IEEE Ultrasonic symposium 2002

Short Course 6: Flow Measurements

Hans Torp
Department of Circulation and Medical Imaging
NTNU, Norway

Internet-site for short course:
http://www.ifbt.ntnu.no/~hanst/flowmeas02/index.html

Lecture 1: Introduction

Flow measurements
Introduction

- Course overview. Browsing the website
- Doppler Techniques for blood flow measurements
- Flow versus velocity measurements. Non-Doppler methods
- Examples on clinical applications

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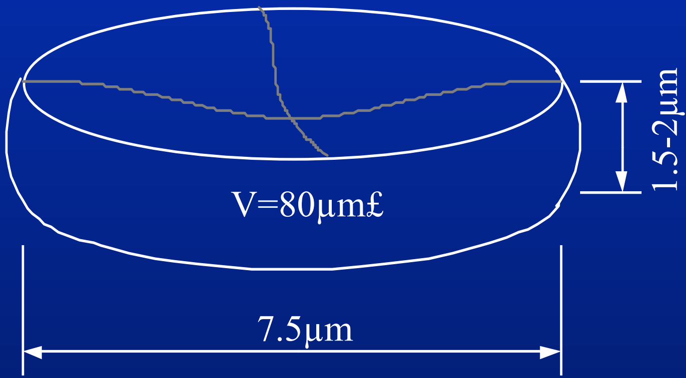
Red blood cells is hardly visible in the ultrasound image



Red blood cell

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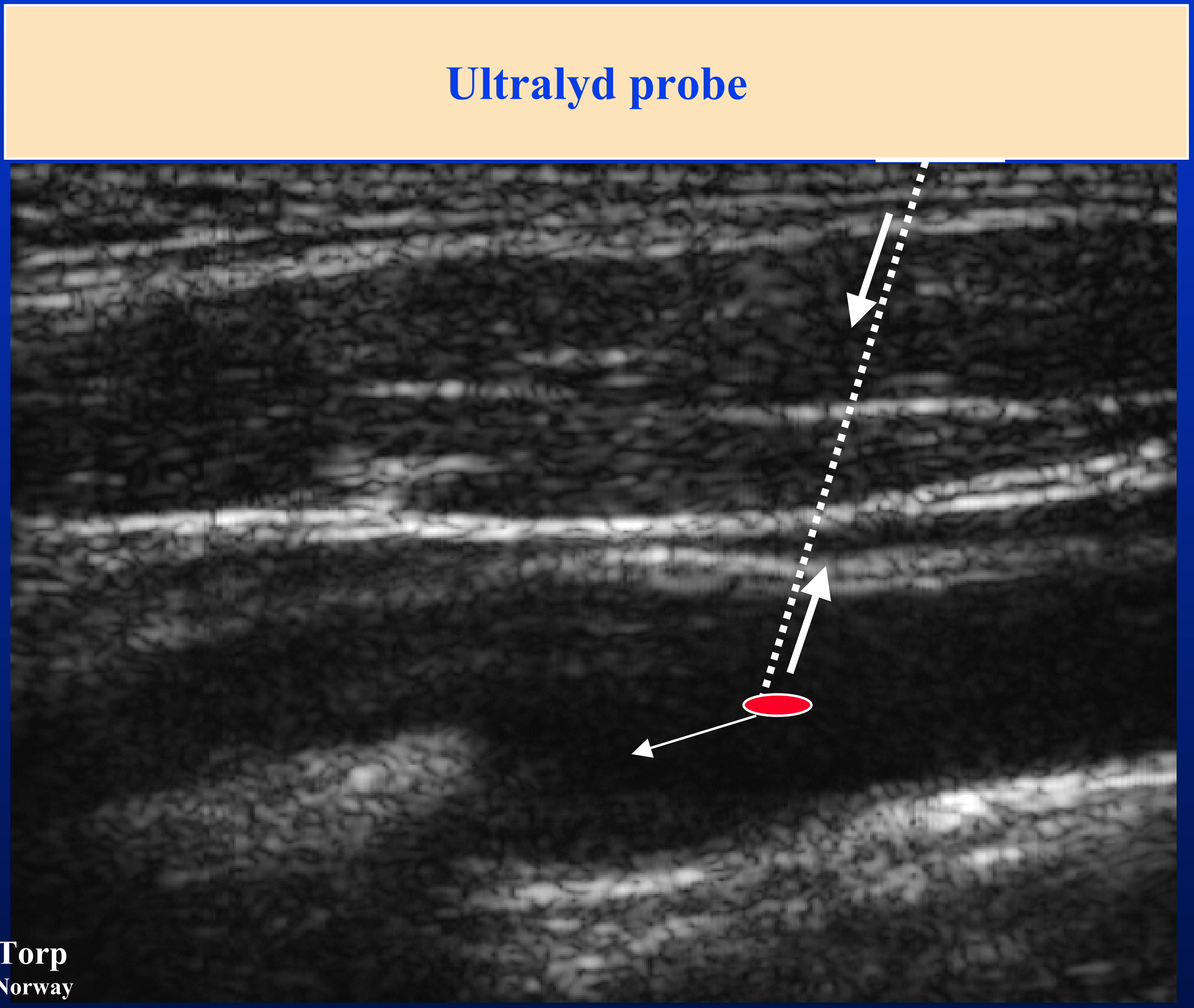
Ultrasound Doppler



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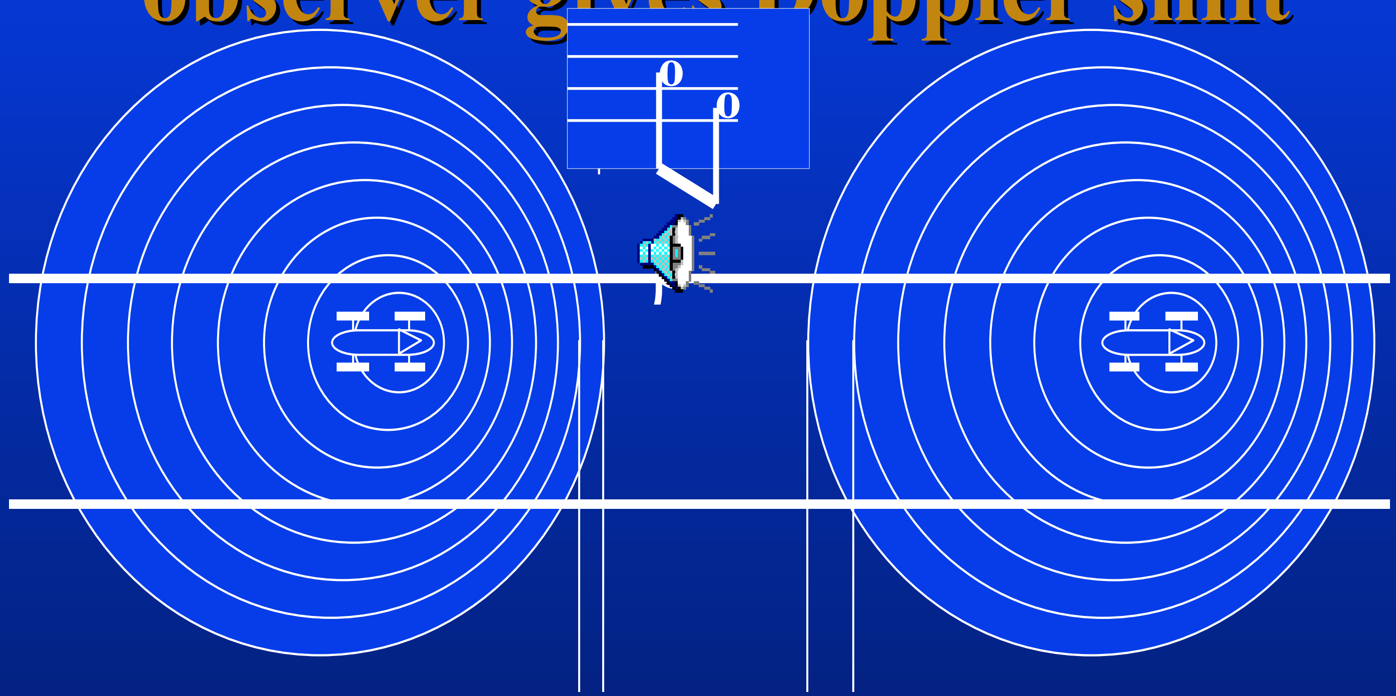
Velocity between sound source and observer gives Doppler shift



Example:

Car speed: 70 km/h ~ 6% of c (speed of sound 340 m/s)

Reduction in pitch: 12 % ~ 2 half tone-interval

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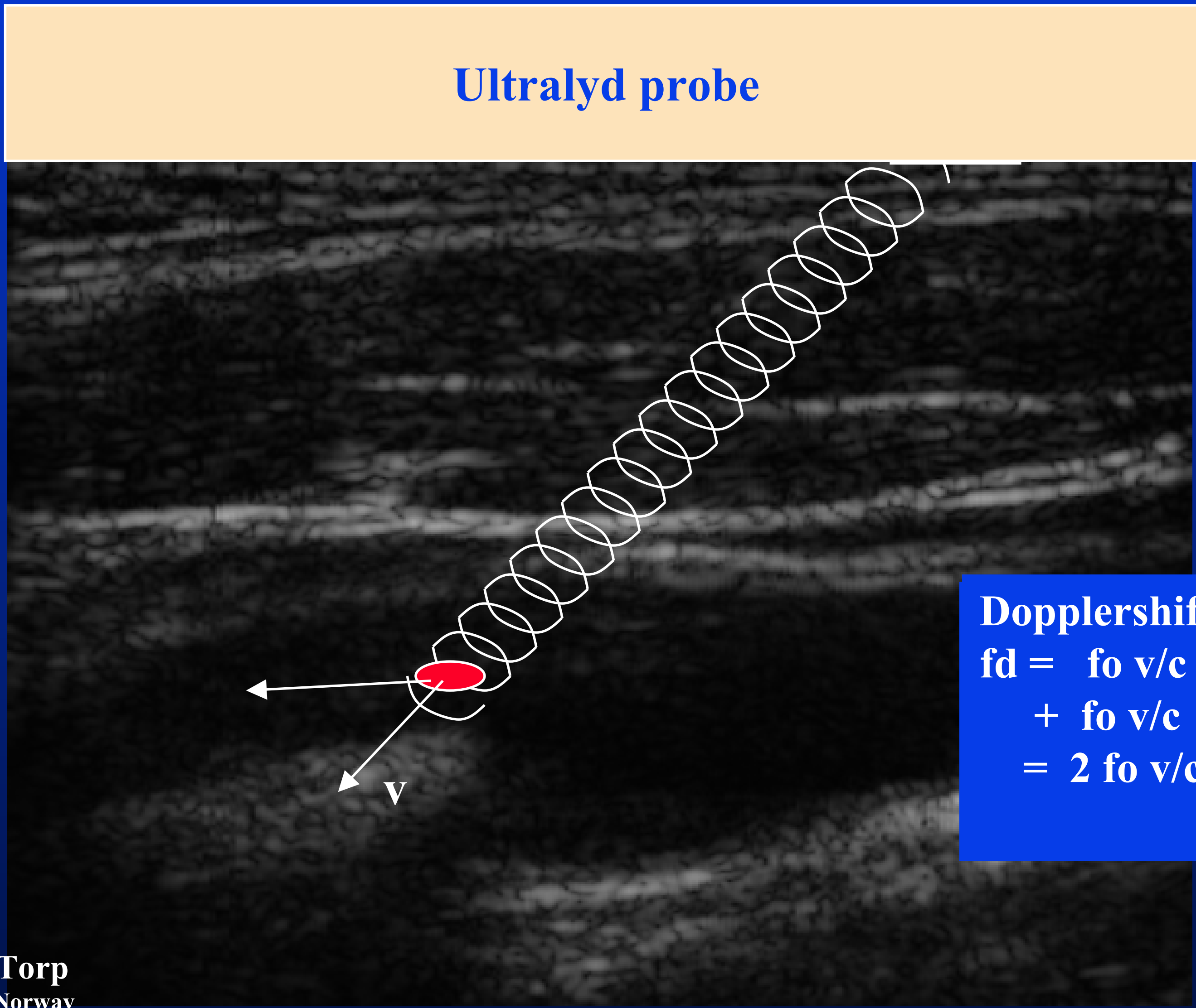
Ultrasound Doppler



Dopplershift

$$f_d = f_0 v/c + f_0 v/c = 2 f_0 v/c$$

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Doppler-equation for echoes from moving blood

$$f_d = 2 f_o \, v \cos(\theta) / c$$

f_d : Dopplershift

f_o : Transmitted frequency

v : Scatterer velocity

c : Speed of sound (1540 m/s)

θ : Angle between v and ultrasound beam

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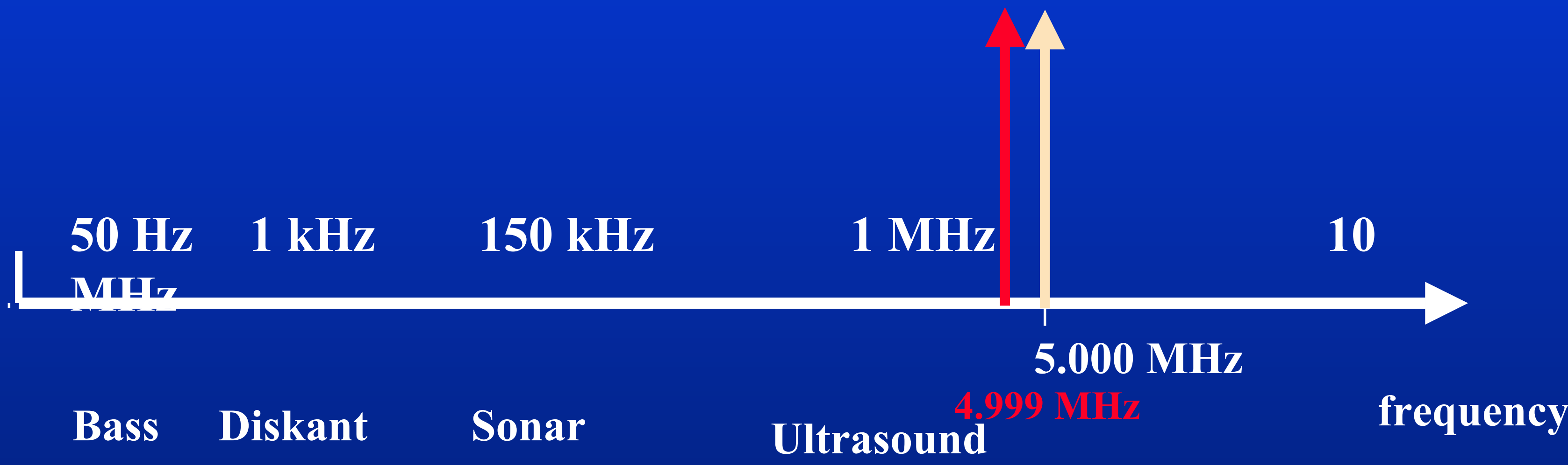
Doppler shift = change in frequnecy



Example : Blood velocity 15 cm/s ~ 0.01 % of 1540 m/s

Dopplershift = 2* 0.01 % * 5 MHz = 1000 Hz ~ Soprano C

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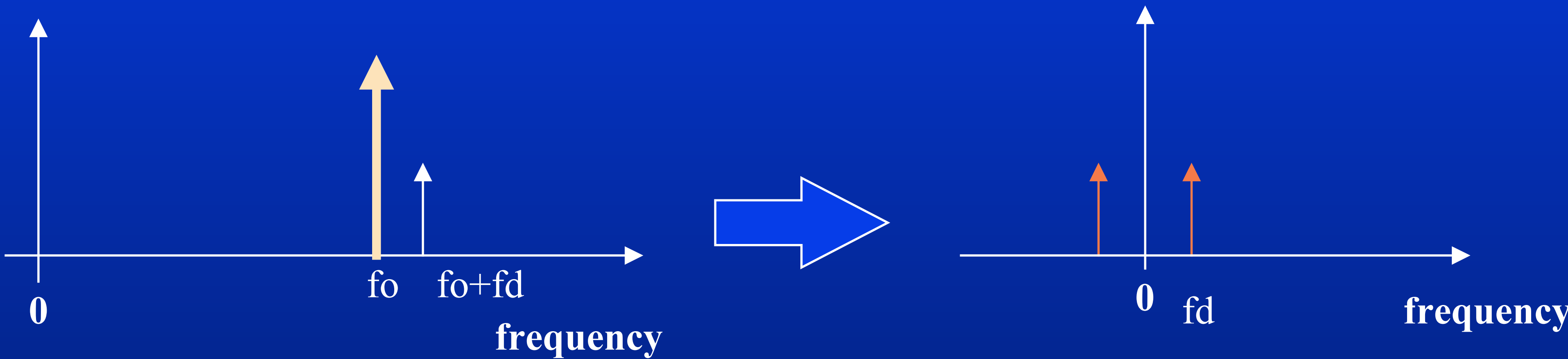
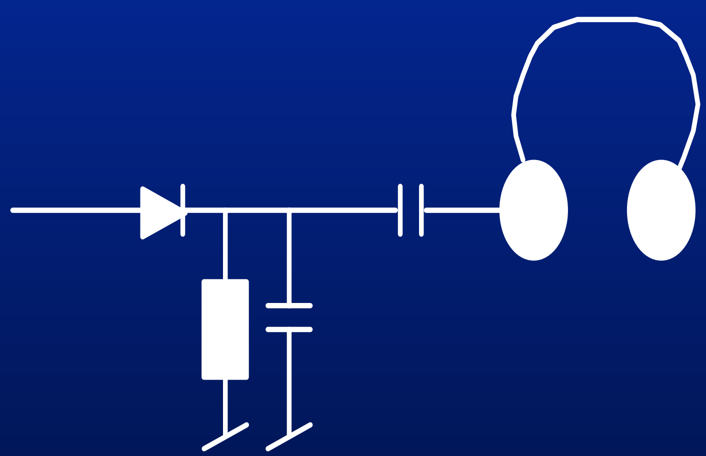
Signal processing for CW Doppler

Amlitude detector gives audio Doppler signal





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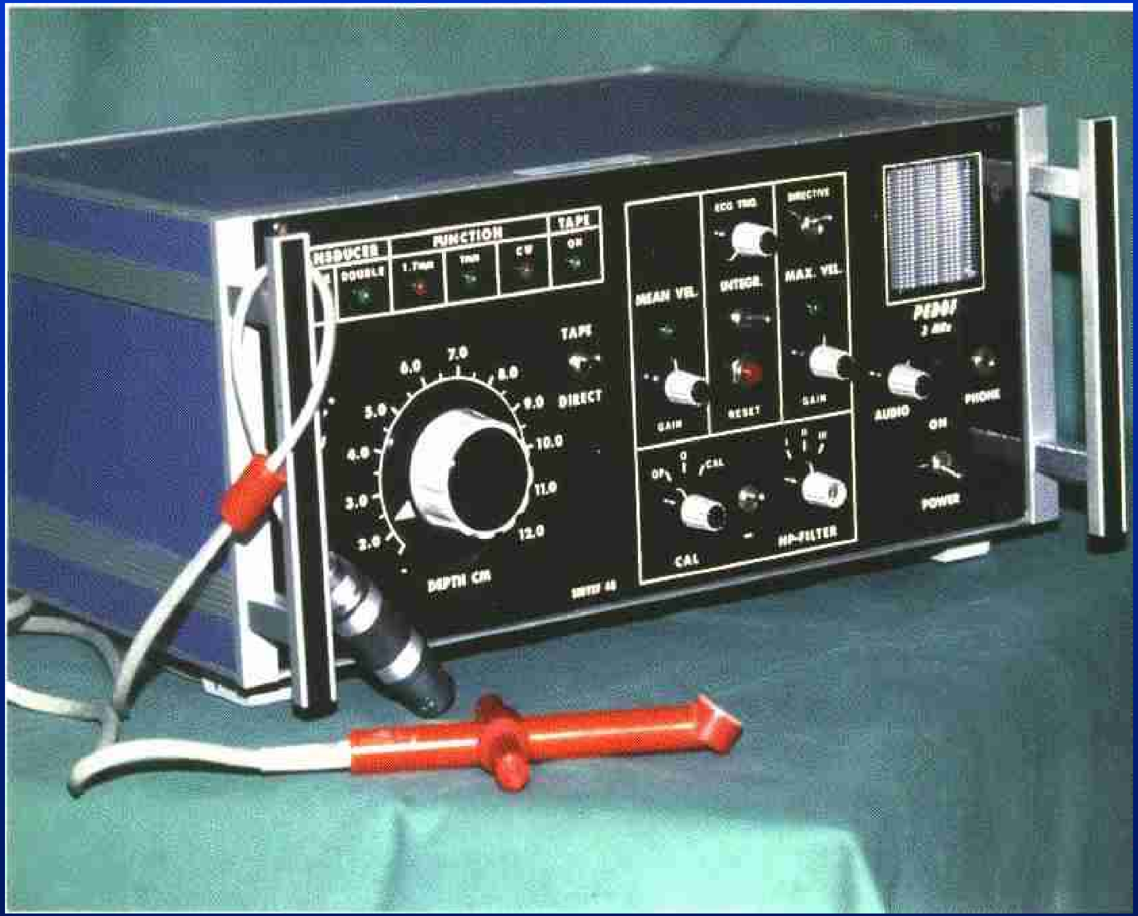
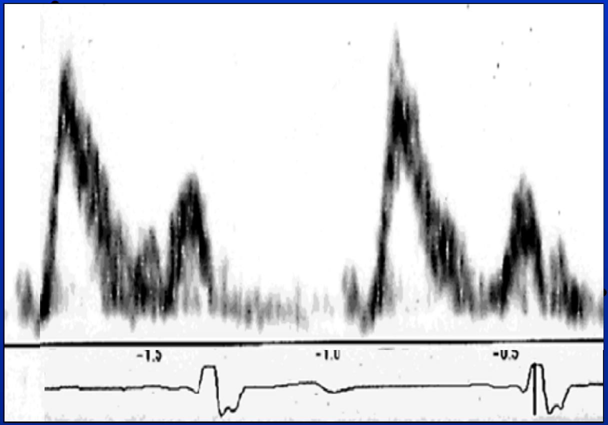
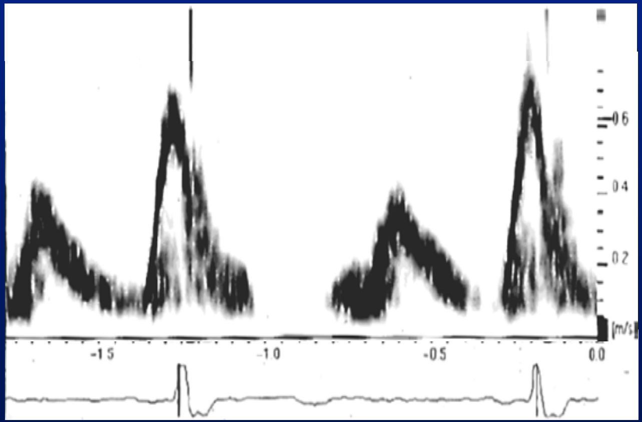
CW/PW Doppler blood flow meter



Blood velocity Mitral inflow



Normal relaxation



Delayed relaxation

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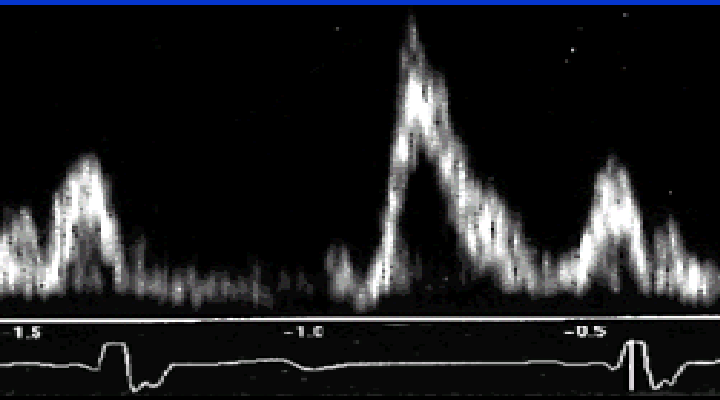
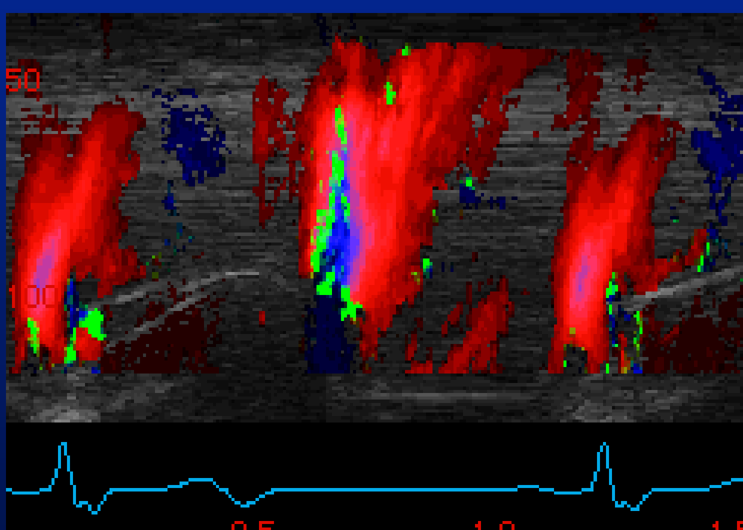
PEDOF developed in Trondheim 1976

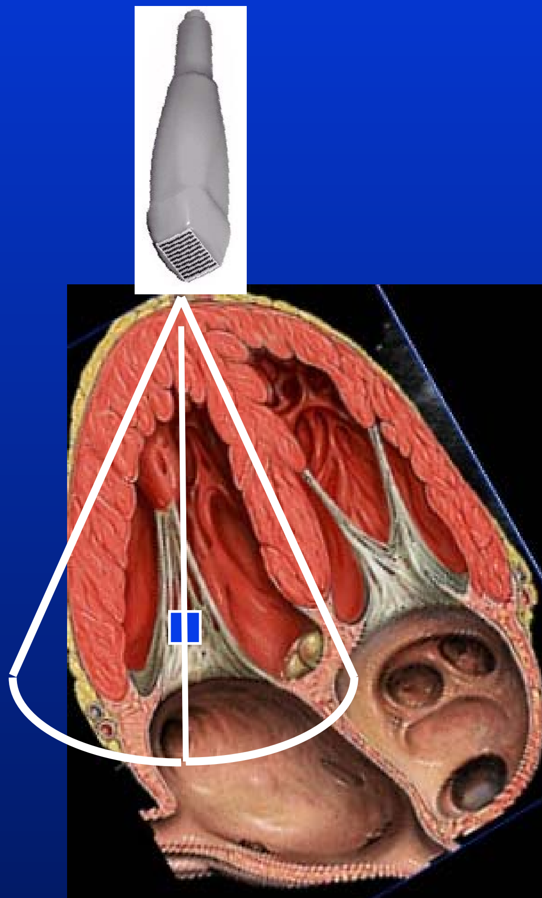
Color Doppler velocity imaging

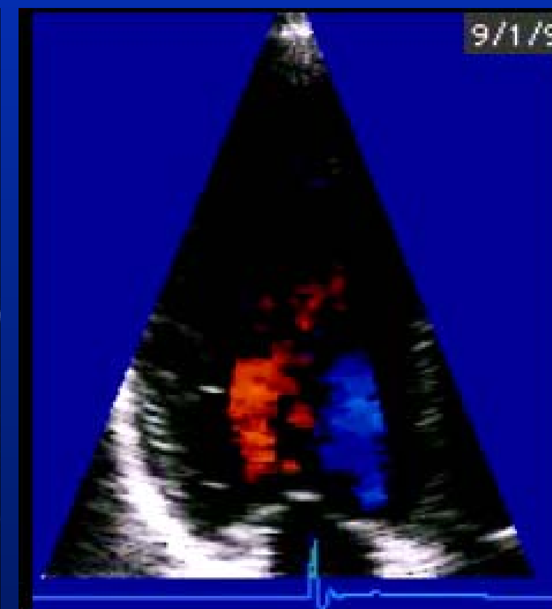


PW Doppler: Velocity from one point



Color M-mode: Velocities along a line





Color flow imaging:
Velocities in the whole imag

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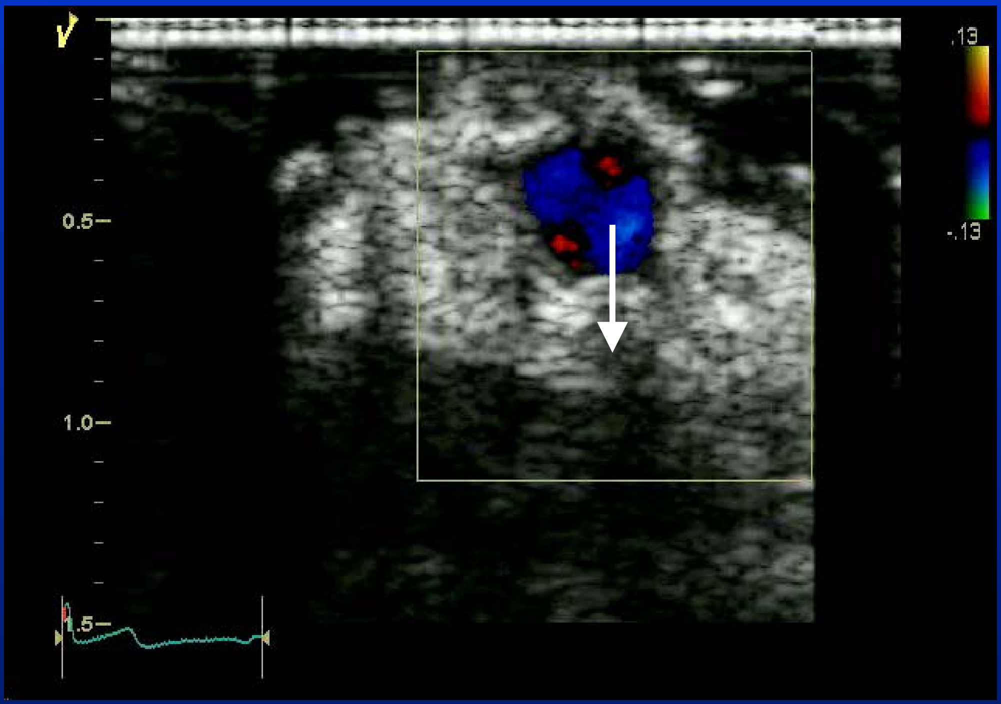
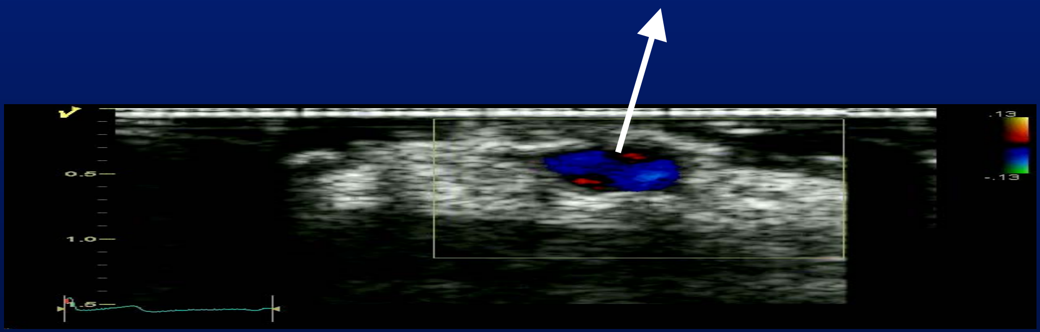
Flow –integration of normal velocity component over area

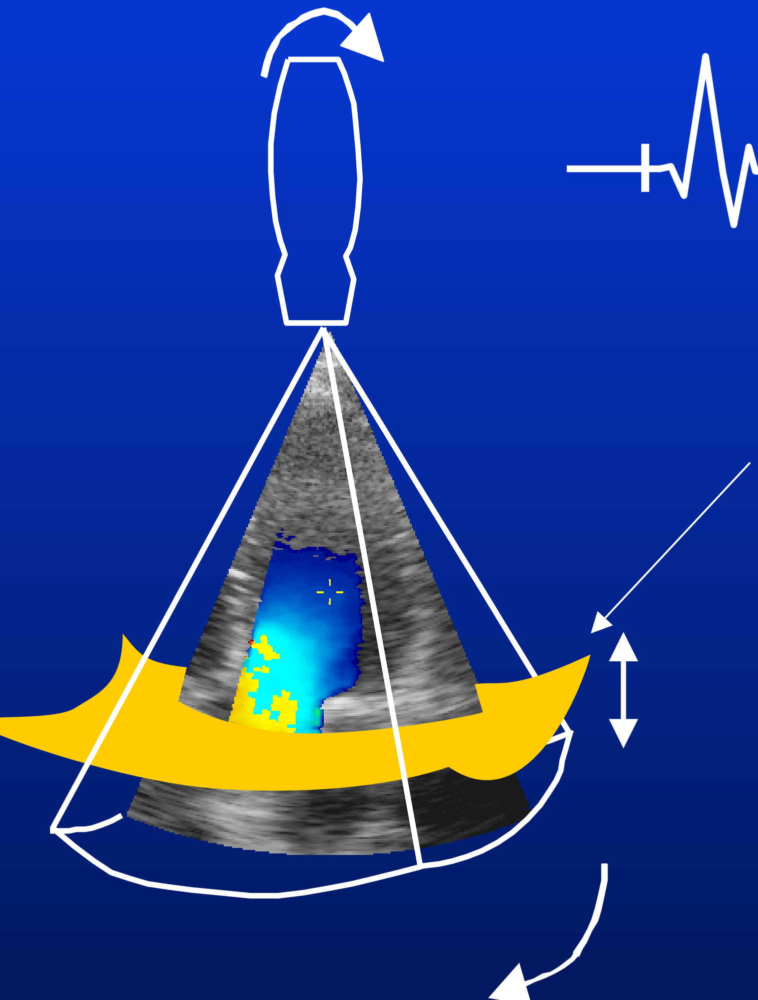


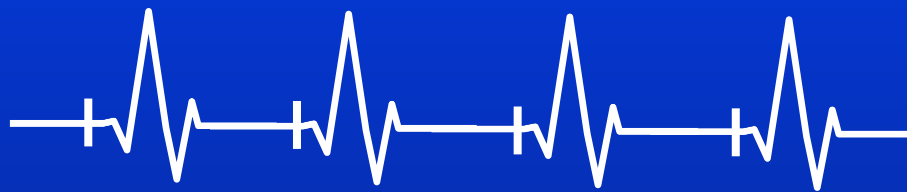
Color flow imaging gives
one velocity component
- along the beam
- in the scan plane



Velocity component
normal to scanplane
is needed for
volume flow calculation

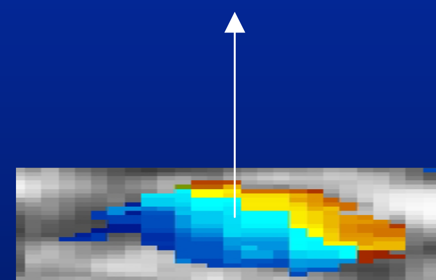
Dynamic 3D Color flow imaging





- ECG-gated aquisition

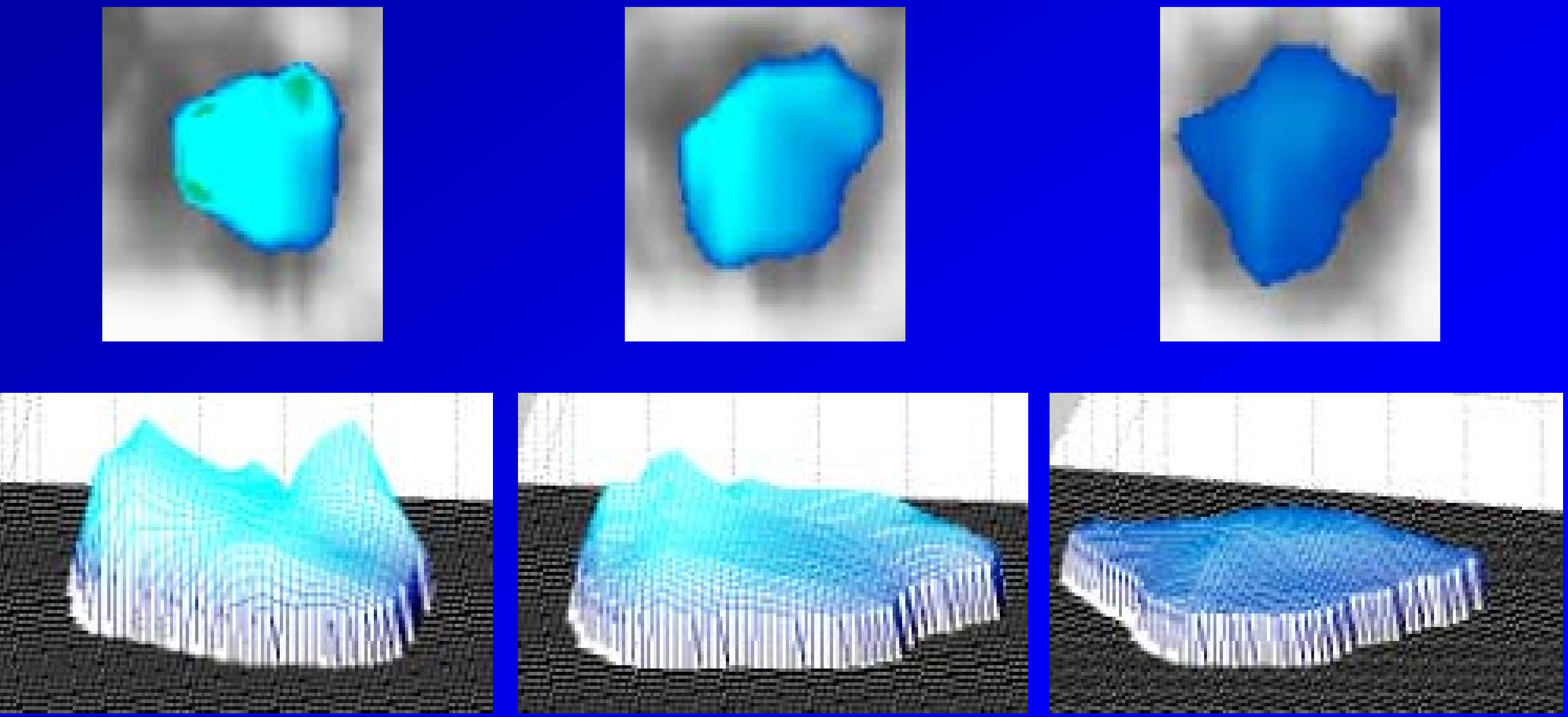
Surface perpendicular to ultrasound beam



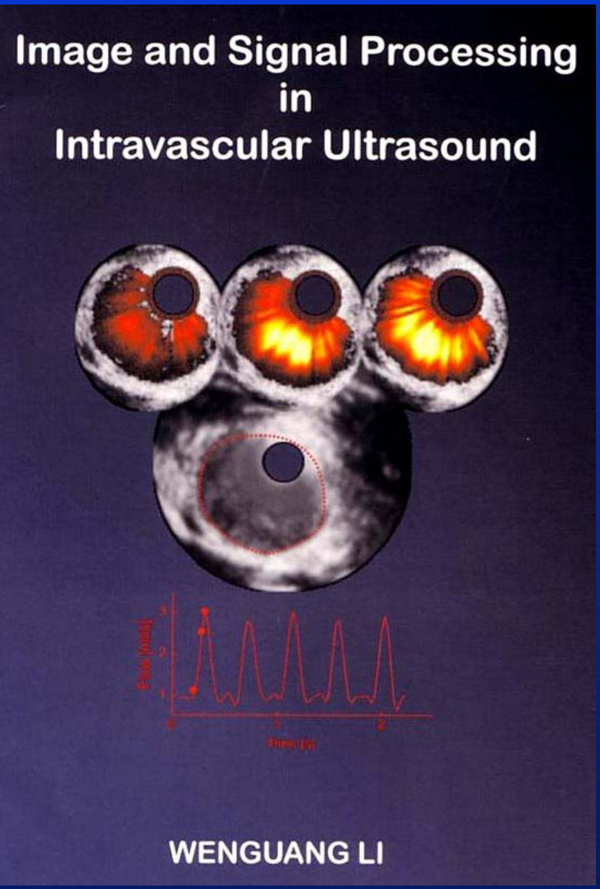
Measured velocity component perpendicular to surface

Dynamic 3D Color flow imaging

- Crossectional velocity profiles
- High frame rate (104 frames per second)
- Volume flow obtained by spatial integration



Velocity measurement by decorrelation



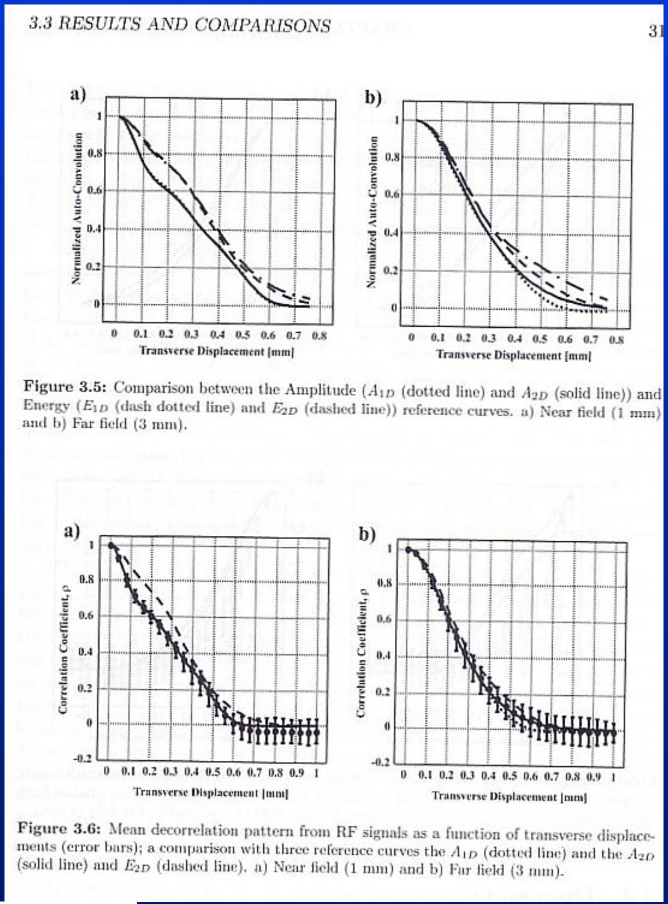
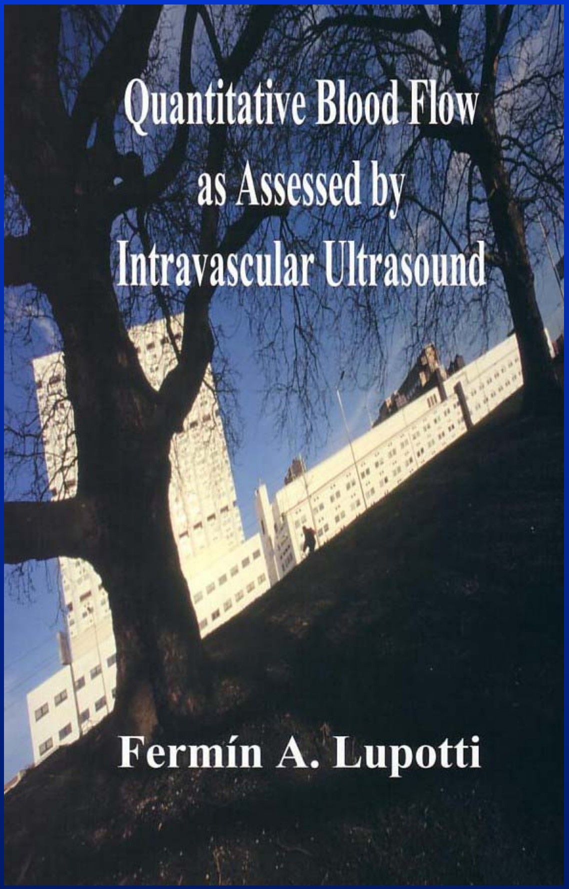
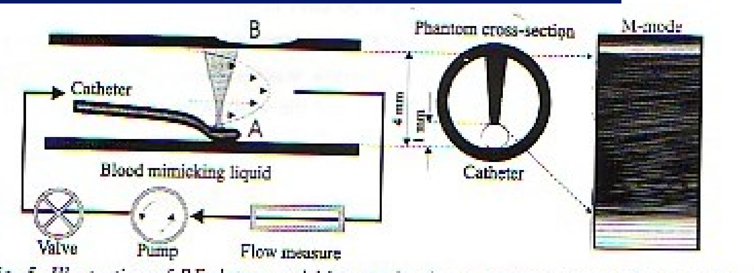


Figure 3.5: Comparison between the Amplitude (A_{1D} (dotted line) and A_{2D} (solid line)) and Energy (E_{1D} (dash dotted line) and E_{2D} (dashed line)) reference curves. a) Near field (1 mm) and b) Far field (3 mm).

Figure 3.6: Mean decorrelation pattern from RF signals as a function of transverse displacements (error bars); a comparison with three reference curves the A_{1D} (dotted line) and the A_{2D} (solid line) and E_{2D} (dashed line). a) Near field (1 mm) and b) Far field (3 mm).





ig. 5. Illustration of RF data acquisition for in vitro experiment setup. The contrast

Velocity components normal to scanplane give increased bandwidth ~ decreased correlation

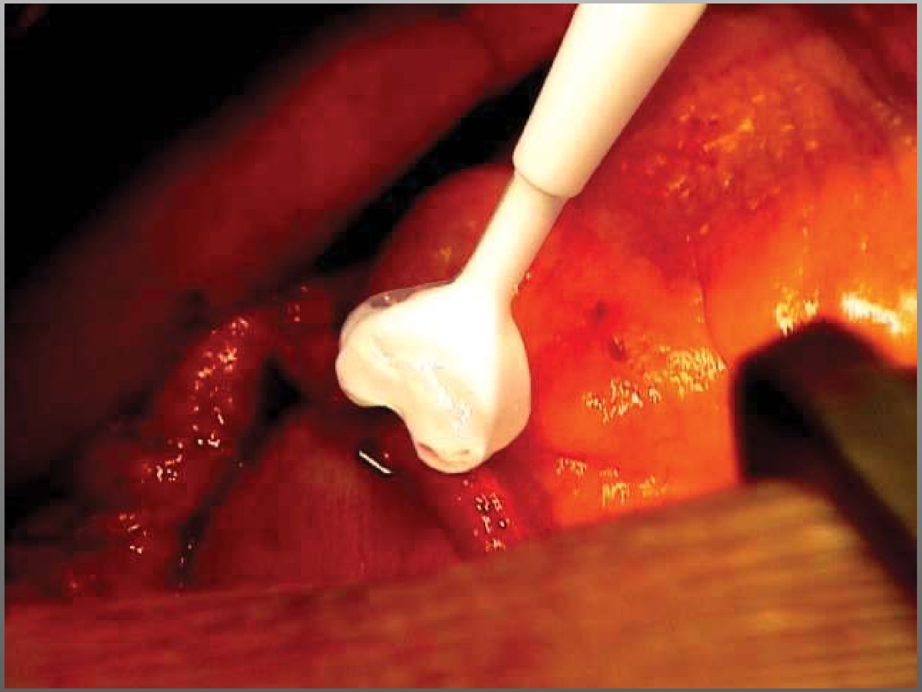
Non-directional technique

Can be integrated to volume flow

Low clutter level required (IVUS)

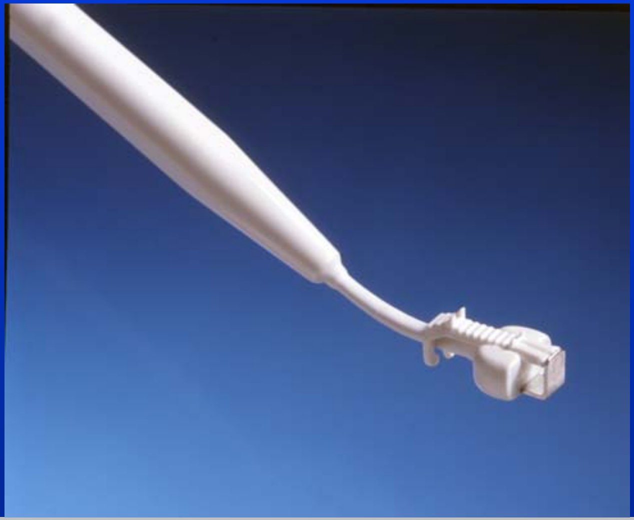
Ultrasound Transit Time flow-meter

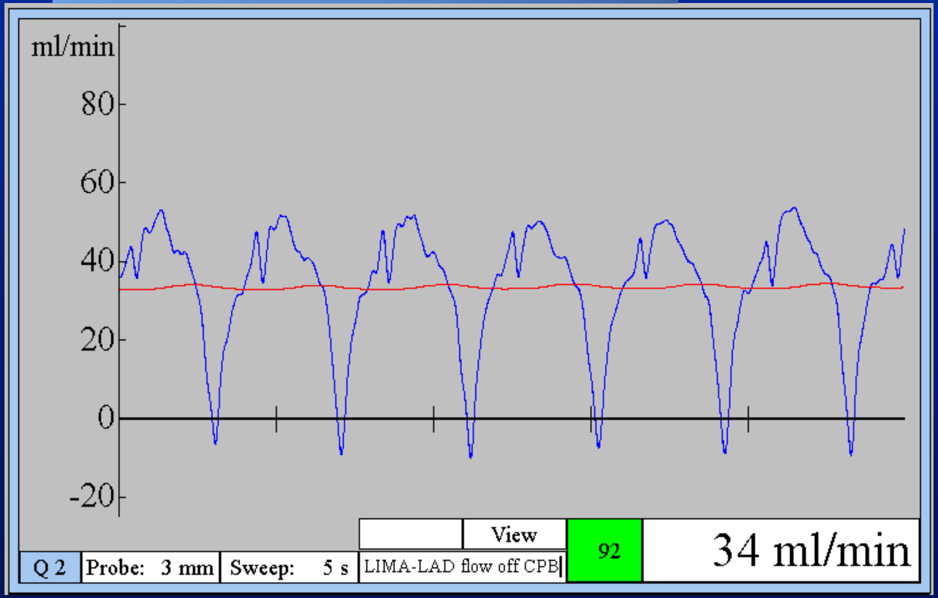
Graft Patency Verification

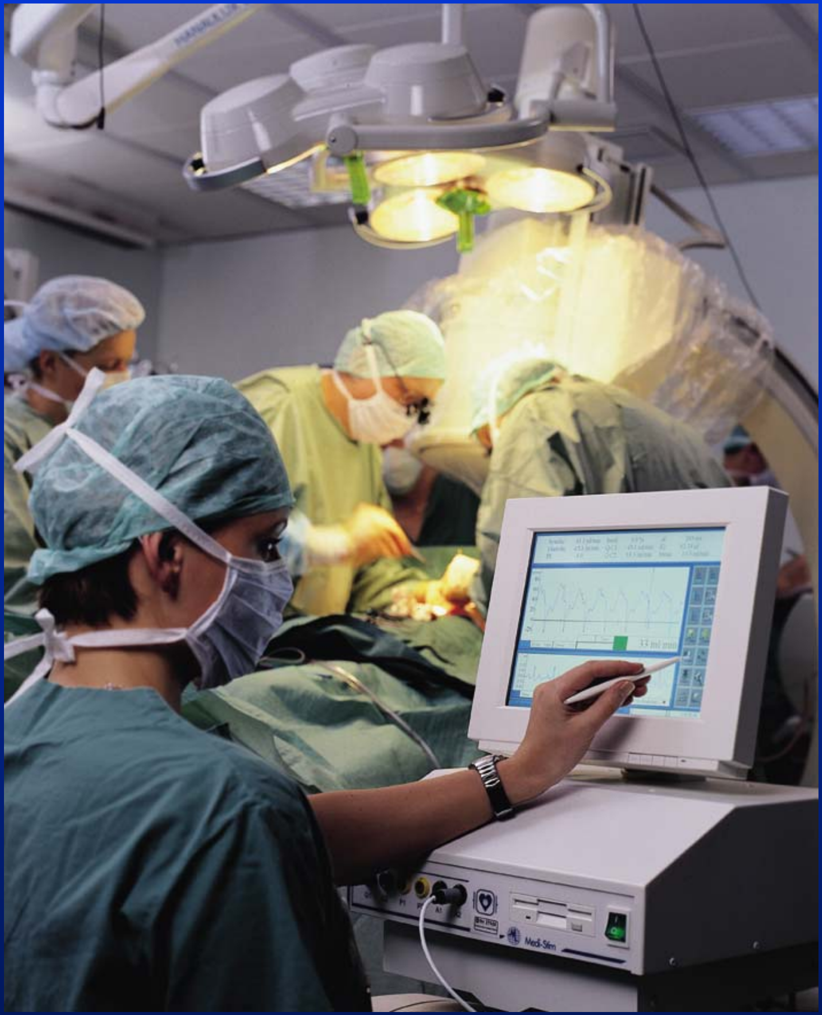


Arne Grip, Medi-Stim

Graft Patency verification

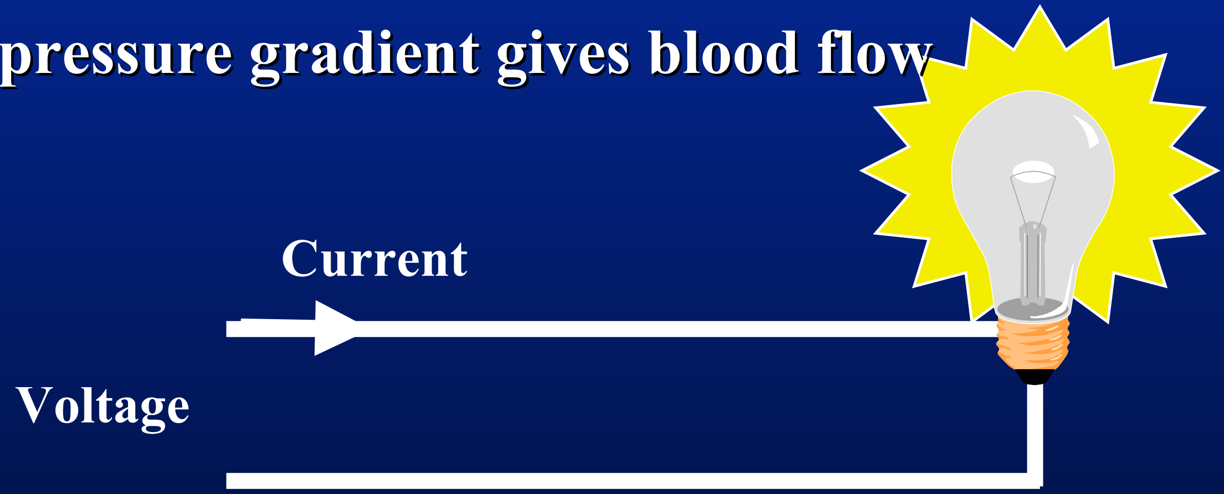




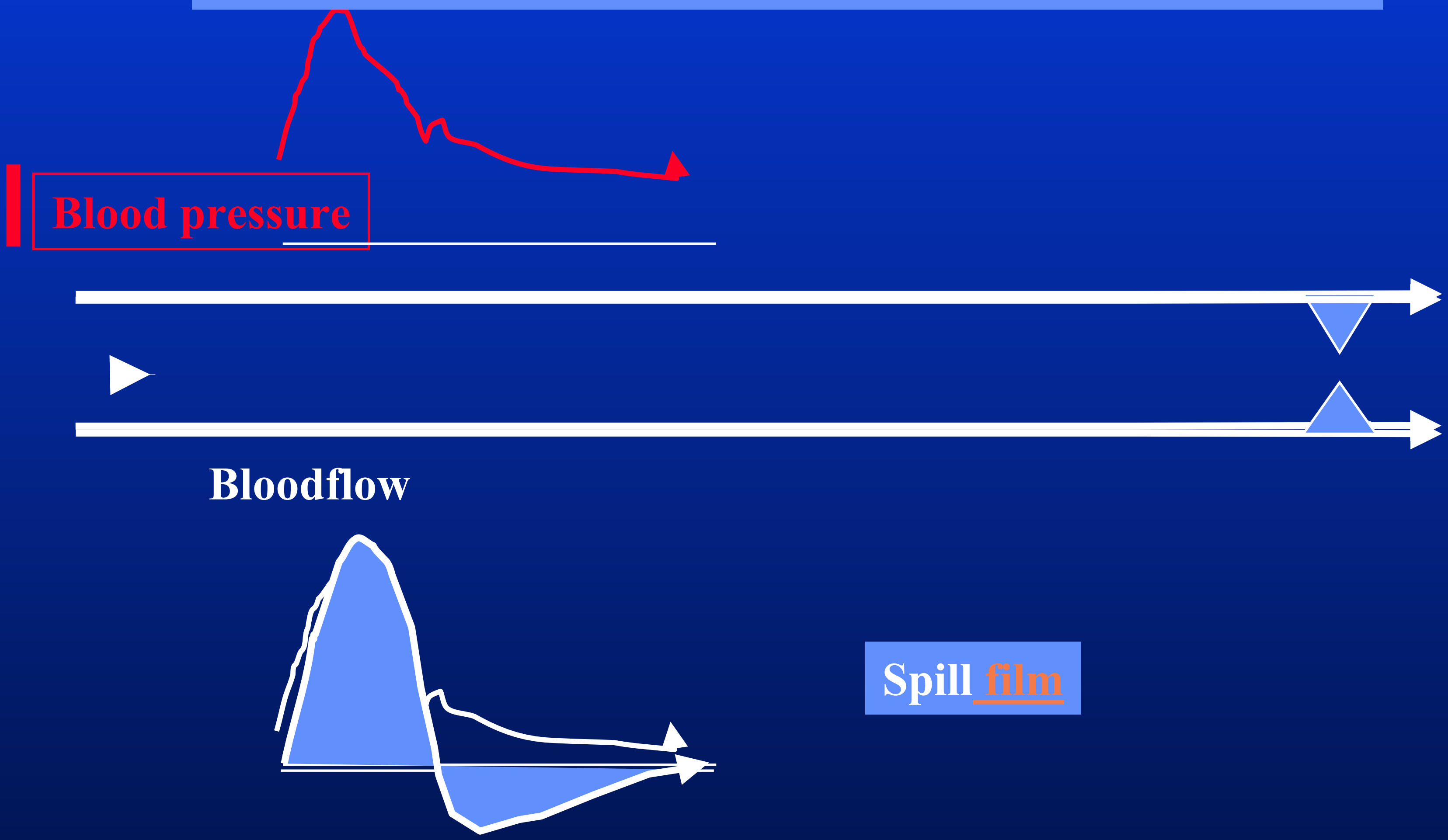


Hemodynamics

- Hemo from *Haima* = Blood
- Dynamics from *Dynamis* ~ Force which create motion
- Blood pressure gradient gives blood flow

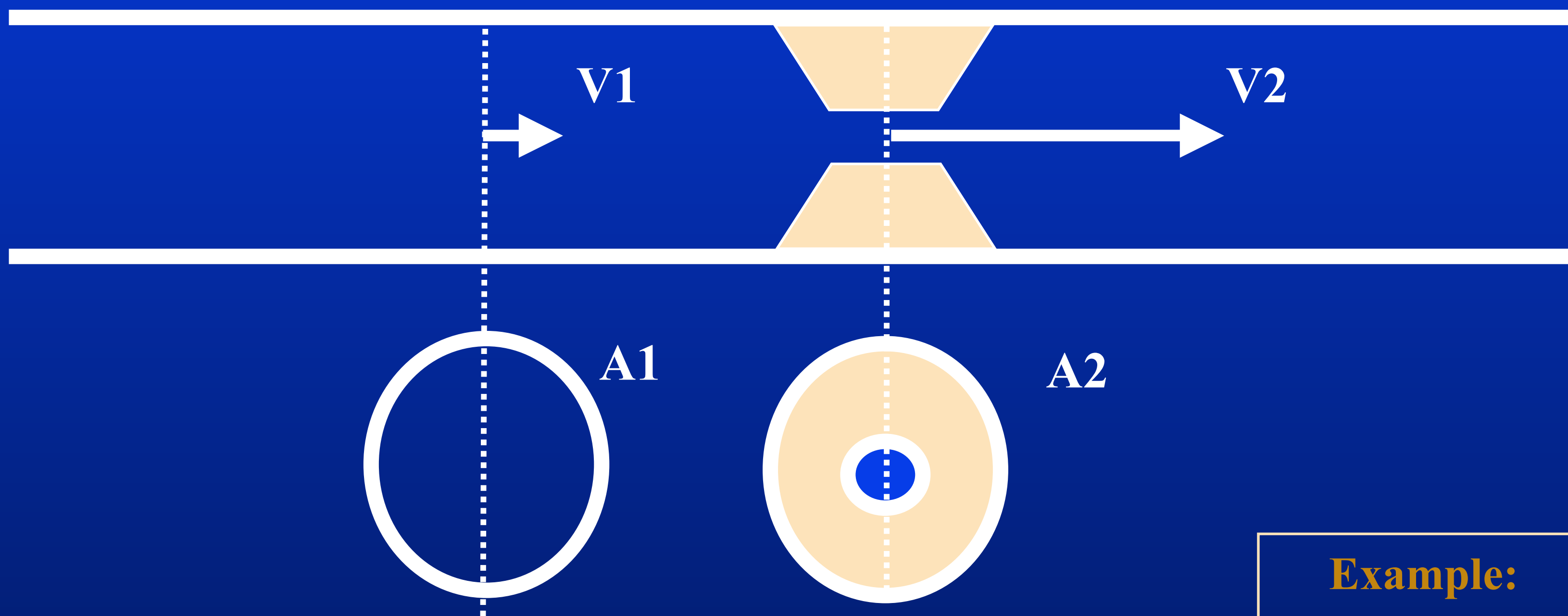


Blood flow, high periferal resistance



Spill film

Continuity of flow to assess stenosis



$$V1 * A1 = V2 * A2$$

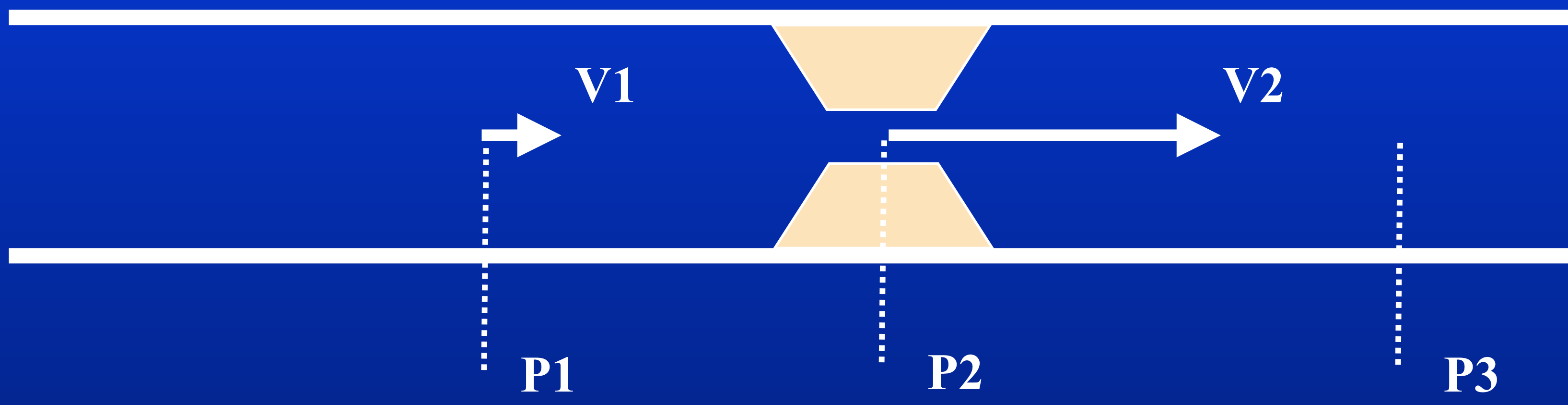
$$\frac{\%\ \text{reduction}}{\quad} \qquad \frac{A1 - A2}{A1} = \frac{V2 - V1}{V2}$$

Example:

5x velocity corresponds to 80% stenose

Area reduction depends only on the velocity V2/V1; independent of diameter and angle

Reduction in blood pressure in a stenosis



Pressure drop (gradient) : $P1 - P3 = 4\, V2^2$

Example: 80% aortic-stenosis

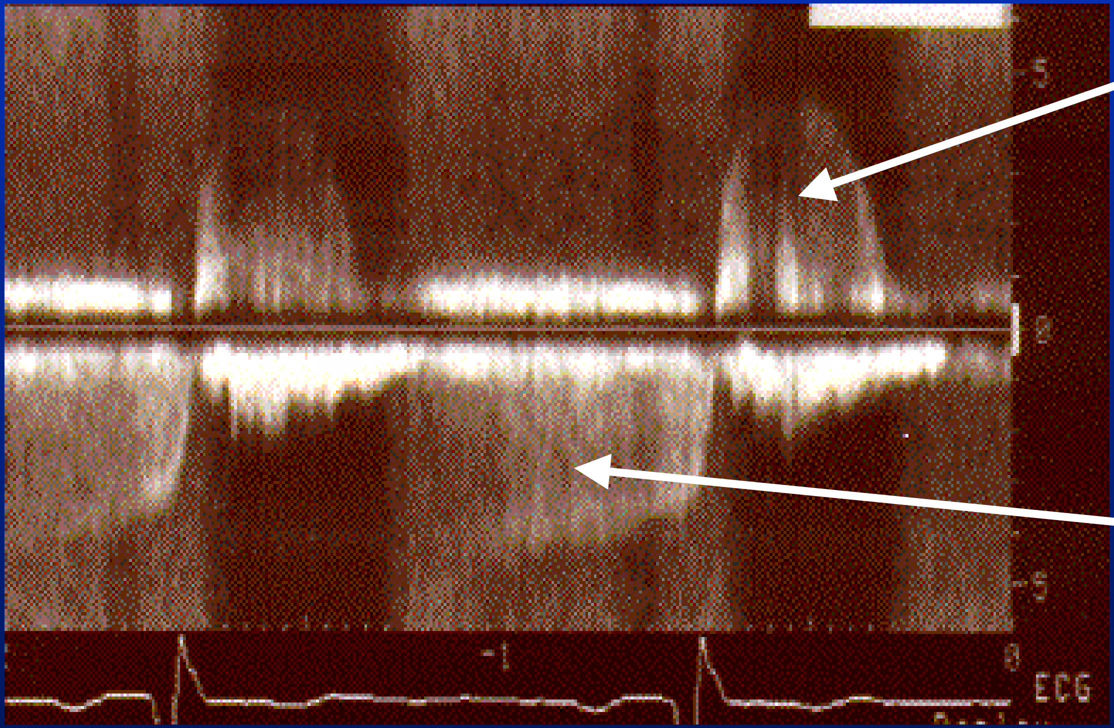
V1= 1 m/s V2 = 5 m/s pressure-gradient 4*5*5 = 100 mmHg

Normal aortic pressure 120 mmHg corresponds to

220 mmHg ventricular pressure!

Hans Torp
NTNU, Norway

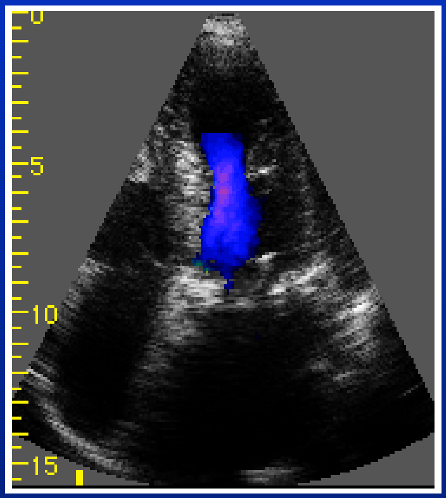
Aortic stenosis + regurgitation by CW Doppler

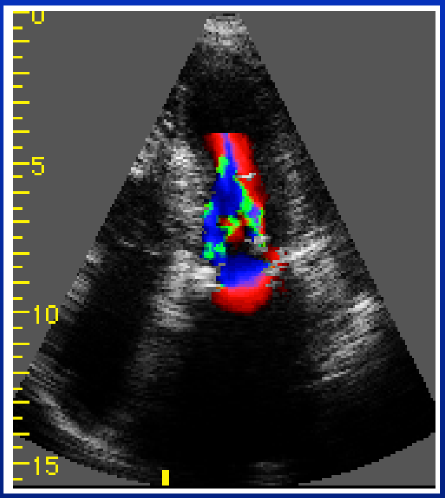


Stenosis (forward flow)

Regurgitation (reverse flow)

Mitral valve prothesis with reduced opening area



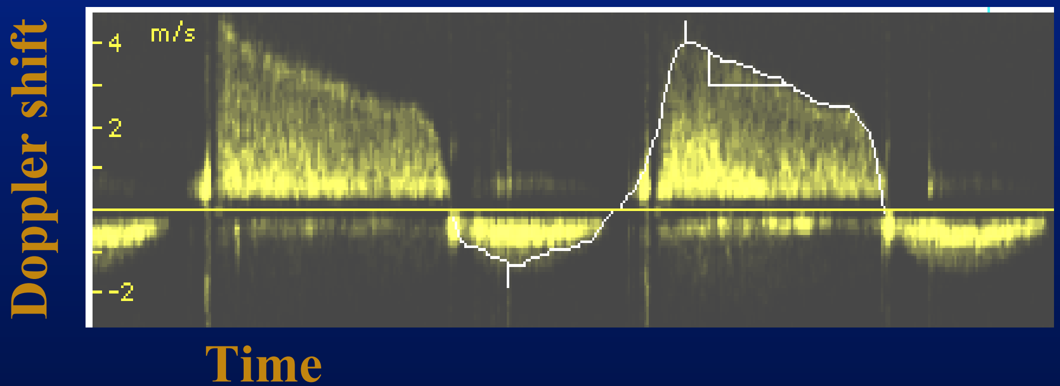


Simplified Bernouli equation:

Pressure gradient

$$dP = 4 v^2$$

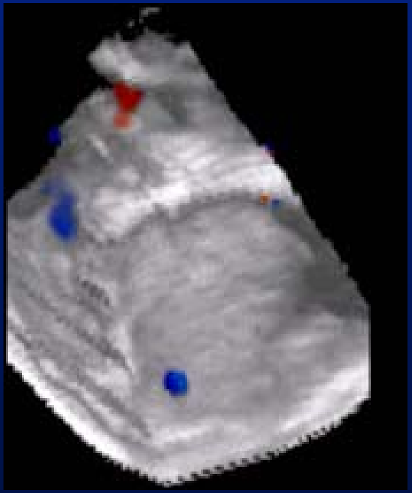
Pressure half time decay gives mitral valve area



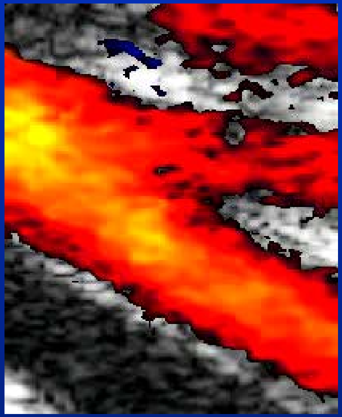
Cardiac dynamic 3D imaging

Magnetic position sensor system

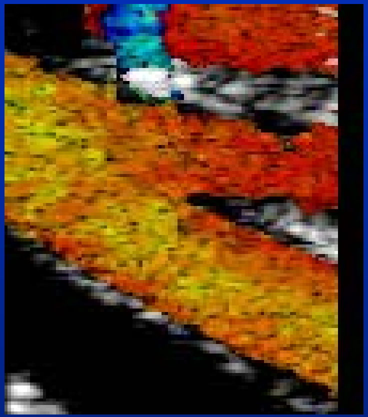
Mitral valve with lupus (vegetation) and reverse flow



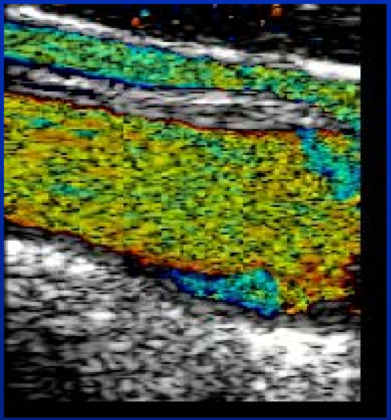
Blood motion imaging: Visualize flow direction in color flow imaging



Arteria bracialis
Conventional CFI



Arteria bracialis
BMI

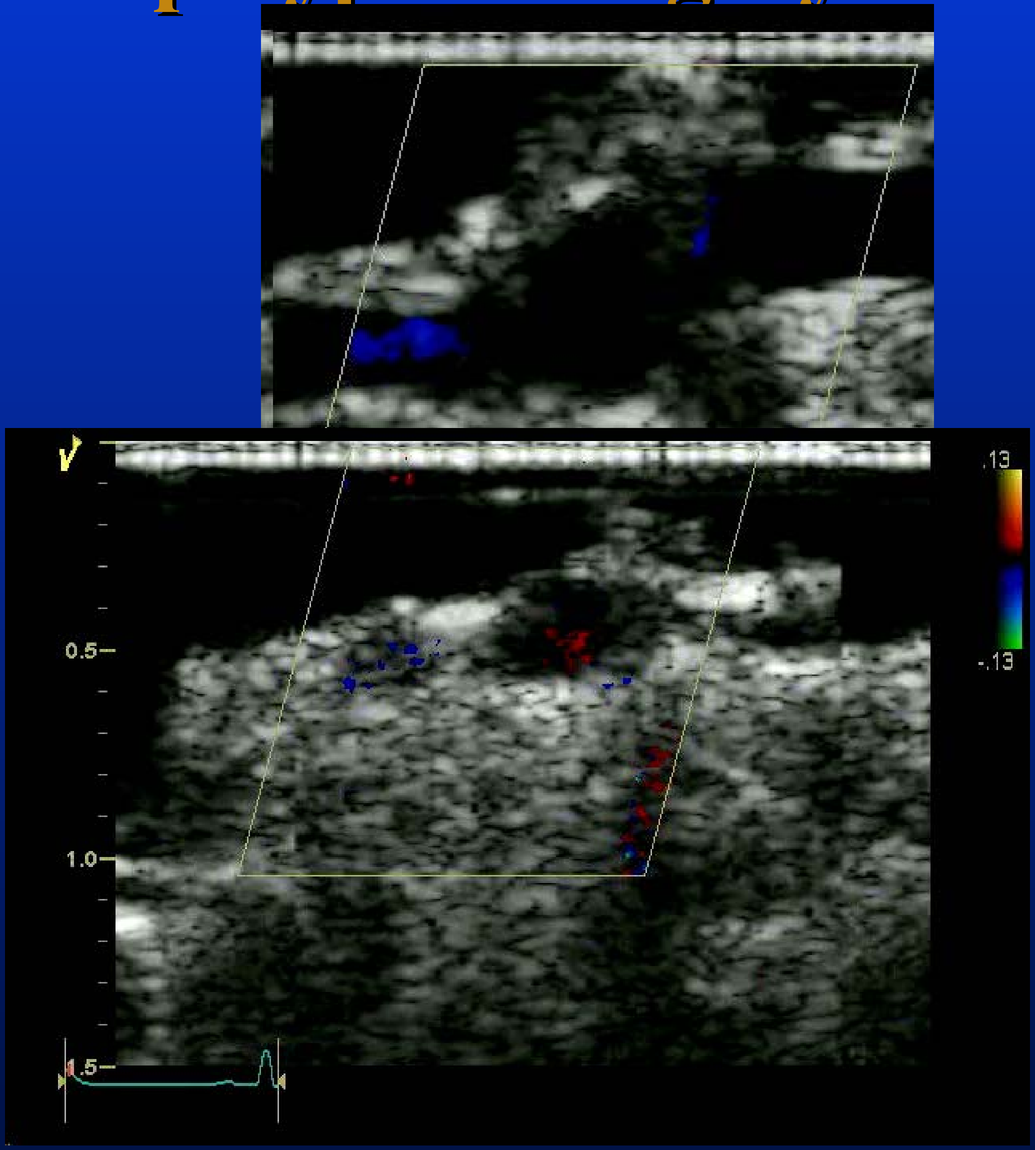


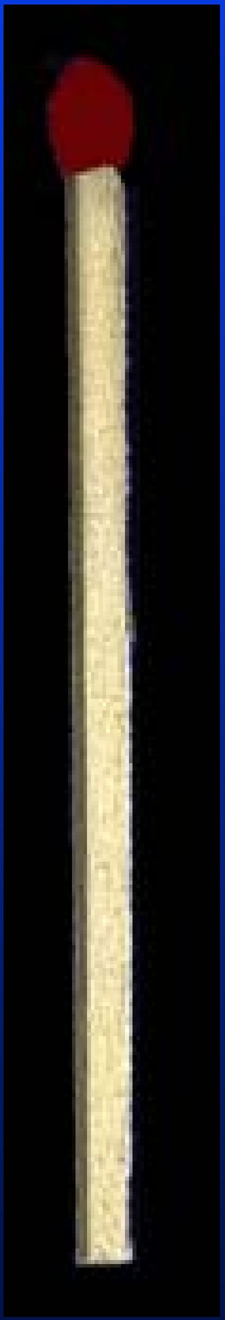
Carotis communis
BMI

Hans Torp
NTNU, Norway

Off-pump bypass surgery

Rune Haaverstad
Stein Samstad
Hans Torp





Vis film!