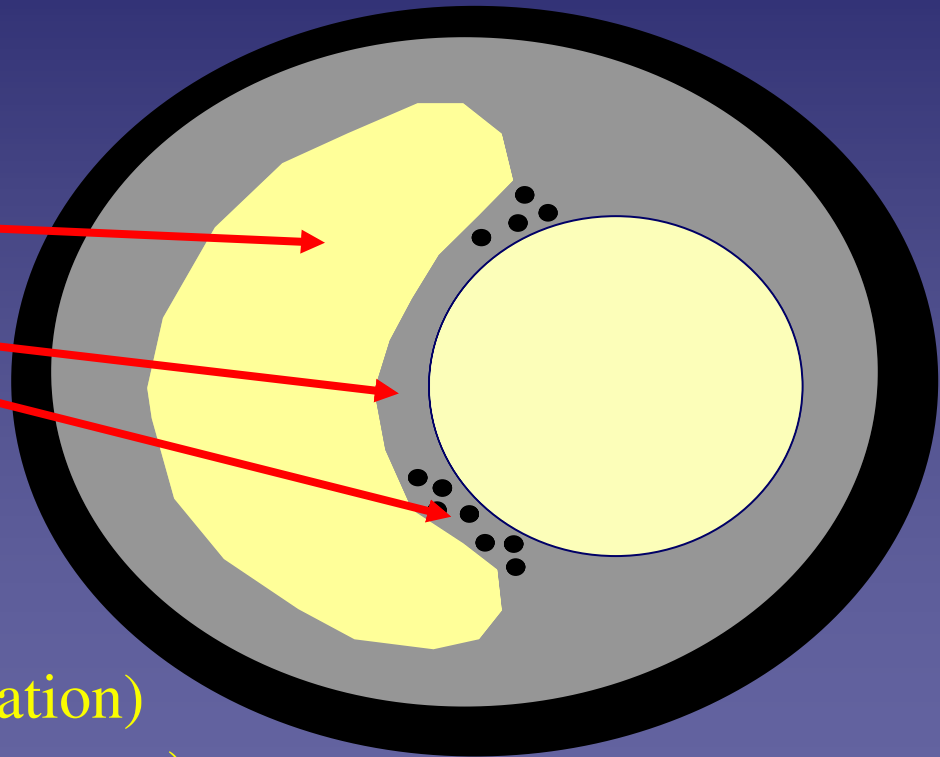


http://cvdinfobase.ic.gc.ca/gcvi/default.htm
www.cbs.nl

Vulnerable Plaque

Plaque composition

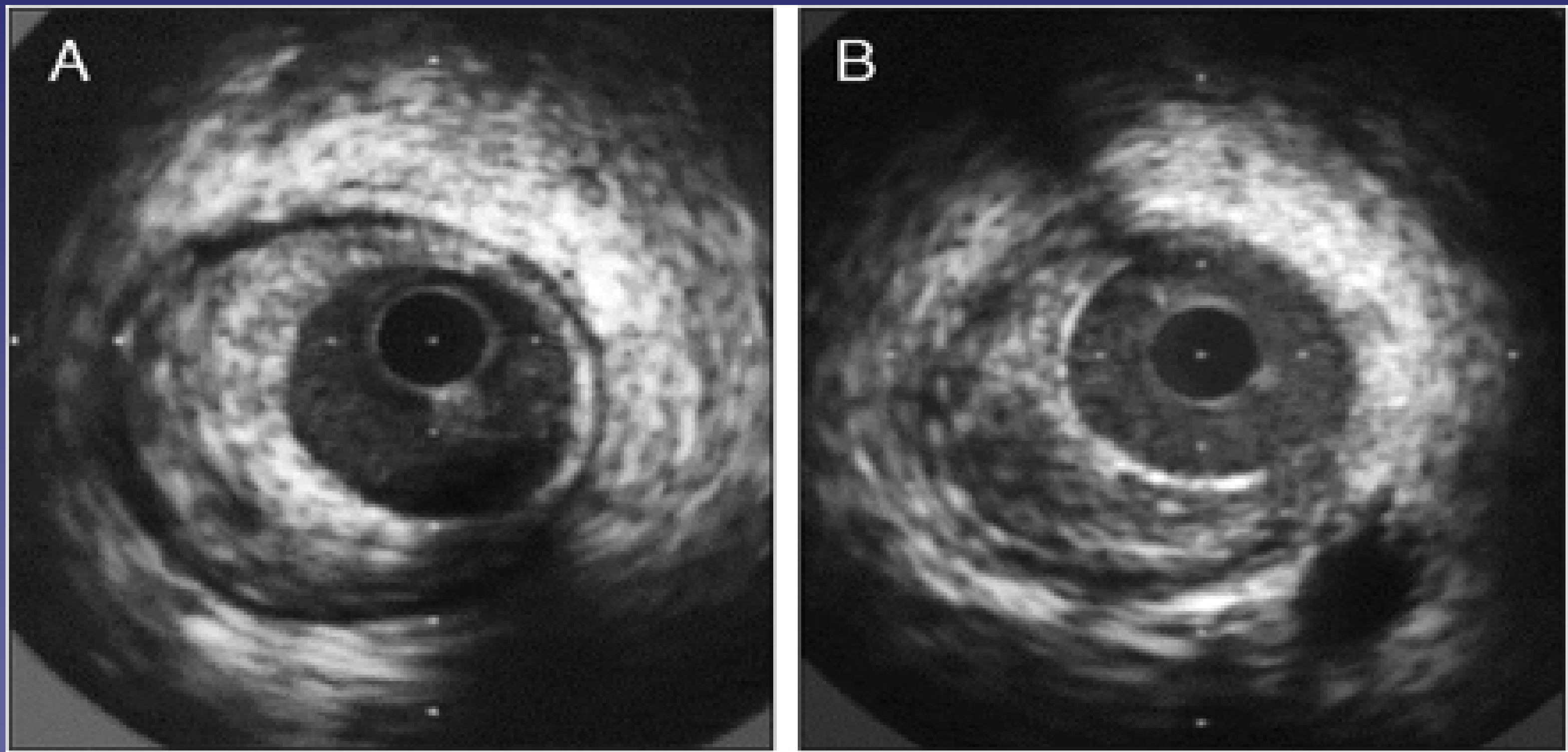
- Large lipid pool
- Thin fibrous cap
- presence of Macrophages



The challenge:

- % of the lipid core (tissue characterization)
- metabolism, inflammation (pH, temperature)
- thickness of the cap (range = 0 – 200 µm)
- stability of the cap (strain)

Vulnerable plaque with IVUS



Boston Scientific

Nissen & Yock Circ 2001;103:604-616

IVUS diagnostic modality under investigation

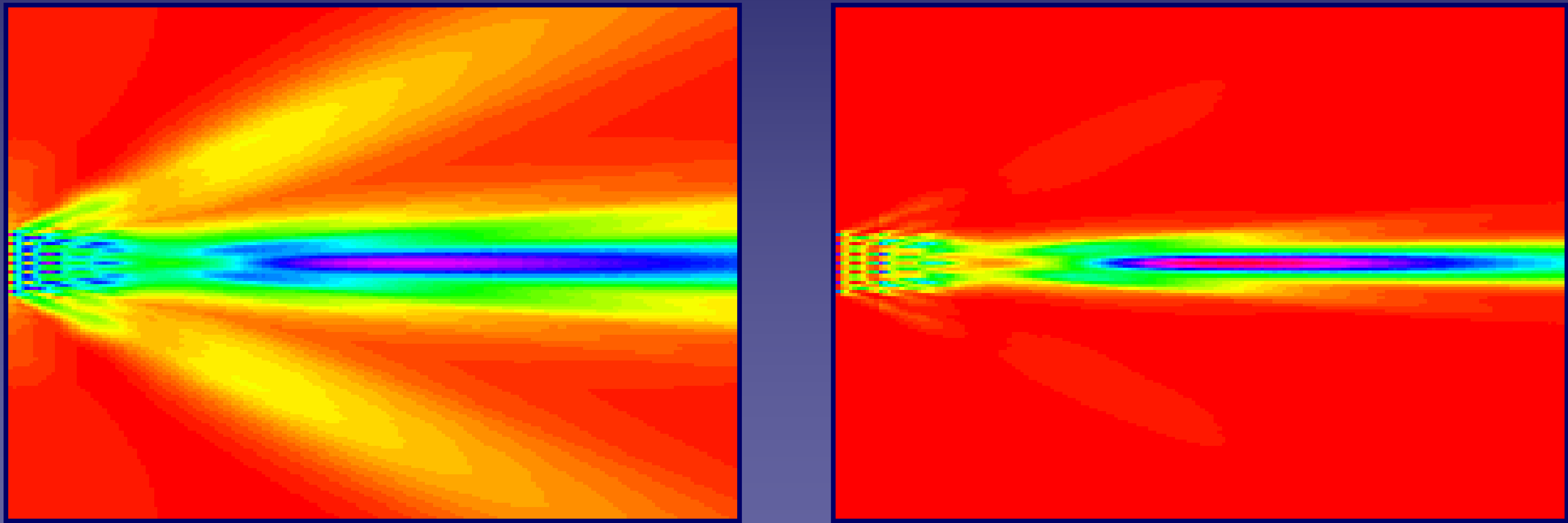
- Elastography and Palpography
- Harmonics
- Thermography
- Modulography
- Contrast agents

IVUS diagnostic modality under investigation

- Elastography and Palpography
- Harmonics
- Contrast agents
- Thermography
- Modulography

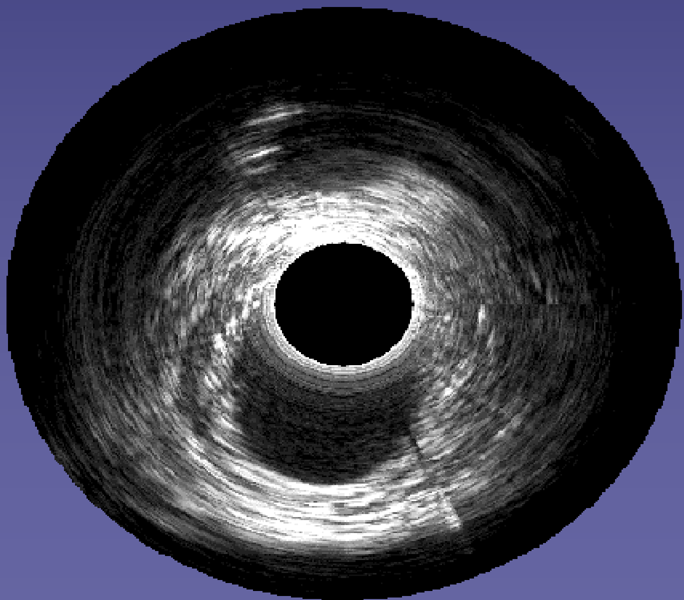
Harmonic Imaging

Fundamental | Second harmonic

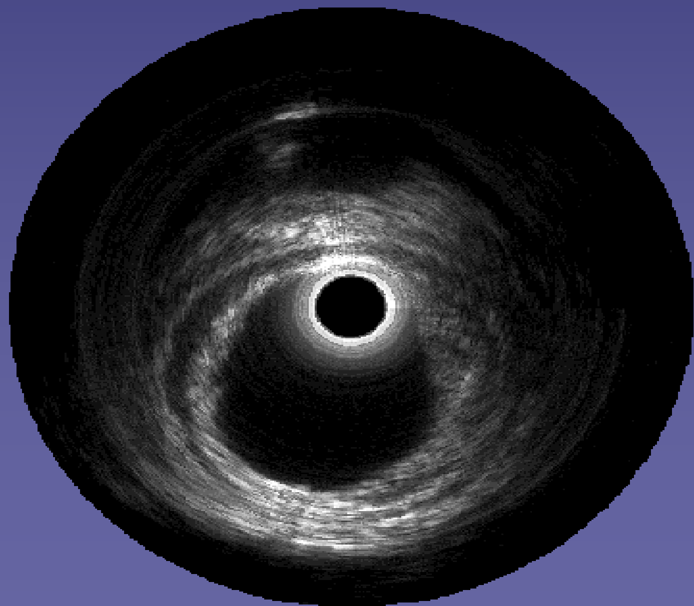


- A pilot study in Toronto (A.F.W. van der Steen et al., 1999) showed already the feasibility of Harmonic Imaging at higher frequencies.

Fundamental 20 MHz



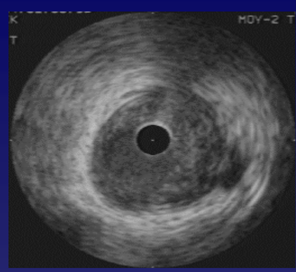
Harmonic 40 MHz

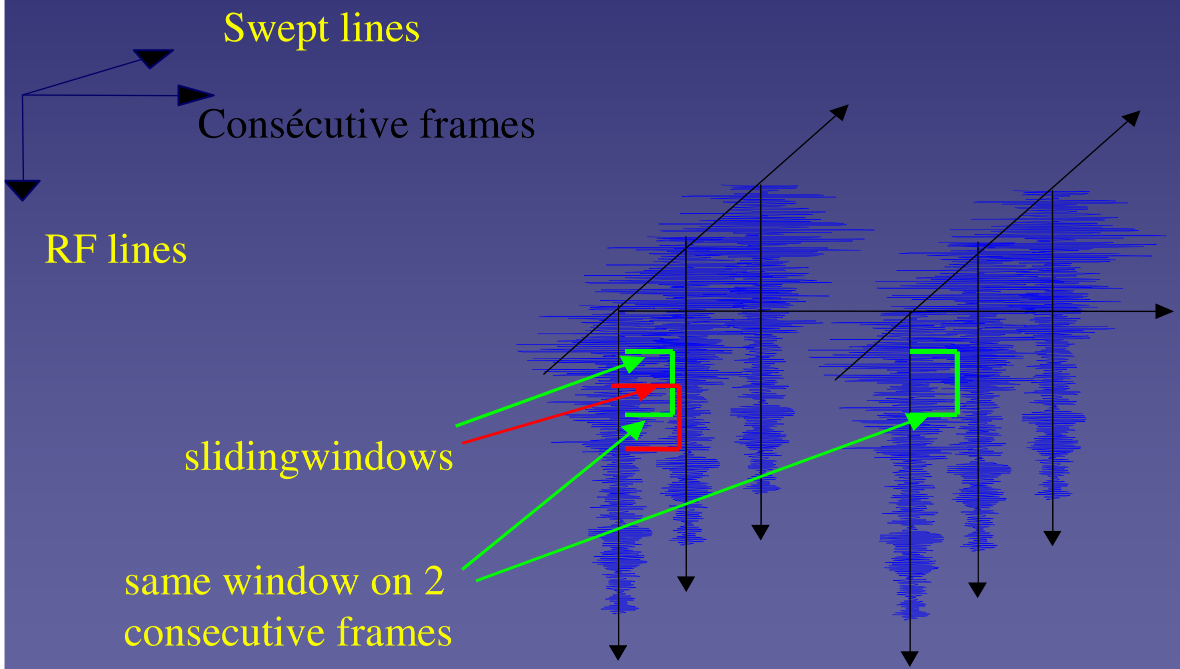


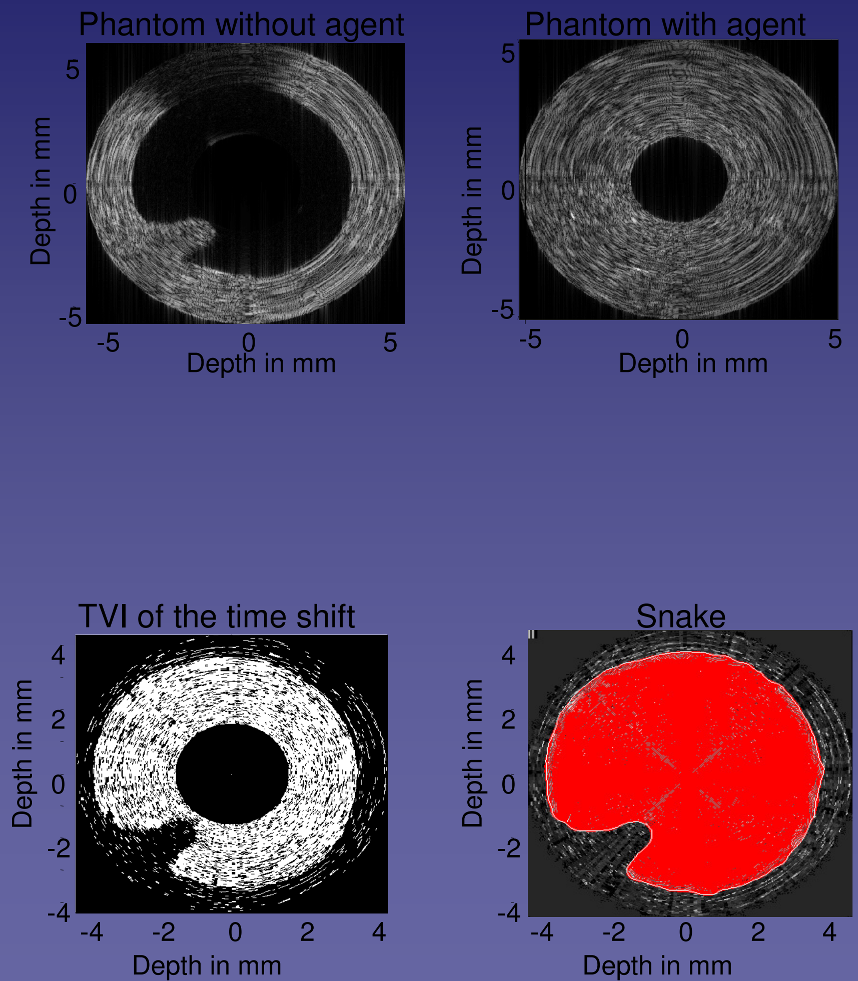
IVUS diagnostic modality under investigation

- Elastography and Palpography
- Harmonics
- Contrast agents
- Thermography
- Modulography

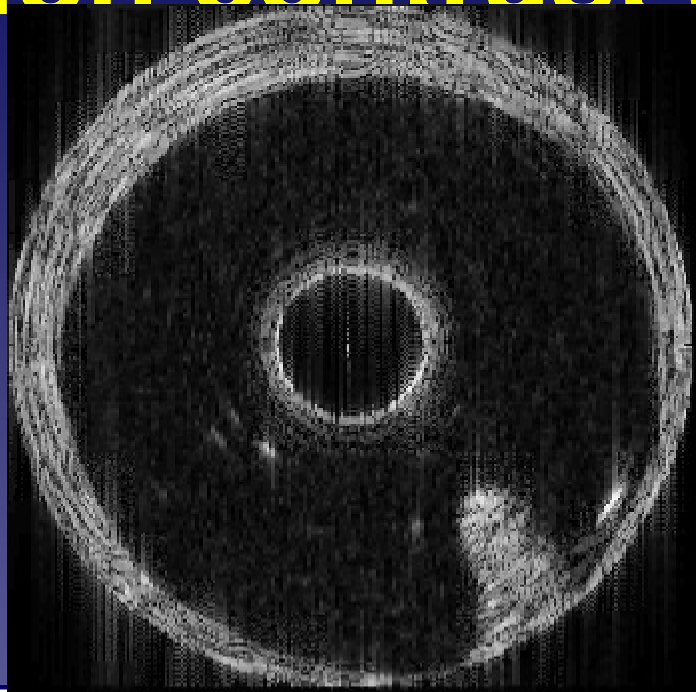
ULTRASOUND CONTRAST AGENT IN INTRAVASCULAR ECHOGRAPHY:
Parametric mapping based on RF output

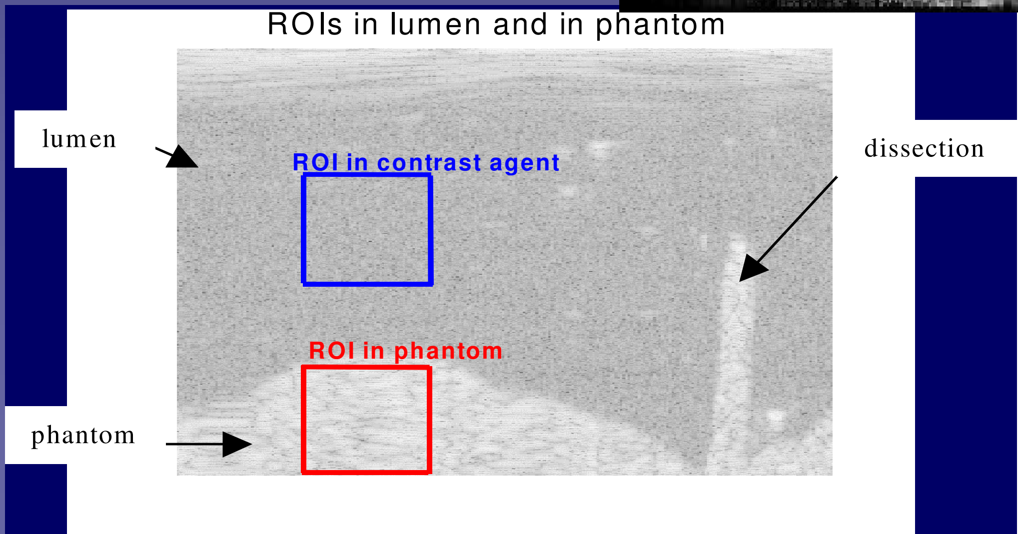


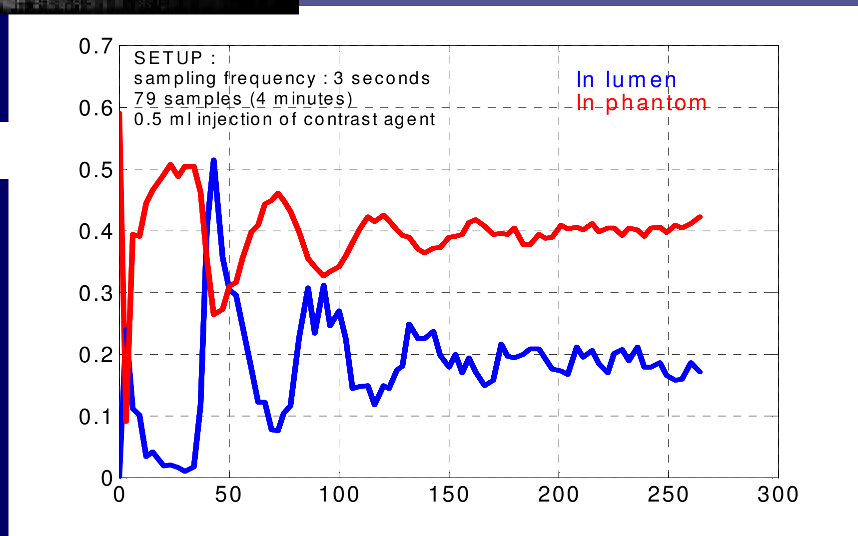




Injection contrast agent







Conclusions

IVUS can provide the answer to all relevant diagnostic problems and therapy guidance related to atherosclerosis and restenosis

IVUS

What it is good at

- Tomographic imaging
- Free lumen assessment
- Plaque burden assessment
- Qualitative flow imaging
- Therapy guidance:
  - PTCA
  - Stent
  - Brachytherapy

What it is not yet good at

- Plaque characterization
- Vulnerable plaque detection
- For moderate stenosis: "Should I treat it or not?"
- Quantitative flow measurement
- Shear stress measurement

Future of intravascular

- Obtain more parameters

  wall characteristics

  perfusion data

- Combine with therapy and other modalities

- Make it less expensive

Aknowledgement/coworkers

Erasmus MC, Rotterdam

- Ton van der Steen
- Charles Lancee
- Nico de Jong
- Jolanda Wenzel
- Dave Goertz
- Martijn frijlink
- Antoinette ten Have
- Frits Mastik
- Chris de Korte
- Peter Burns
- Peter Frinking
- Jos Roelandt
- Folkert ten Cate
- Rob Krams
- Patrick Serruys

CREATIS, Lyon

- Gerard Finet
- Philippe Delacharte
- Elisabeth Brusseau

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