Ultrasound Basis

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Imaging Using Ultrasound

- Ultrasound - High frequency sound waves above human perception
- Ultrasound's use in medicine based on:
  - Transmit - Reflection - Receive Measurements
    - Time measured for "echo" of transmitted wave is related to the distance from transmitter
  - Doppler principle
    - Velocity and direction related to frequency changes in ultrasound reflection

Echocardiography

Ultrasounds

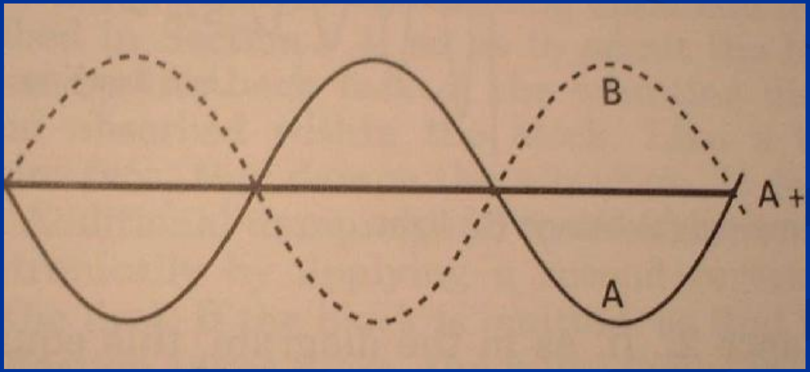
- 4 critical points
  - Fréquency
  - Energy
  - Impédance
  - PRF

Frequency

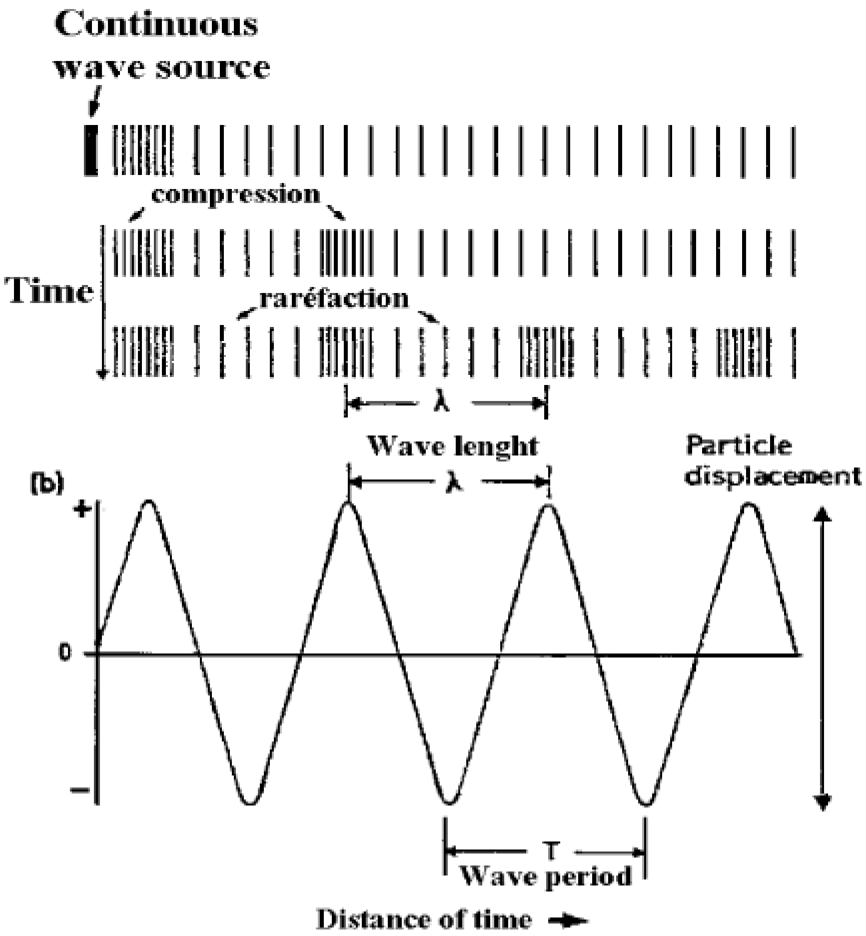
PHYSICS OF ULTRASOUND

- Wavelength.
- Audible sound 15 Hz-20,000 Hz.
- Ultrasound Above 20 KHz.
- Medical Ultrasound- 1-20 MHz.
- Velocity= Wavelength x Frequency

$$v = \lambda \times Hz$$



FREQUENCY



Ultrasound in medicine from 1 to 10 MHz

- $\lambda = c.T$
  - c = Propagation speed
  - T = période = 1/f
  - f = Frequency

Velocity of sound

- Dependent on physical make up of material.
- Velocity is inversely proportional to compressibility
- Directly proportional to density
- In body it is almost constant.

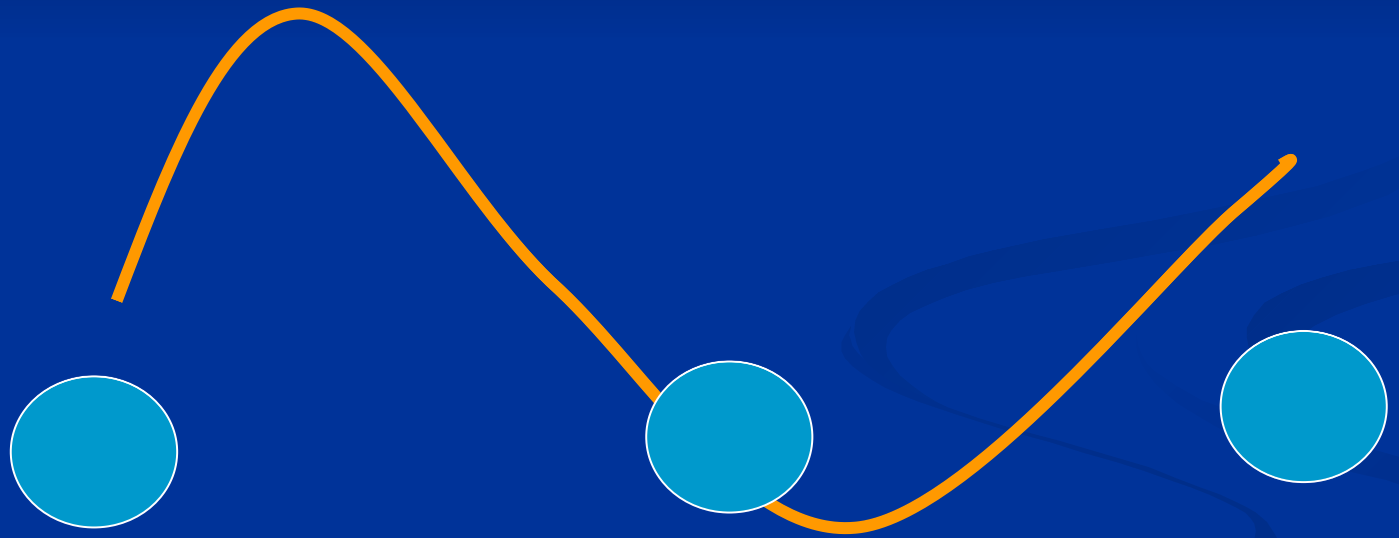
Table 20–1. Velocity of Sound in Various Materials

MATERIAL	VELOCITY (m/sec)
Air	331
Fat	1450
Mercury	1450
Castor oil	1500
Water (50° C)	1540
"HUMAN SOFT TISSUE"	1540
Brain	1541
Liver	1549
Kidney	1561
Blood	1570
Muscle	1585
Lens of eye	1620
PZT-5A	3780
PZT-4	4000
Skull (bone)	4080
Brass	4490
Quartz	5740
Aluminum	6400

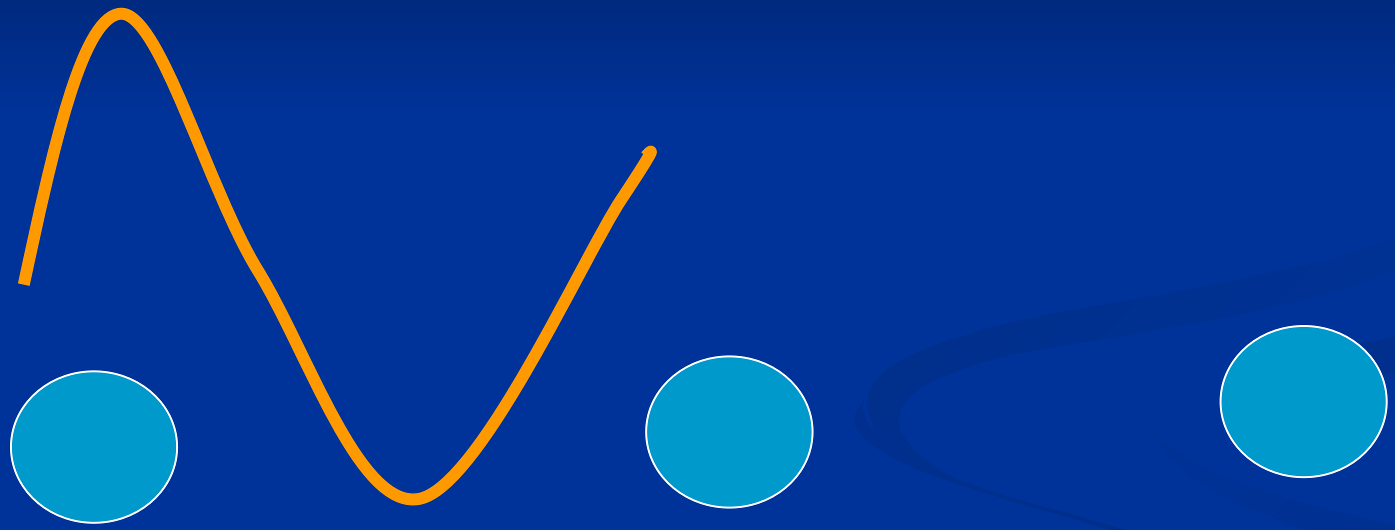
Messages

- Propagation velocity is high in bones
- Propagation velocity is low in the air
- In human tissue 1540 m/s

Axial resolution



Axial resolution



Small wavelenght means high frequency

Frequency and axial resolution

- λ = C/F
- C in human tissu is 1540 m/s
- Frequency 2 MHz, λ = 0.77 mm.
- Frequency 5 MHz, λ = 0.31 mm.
- Frequency 10 MHz, λ = 0.15 mm.

Higher frequency, Higher axial resolution

Message

- **Higher the frequency is, higher is the axial resolution**

Energy

Energie

- An ultrasound is emitted with a certain energy
- This energy is lost in tissues
- Conversion of US to Heat

ATTENUATION OF ULTRASOUND

- Exponentially with depth of travel,
- Dependent on Absorption and Scatter

- On average for every 1 MHz, there is 1 db/cm loss, eg. 3.5 MHz loss in 2 cm of tissue is 7 db.

Tissue and Materials: Acoustic Characteristics

Material	Density Kg/m3	Speed of Sound mm/us	Impedance Million Rayls	Attenuation DB/cm@1mHz
Air	1.2	.33	.0004	100+
Lung	300	.6	.18	40
Fat	924	1.45	1.34	.5-1.8
Water	1000	1.48	1.48	.0002
Blood	1058	1.56	1.65	.18
Muscle	1068	1.6	1.71	.2-.6
Bone	1912	4.08	7.8	13-26

Message

- High frequency probe has low penetration
- Low frequenc probe has high penetration.

Message

- A balance should be made between Best Resolution (High frequency) and propagation depth (Lower frequency)

Impedance

Tissue and Materials: Acoustic Characteristics

Material	Density Kg/m3	Speed of Sound mm/us	Impedance Million Rayls	Attenuation DB/cm@1mHz
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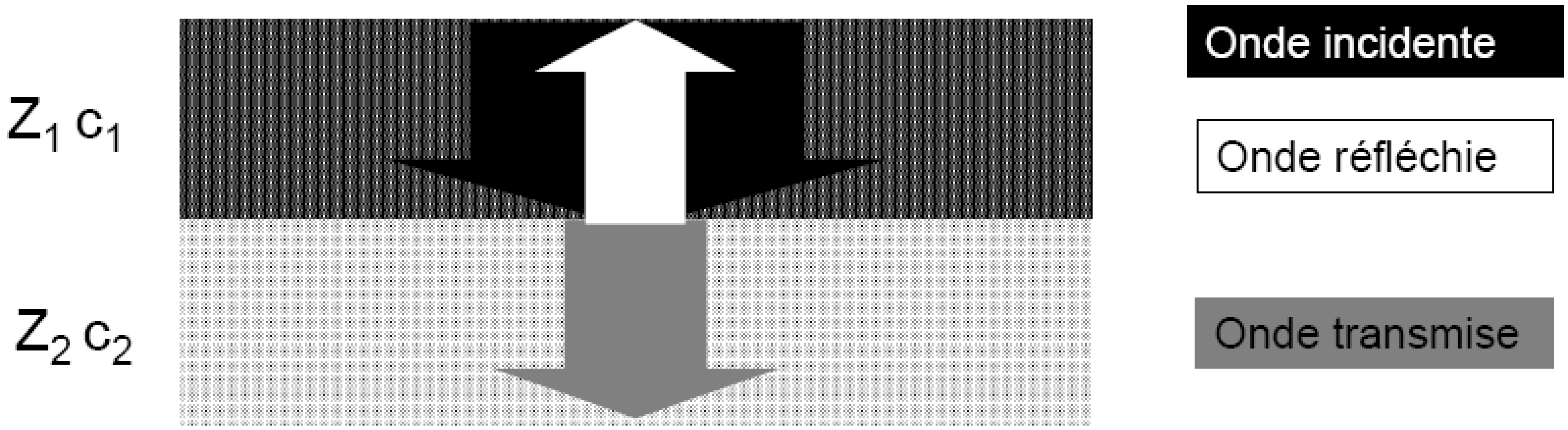
Bone	1912	4.08	7.8	13-26

R = coefficient de réflexion
Ii = intensité incidente
Ir = intensité réfléchie
Z1 = impédance proximale
Z2 = impédance distale

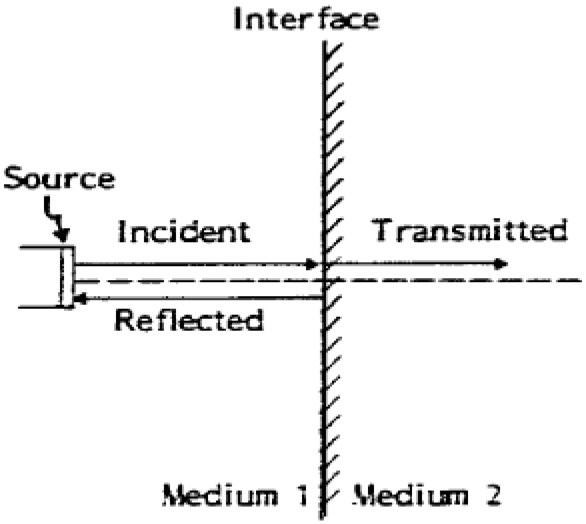
$$R = \frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$



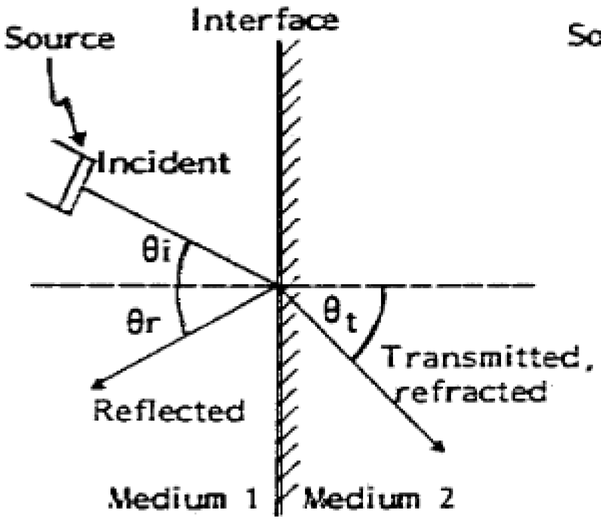
Message

- To see any structure this structure should have a different impedance with the previous structure

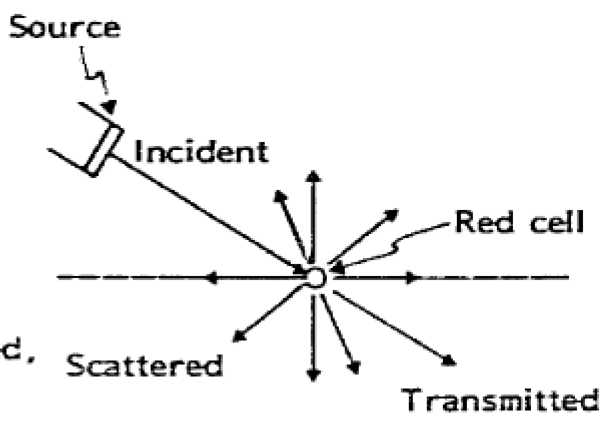
Angle



Perpendicular reflexion



Reflexion



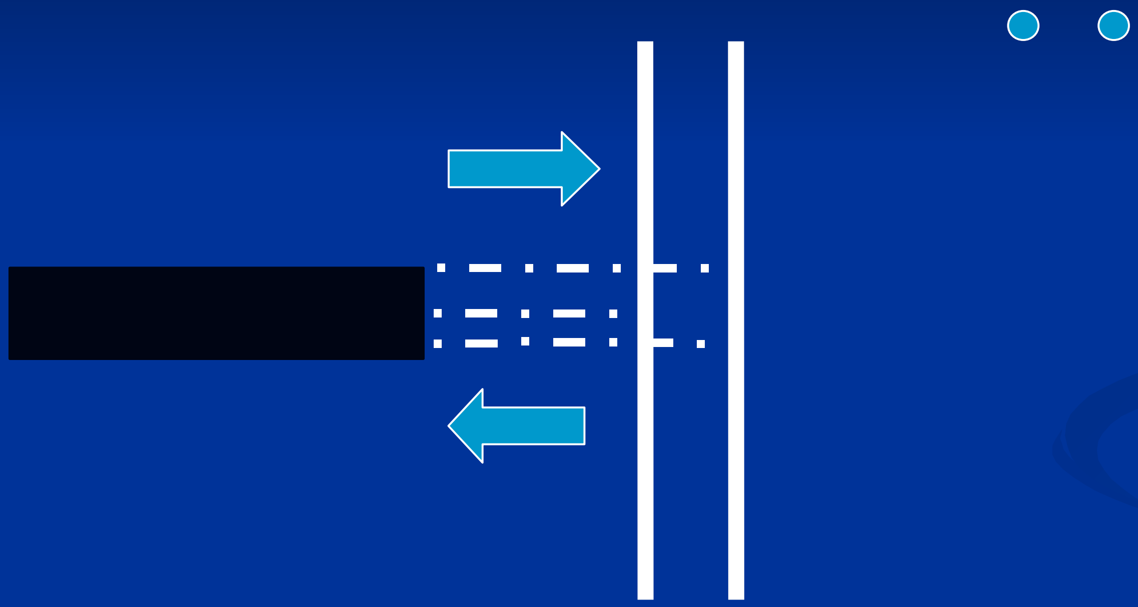
Diffusion

Message

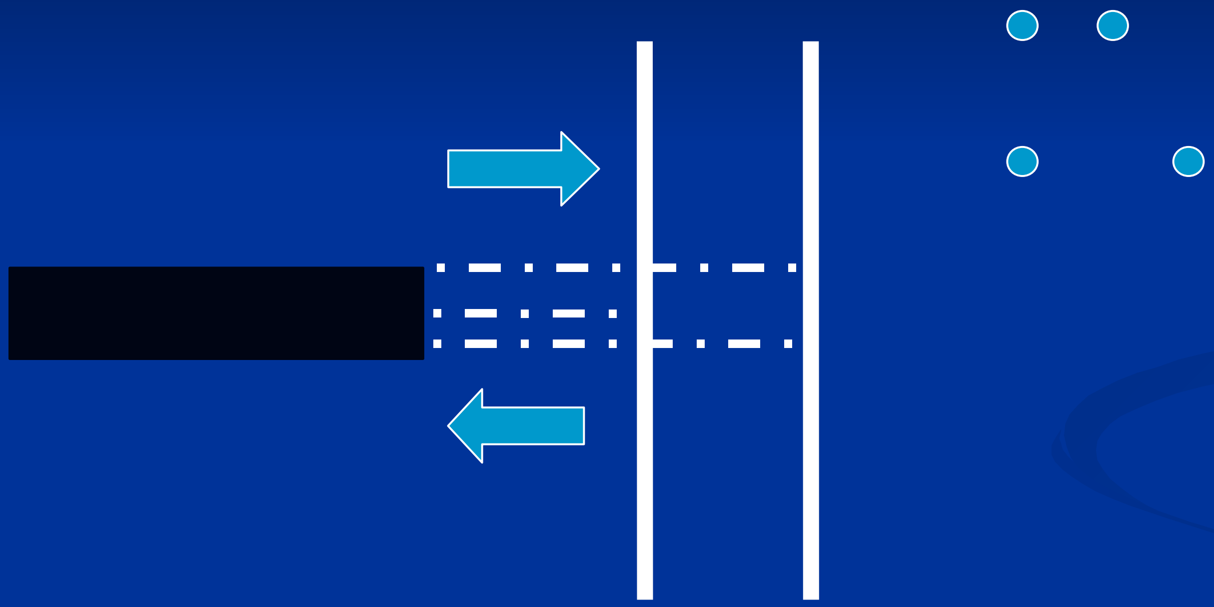
- To get the best signal it is better to work perpendicularely to studied structures when using echocardiographic technique

Echocardiographic modes

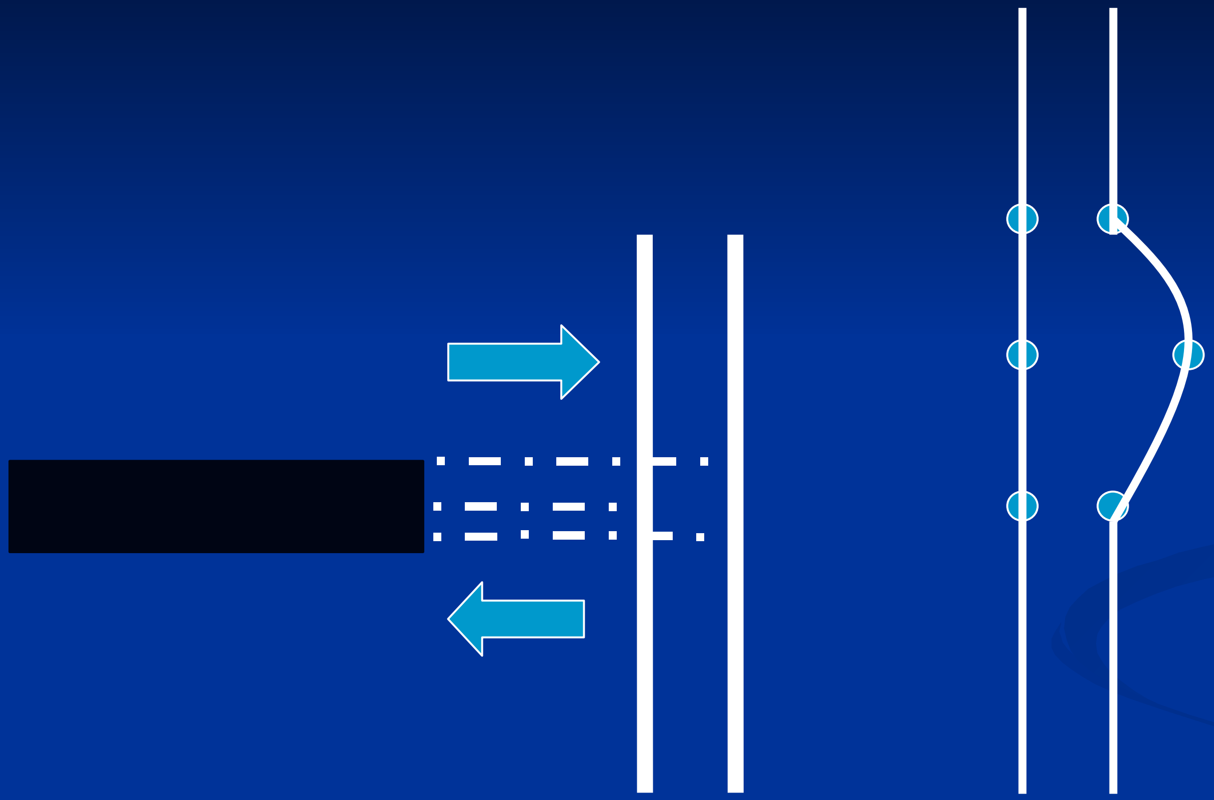
M-Mode



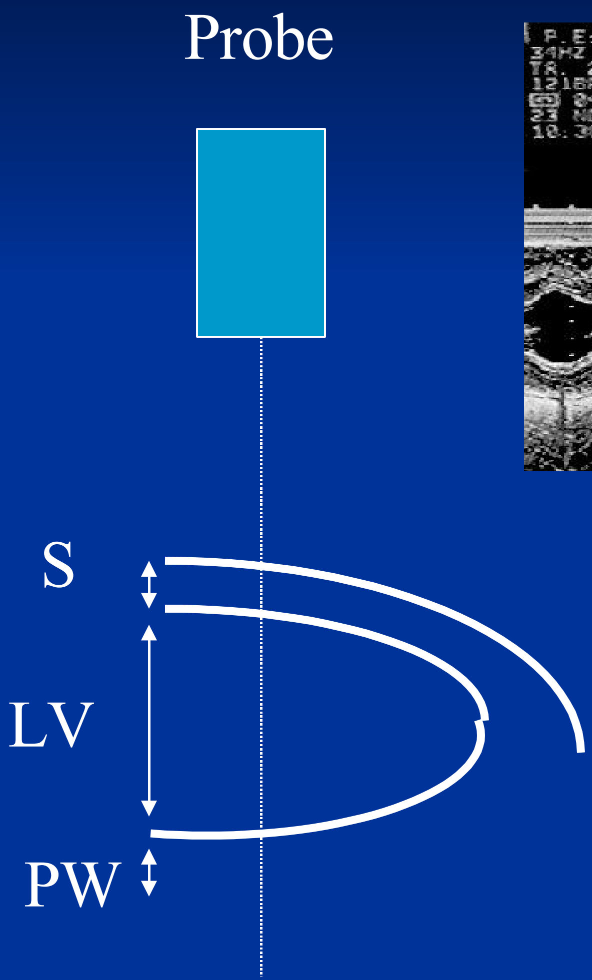
M-Mode

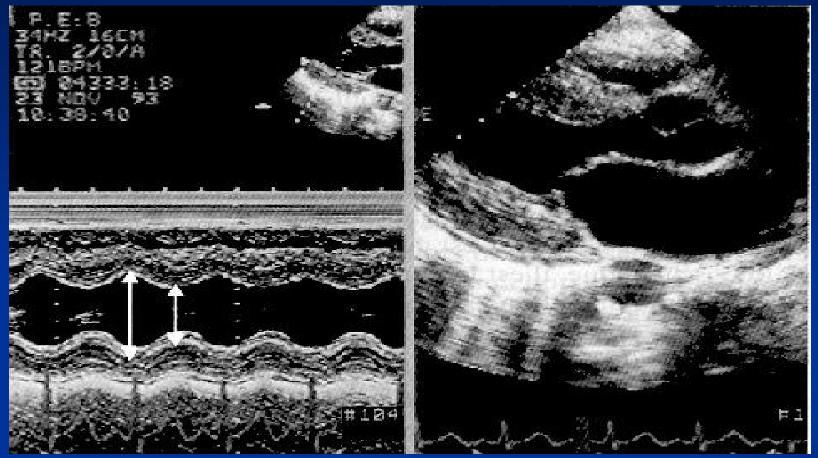


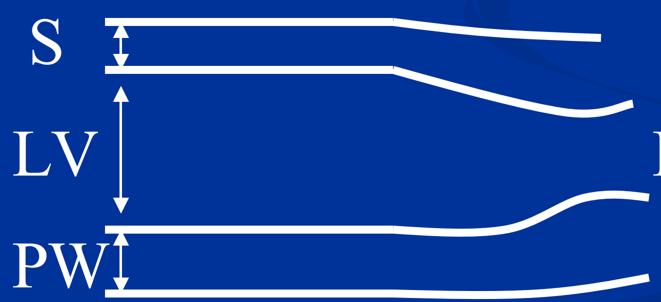
M-Mode

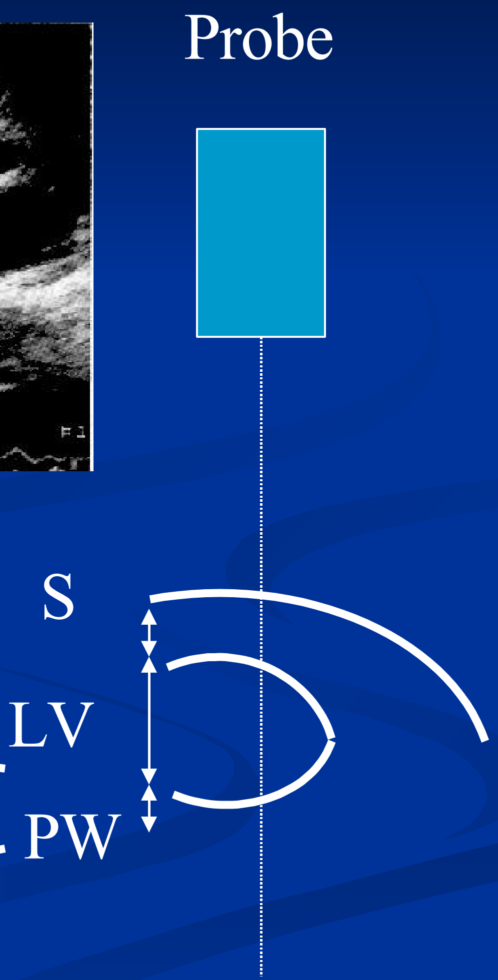


M-Mode

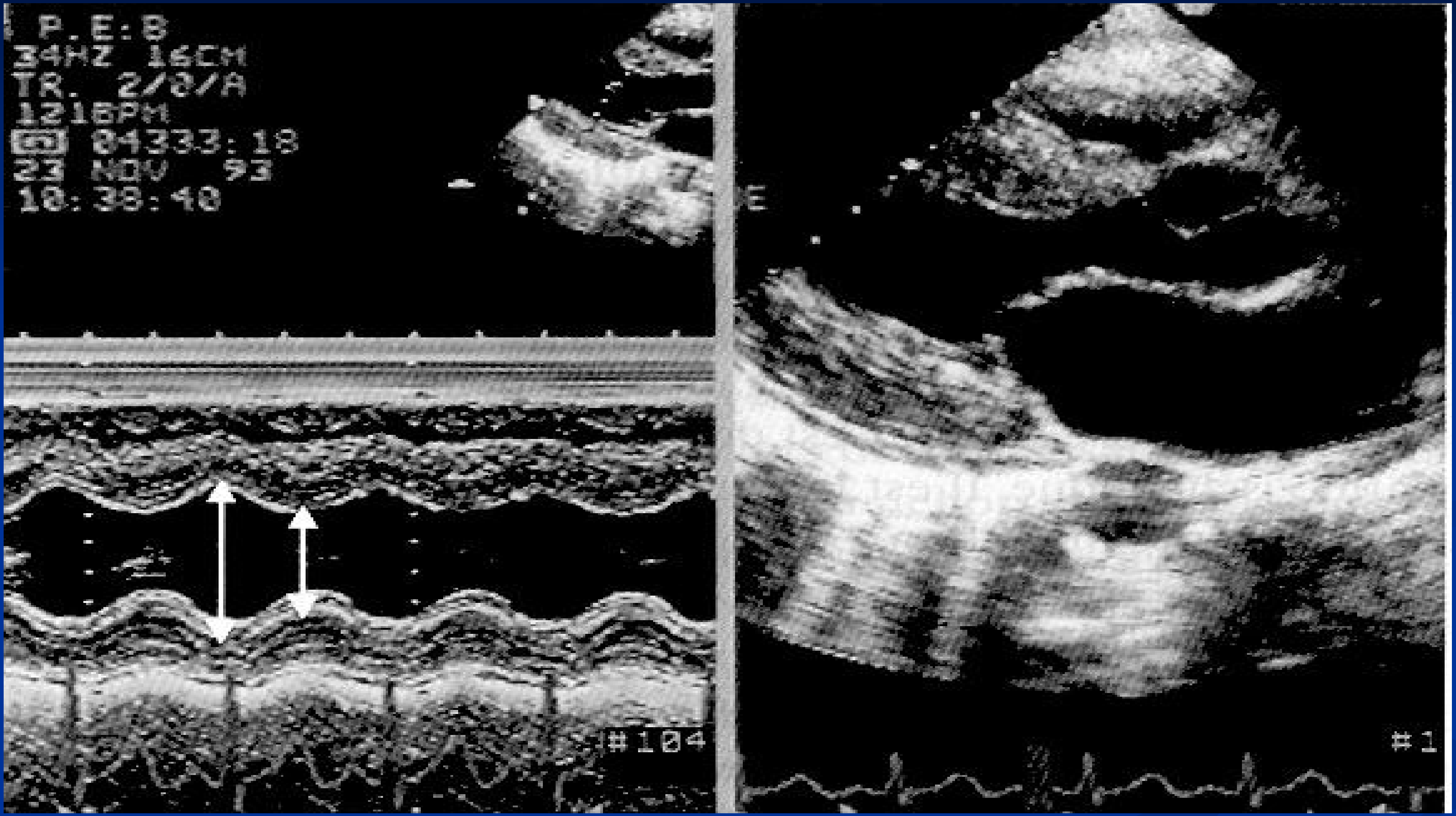








M-Mode



Shortening Fraction = (LVEDD – LVESD)/LVEDD

Velocity of Fiber Shortening = SF/Ejection Time

Echocardiography: principles

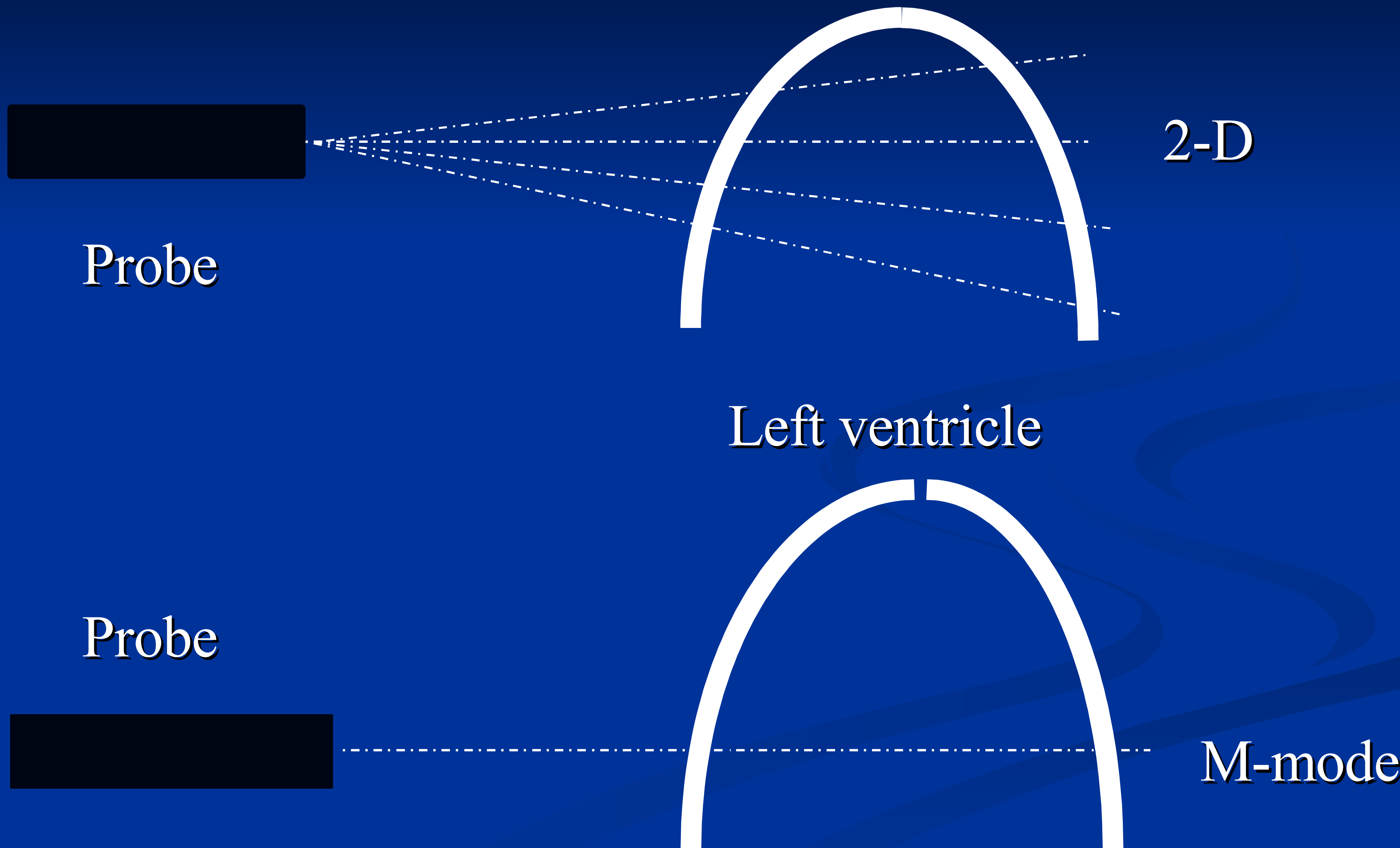


Image Analysis

Better lateral resolution proximal than distal

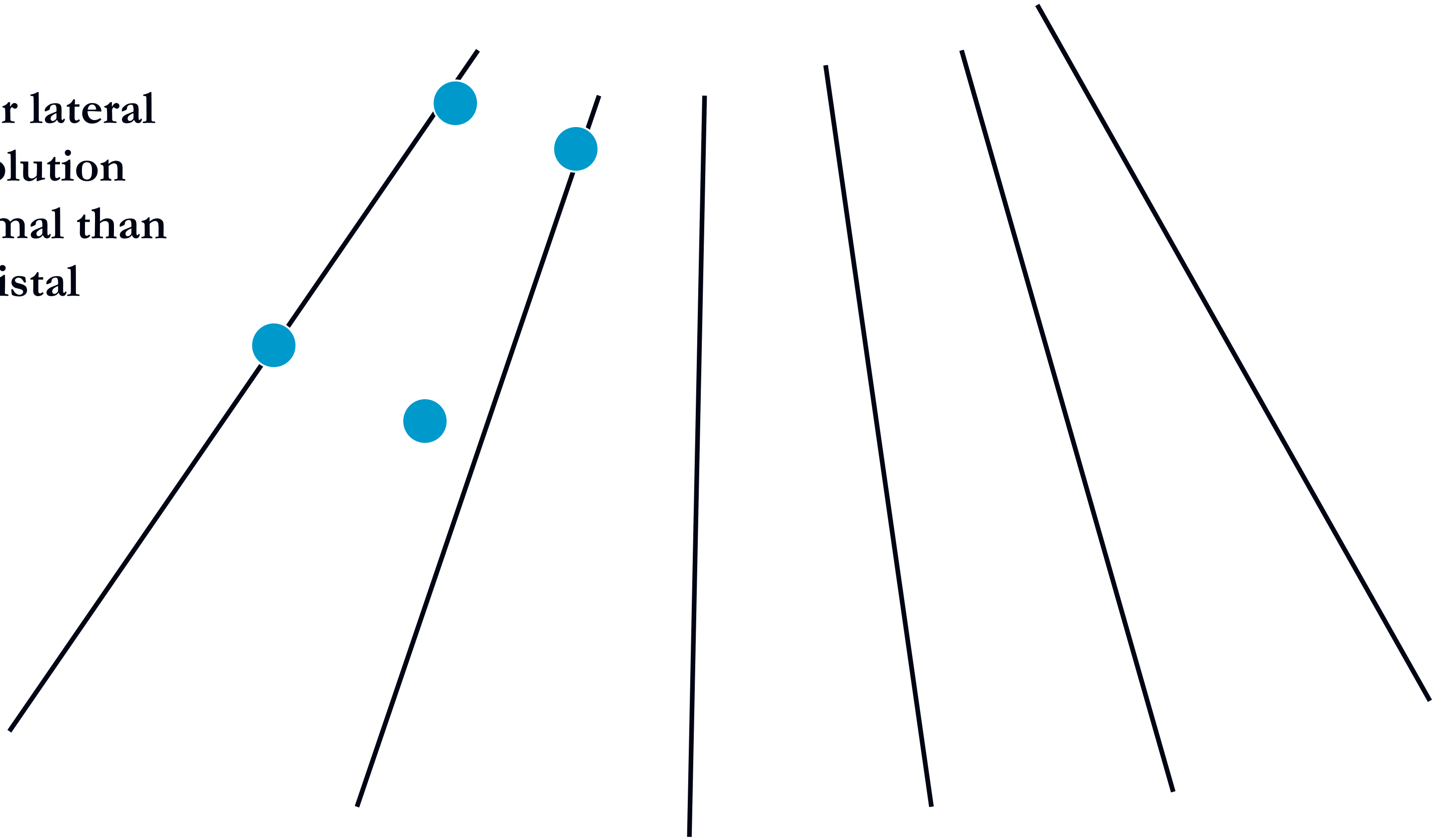
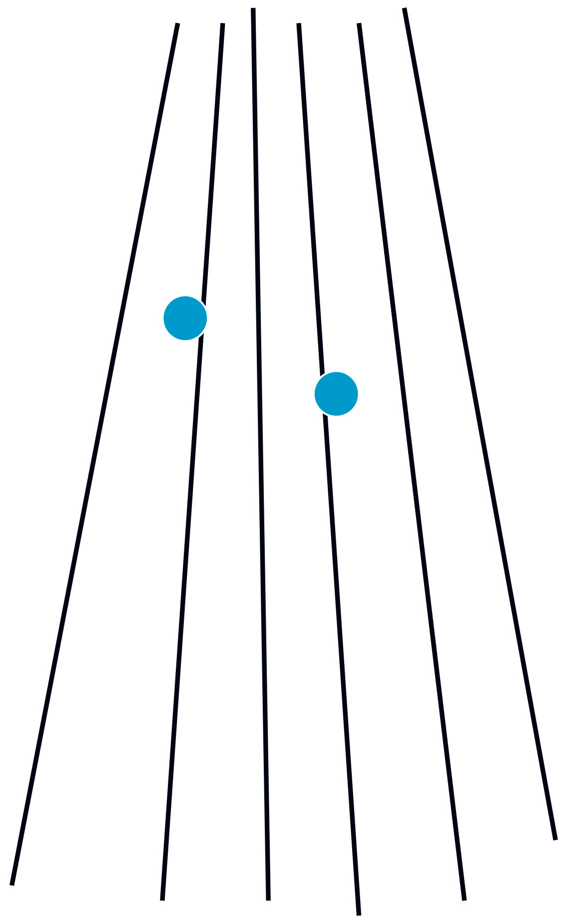


Image Analysis

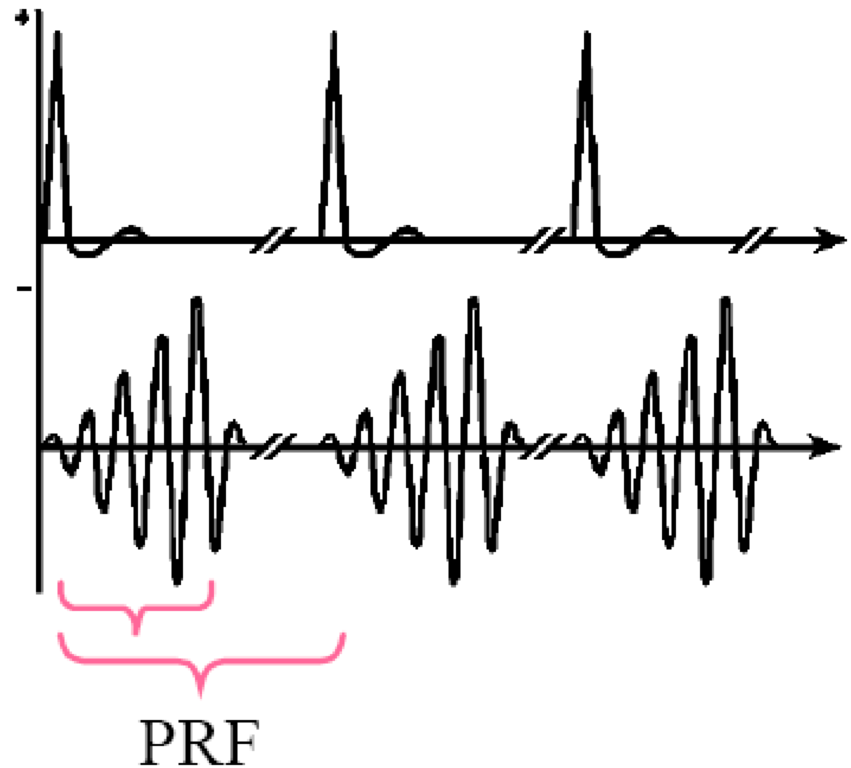
Shorter sector plane

Higher axial resolution



Pulse Repetition Frequency

Pulse



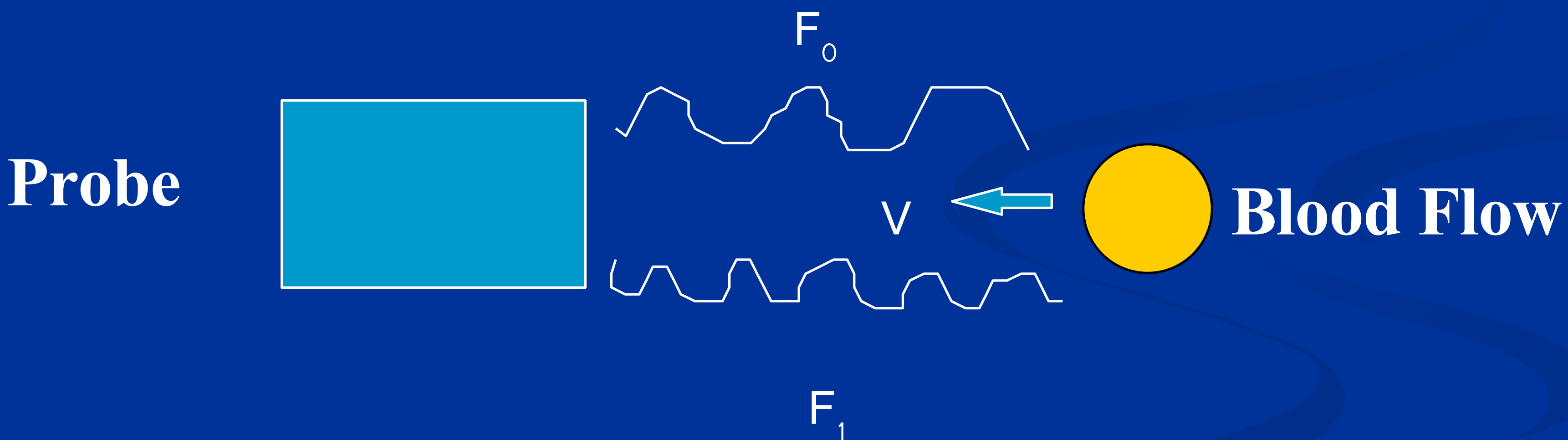
Echocardiography

- Analysis of close structures permits high PRF and therefore high image rate.
- In contrast deep structure cannot be analysed high image rate

Doppler

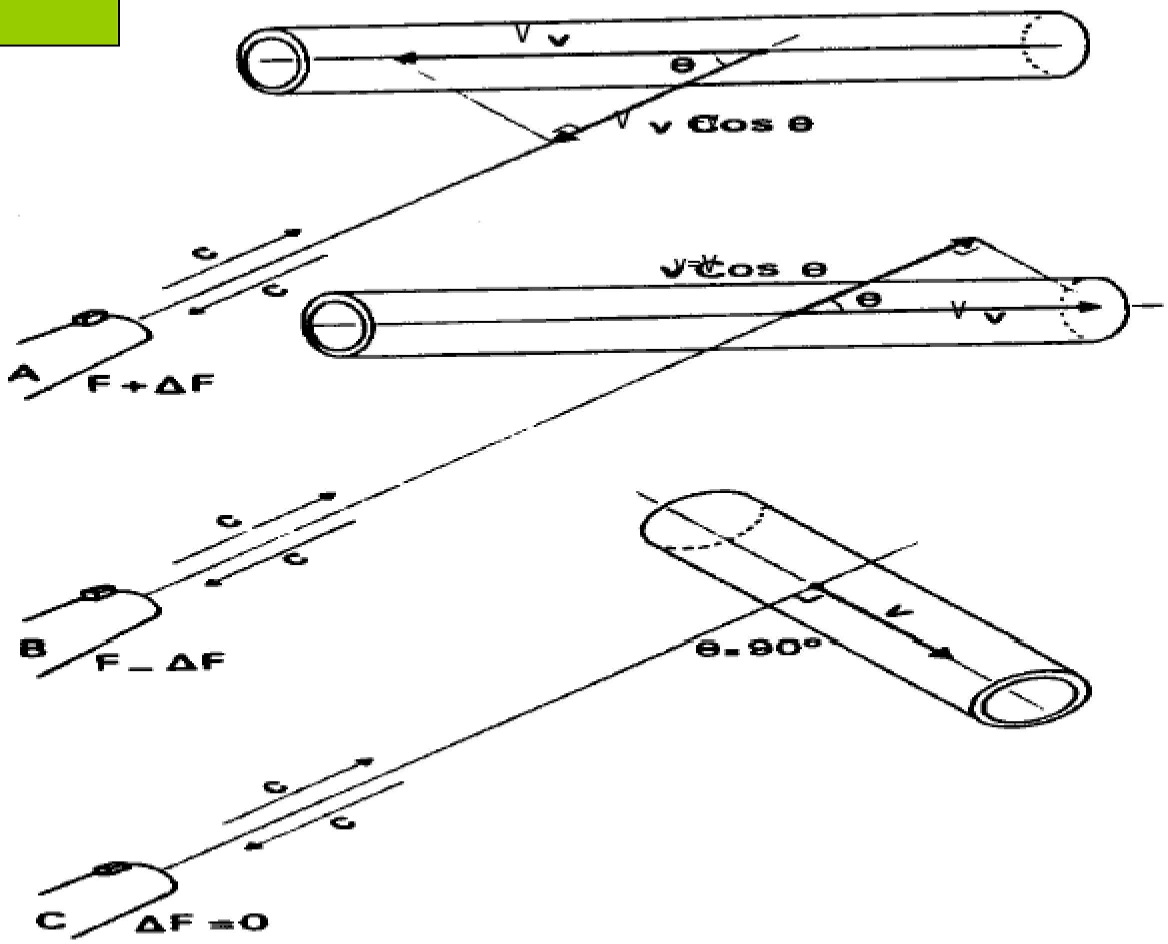
Velocity

- **Cardiac Doppler**



$V = (F_1 - F_0) \times C / 2 \times F_0 \times \cos a$

$$\Delta F = \frac{2V \cdot F_0 \cos\theta}{c}$$



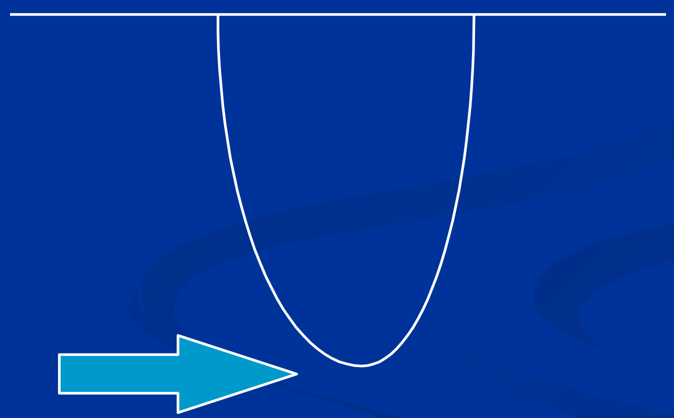
Doppler

- Doppler ultrasound beam should in the alignement of the blood flow
- Possible under estimation of the true velocity
- No over estimation

Velocity

Systolic flow recorded at aortic valve level

0 m/s



V max = 1 m/s

VTI : velocity time integral

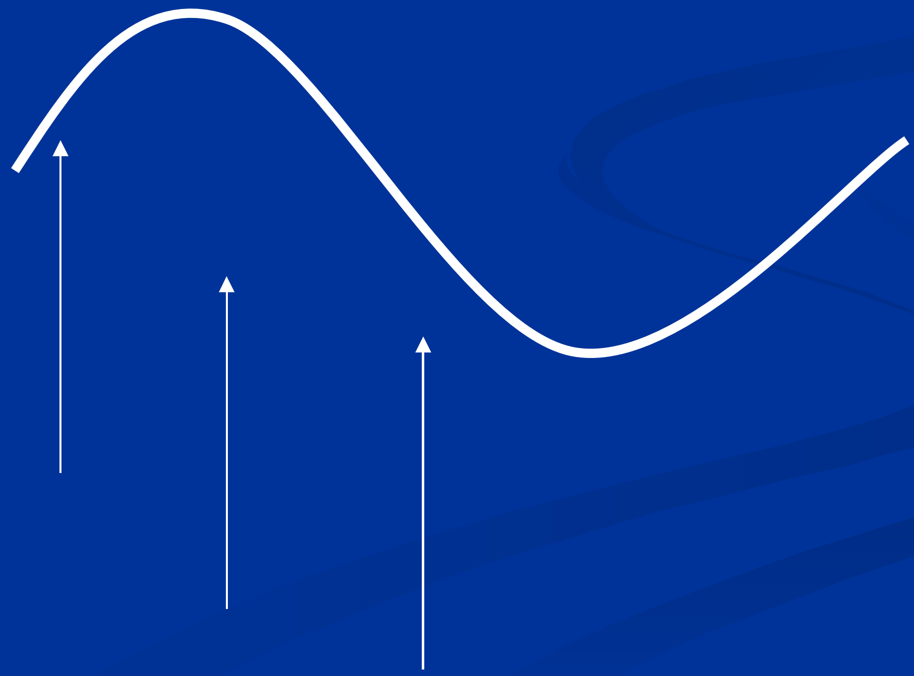
Doppler

Pulsed Doppler

- One cristal which sends and receives alternatively the ultrasound wave

Pulsed Doppler

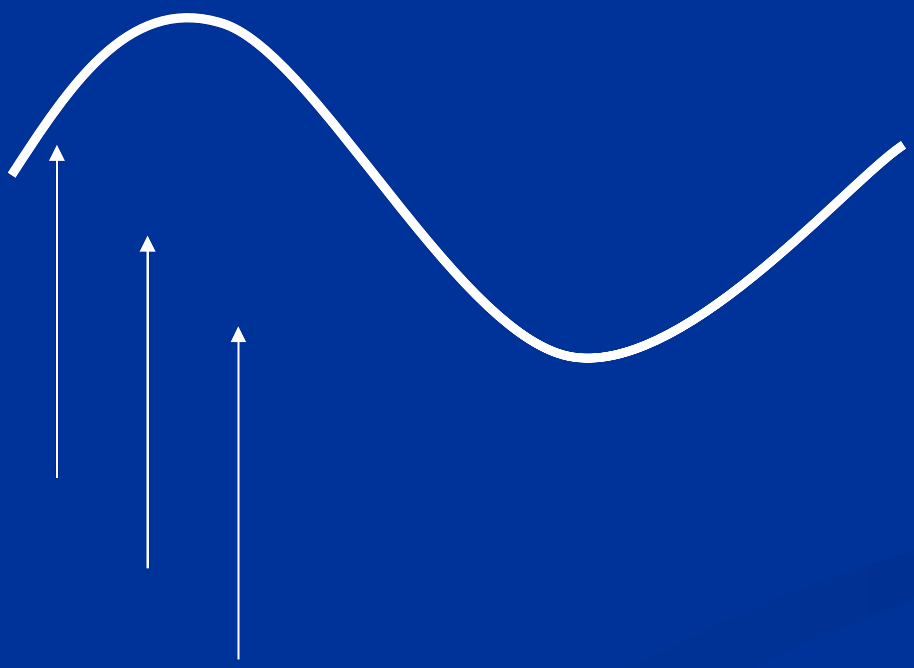
- To analyse correctly an ultrasound wave we need at lest to analyse ¼ of this wave.



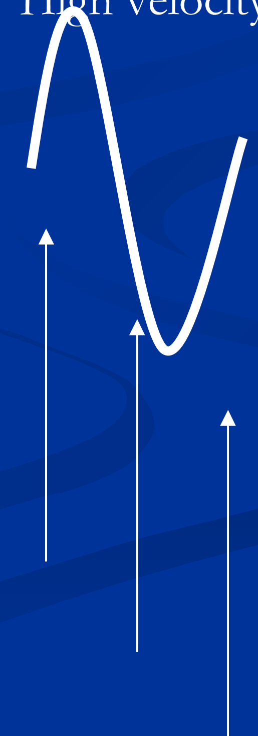
Pulsed Doppler

- Consequences:
  - High velocity of flow = high frequency

Low velocity



High velocity

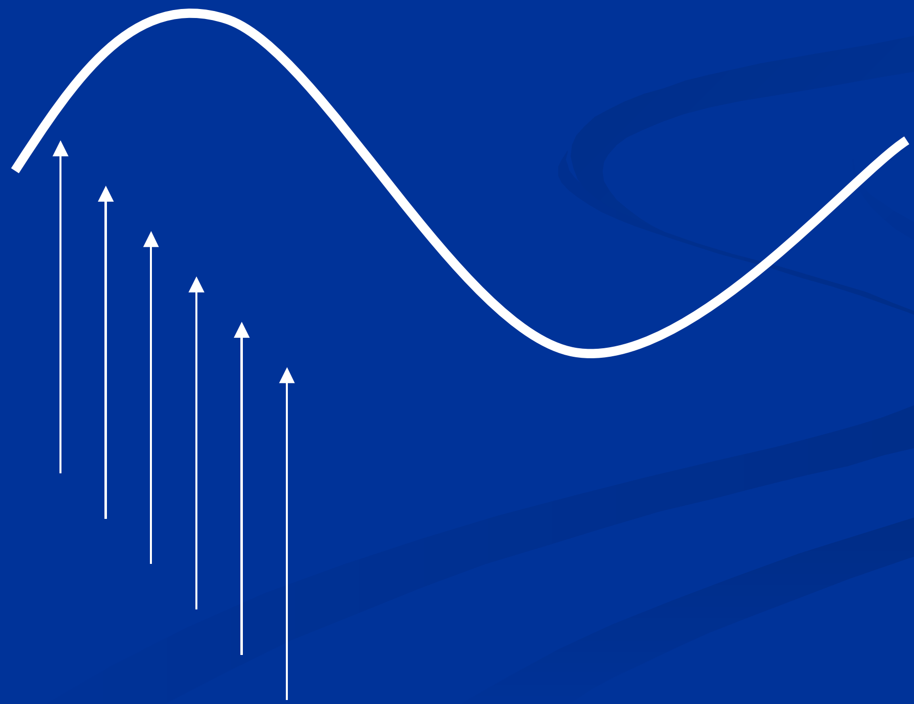


Pulsed Doppler

- Flows with high velocities cannot be analysed by using pulsed Doppler.
- All physiological flows have low velocity (1 m/s) and can be analysed by using pulsed Doppler
- In contrast pathological flows have high velocities and CANNOT be analysed by using Pulsed Doppler.

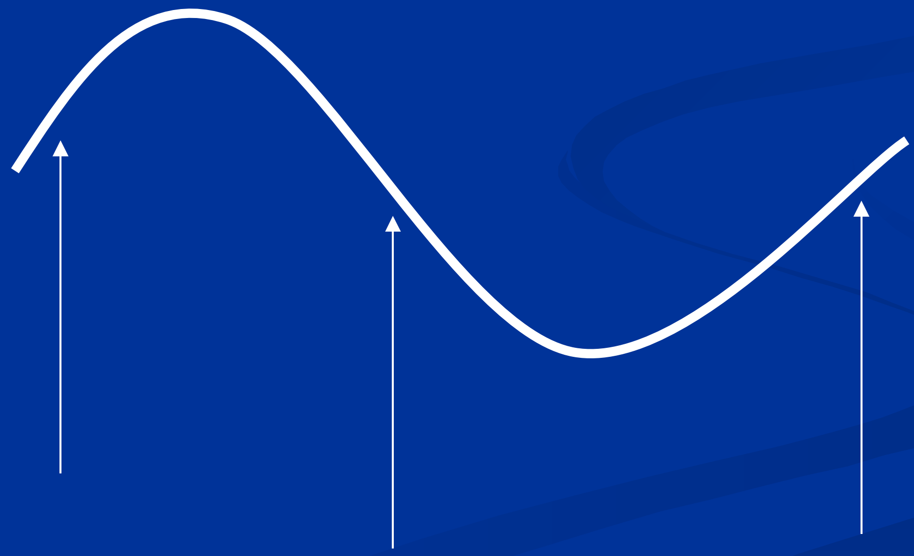
Pulsed Doppler

- Consequences:
  - Close structure



Pulsed Doppler

- Consequences:
  - Deep structure



Pulsed Doppler

- Deep and fast flows CANNOT be analysed by using pulsed Doppler
- Close flow CAN be analysed by using pulsed Doppler even if this flow is fast

Pulsed Doppler

- Advantages
  - Spacial resolution
  - Analyse of physiological flows
- Disadvantages
  - Flows with high velocities and deep cannot be analysed

Continuous wave Doppler

- Continuous emission of ultrasound beam
- Continuous reception

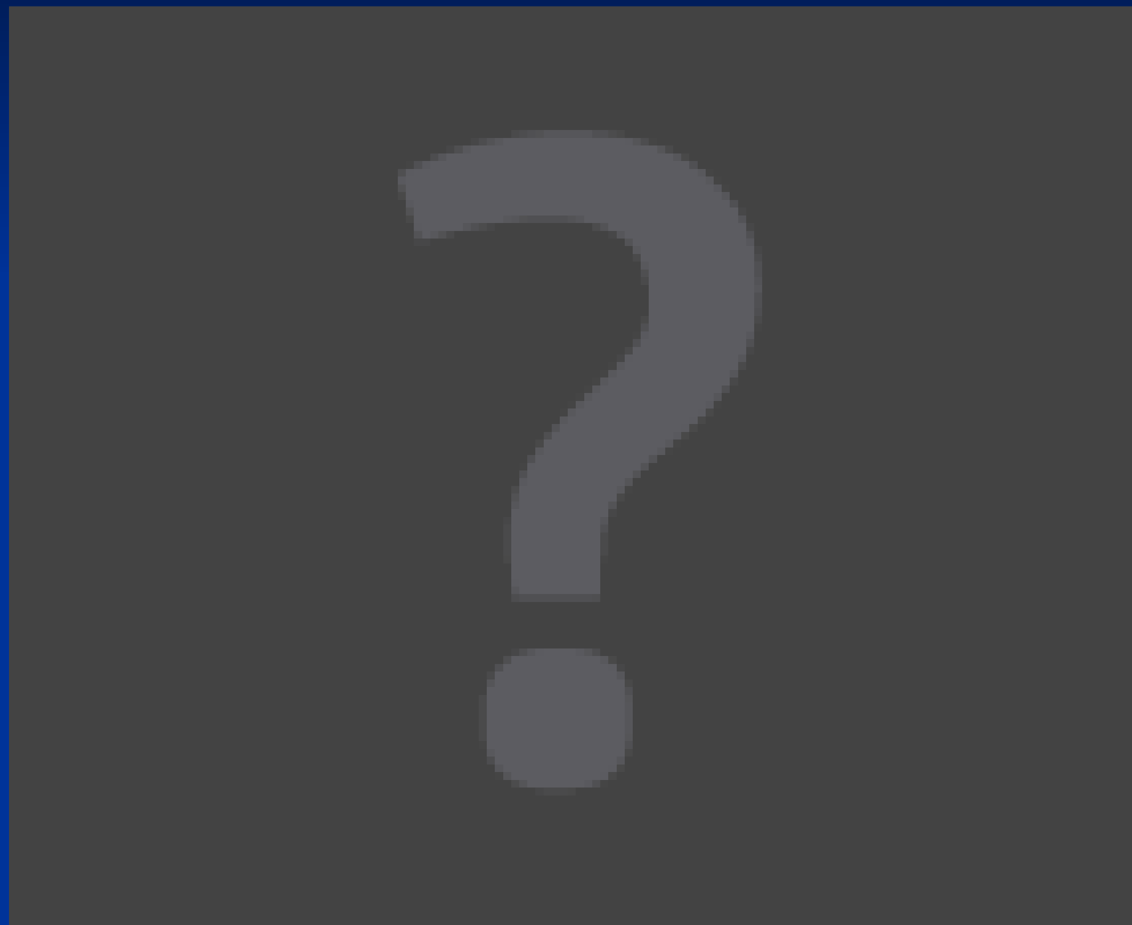
Continuous wave Doppler

- Advantages
  - Analysis of flows with high frequency
  - Analysis of close and deep flows
- Disavantages
  - Spacial ambiguity

Color Doppler

Color Doppler

Color Doppler

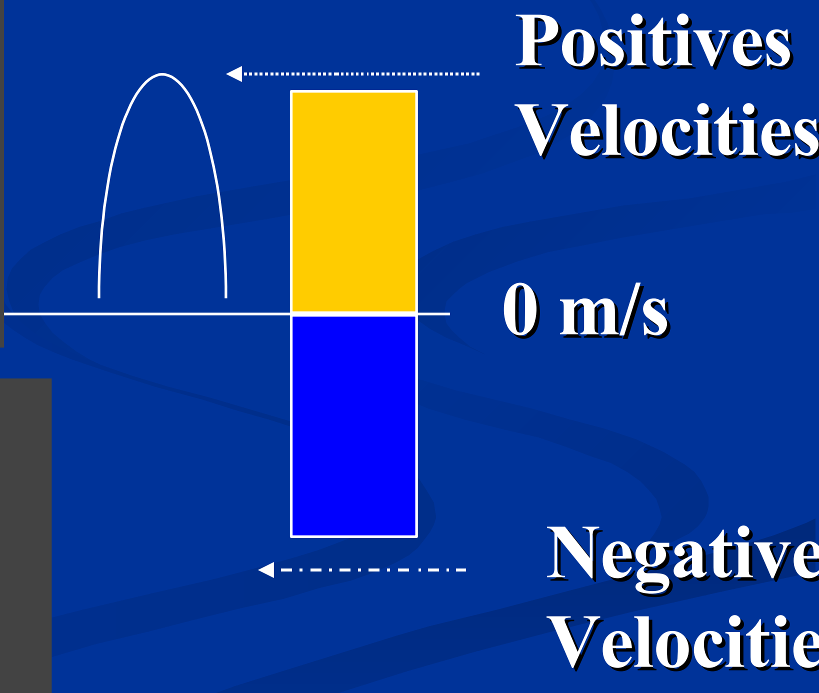


Doppler

- Pulsed Doppler

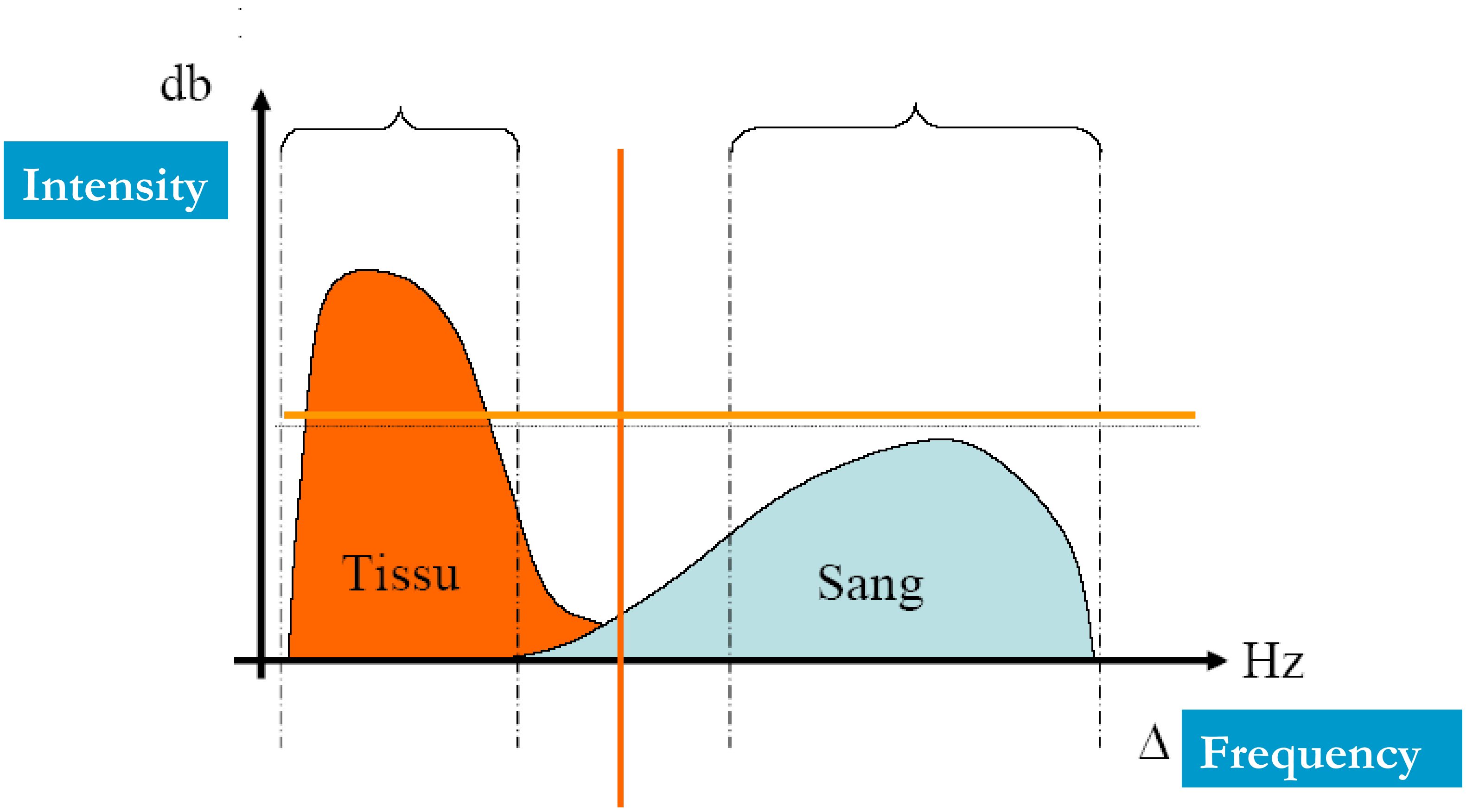
- Continuous Doppler

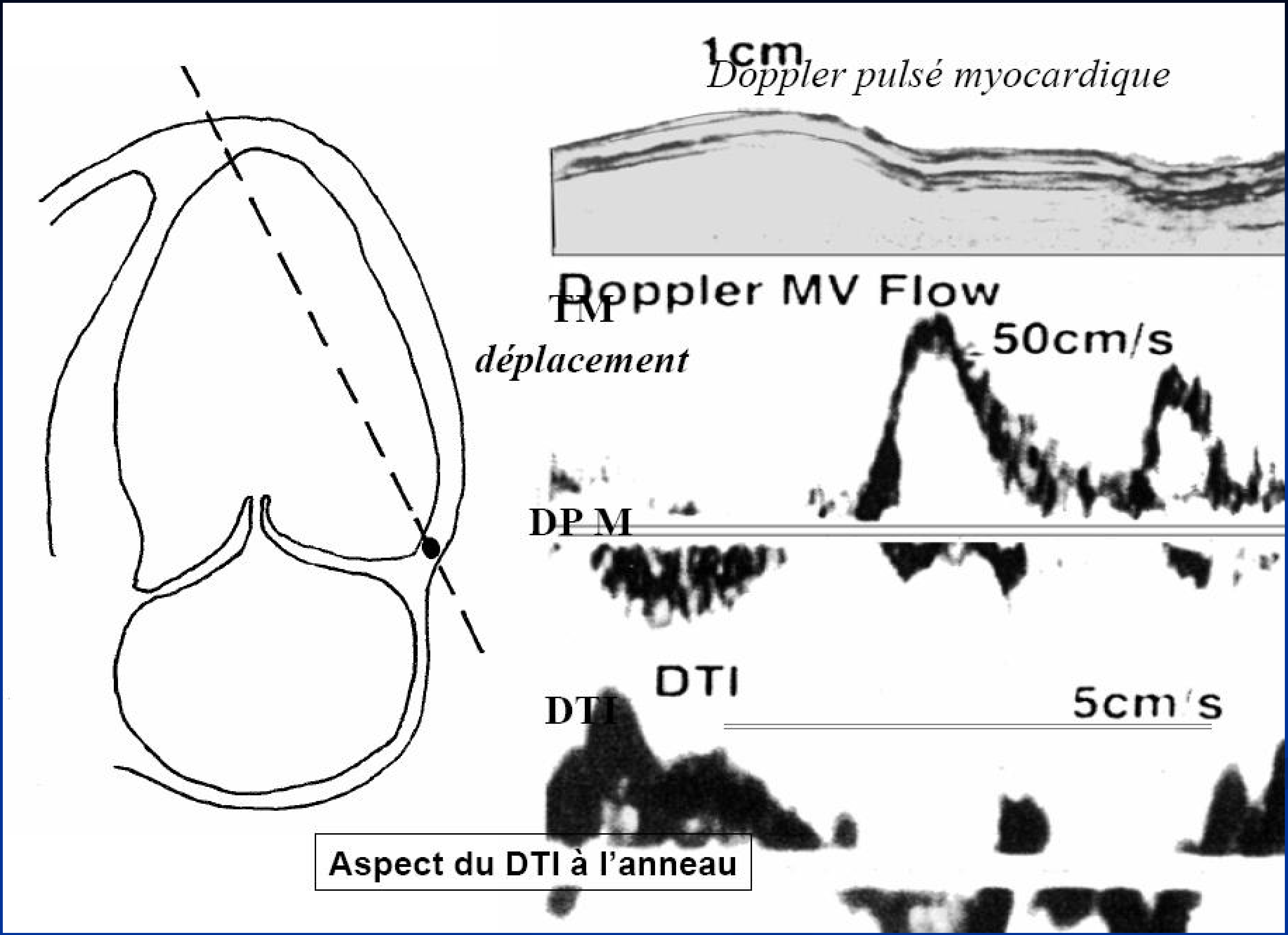
- Color Doppler



Tissue Doppler Imaging

Tissue Doppler Imaging




1cm
Doppler pulsé myocardique
Doppler MV Flow
TM
déplacement
50cm/s
DP M
DTI
DTI
5cm/s
Aspect du DTI à l'anneau

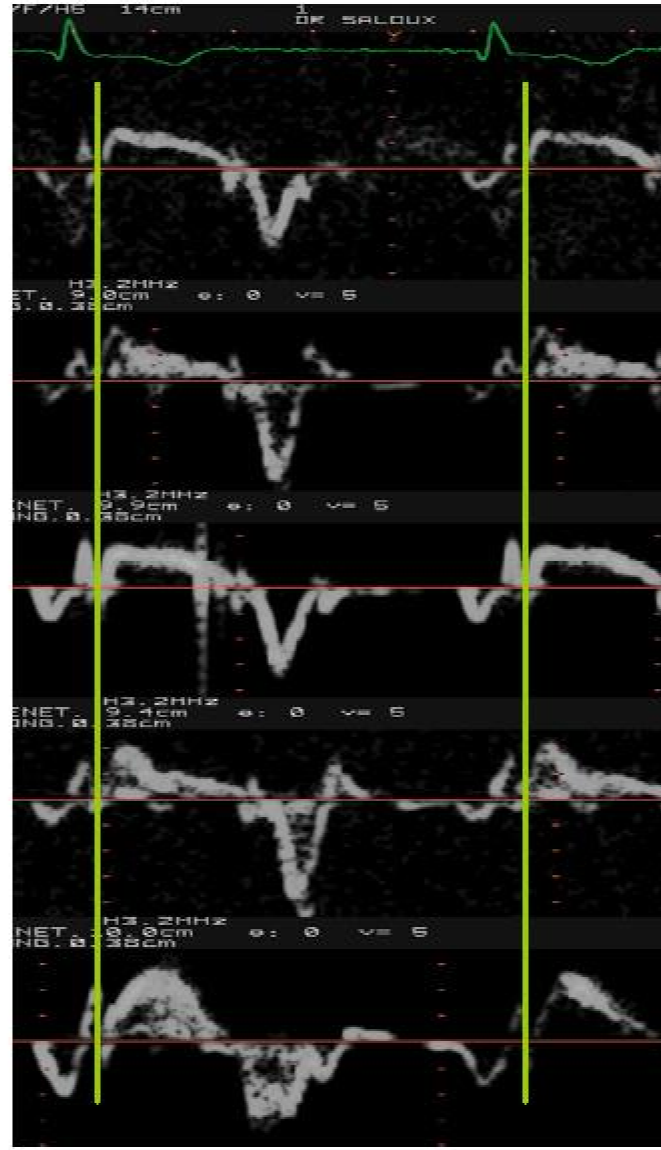
Synchronisation

Ventricule gauche

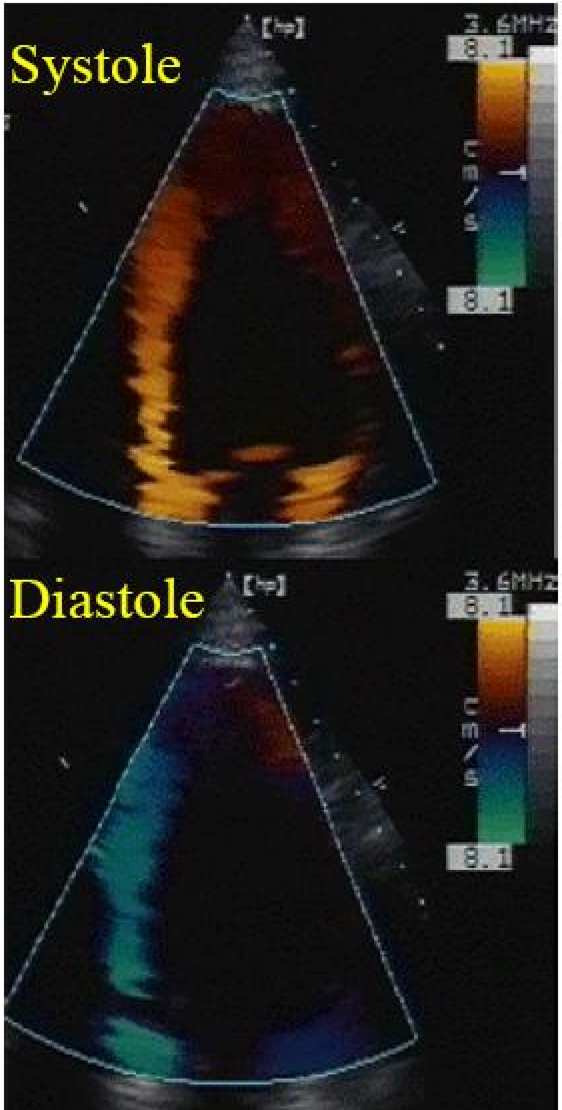
- Septum basal →
- Latéro basal →
- Postéro basal →
- Antéro basal →

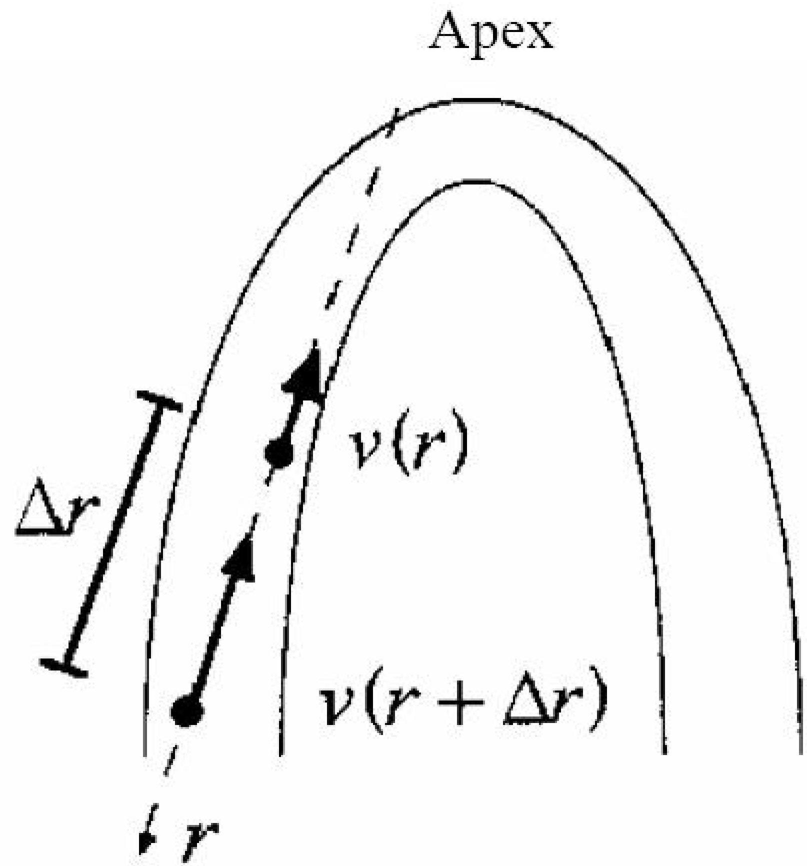
Ventricule droit

- Latéro basal →



Doppler couleur myocardique 2-D

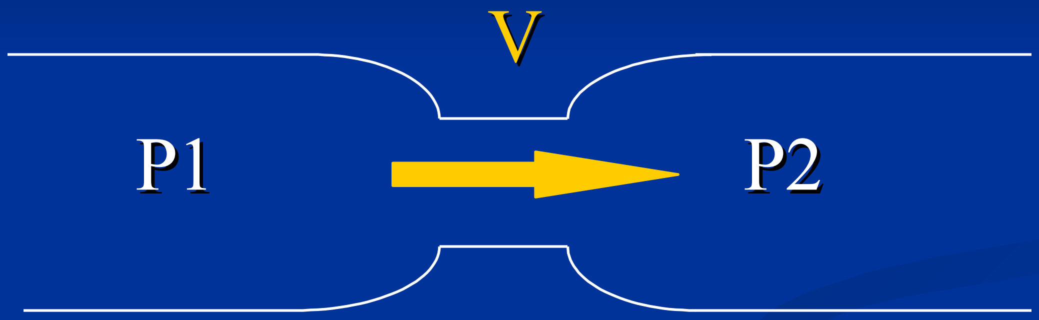




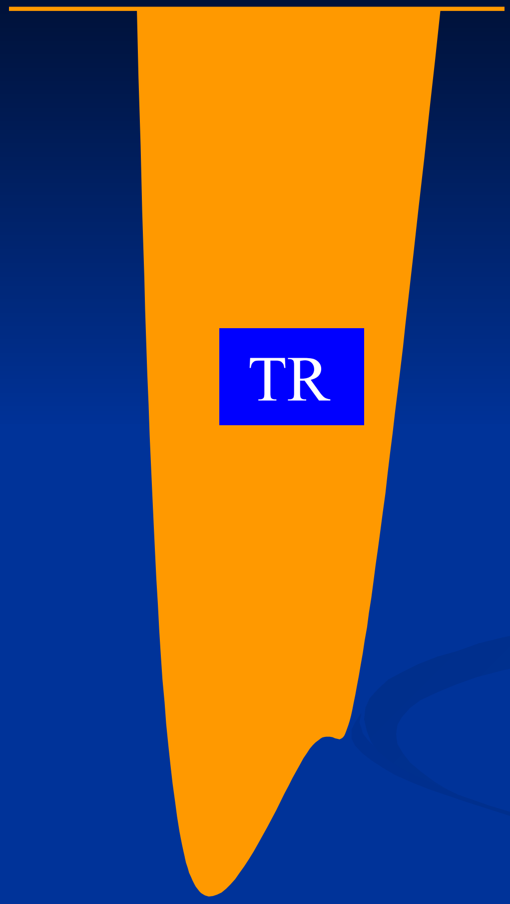
Heimdal JASE 1998;11:1013-9

Dynamics of fluids

Doppler : non-invasive "Swan-Ganz"

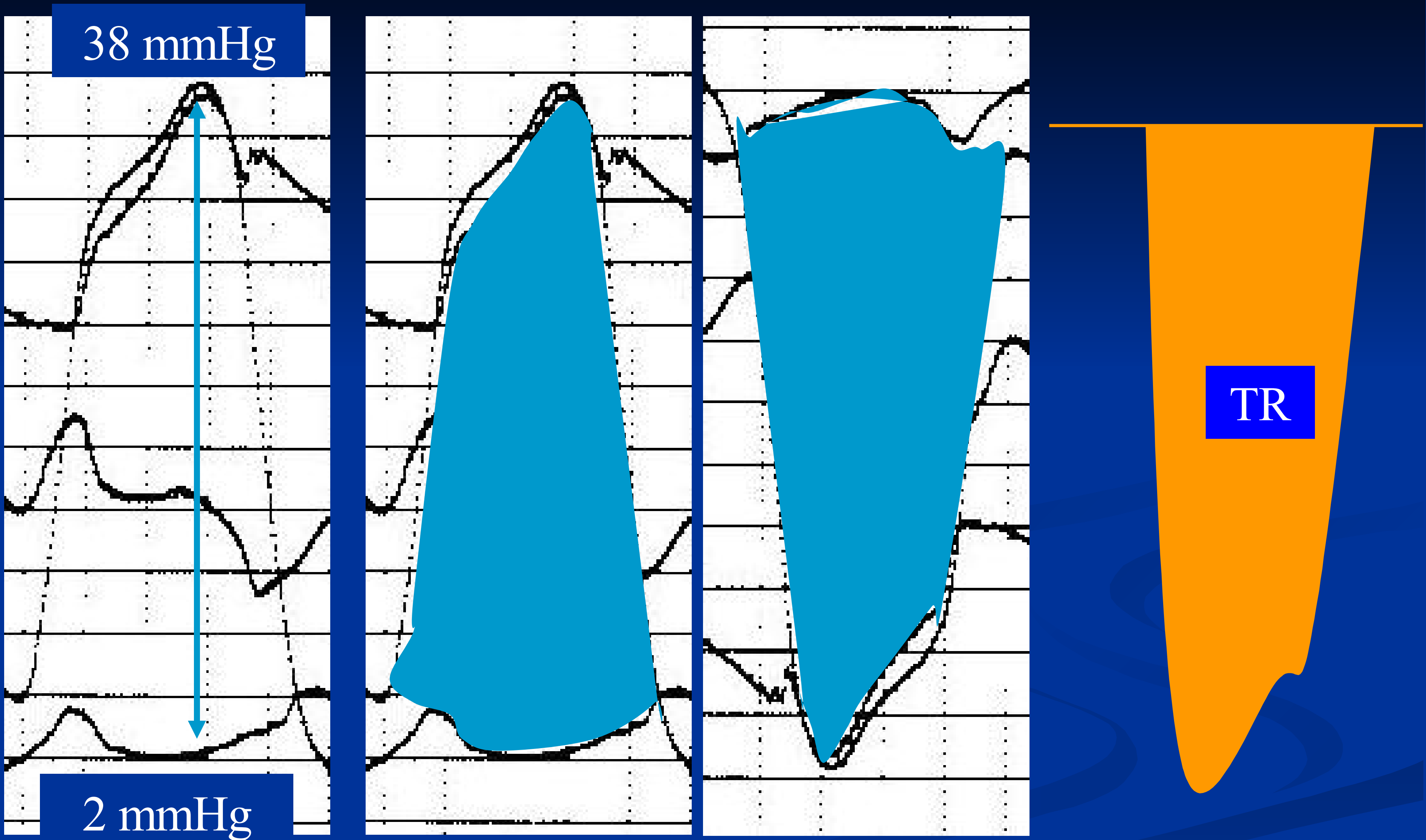


$$P2 - P1 = 4 \times V^2$$



Velocity= 3 m/s

Velocity= 3 m/s

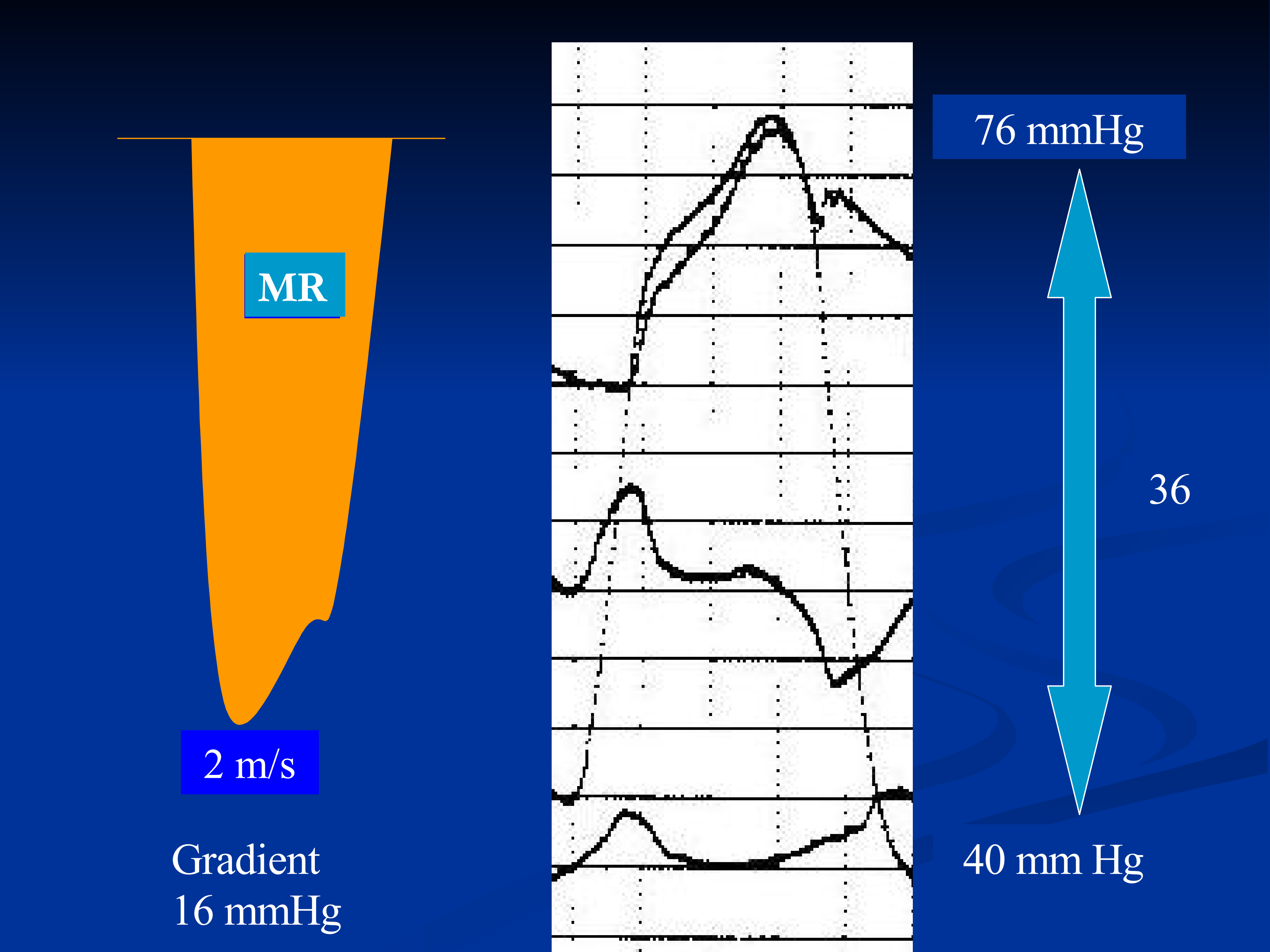


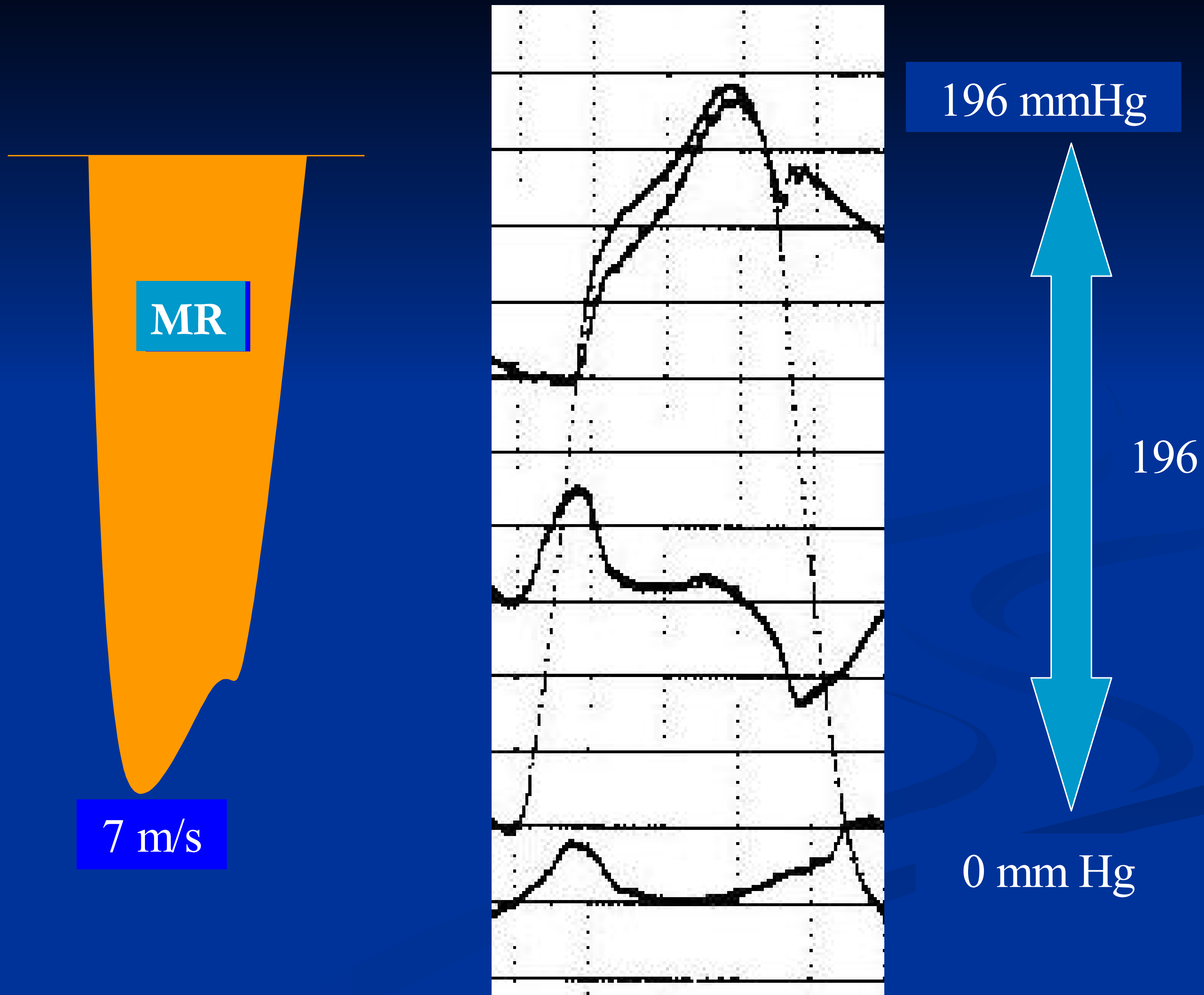
Gradient = 36 mmHg

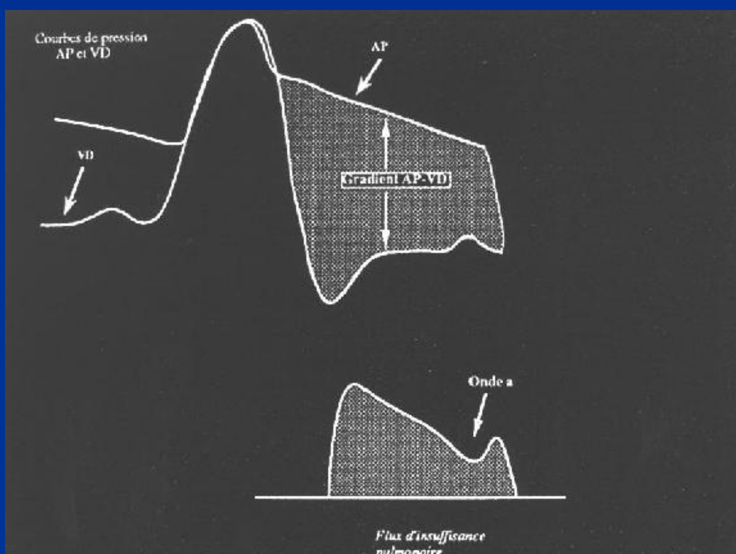
dP = 4 V²

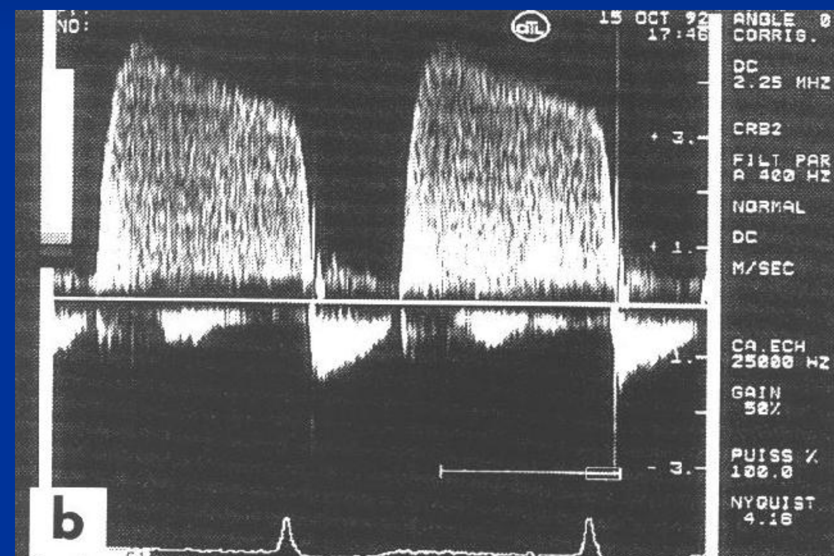
Velocity= 3 m/s

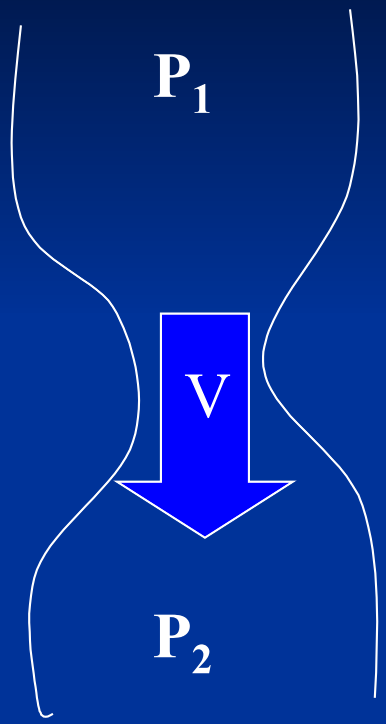

MR
2 m/s

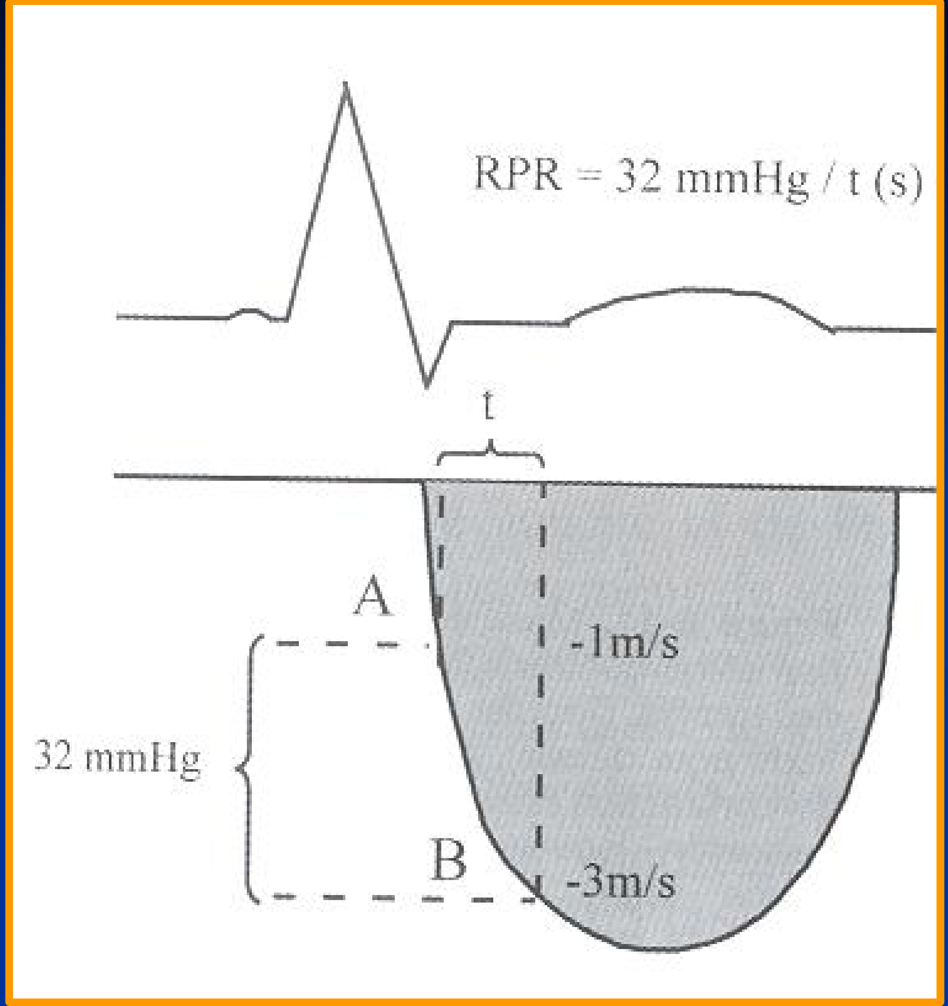

MR
2 m/s
Gradient
16 mmHg
76 mmHg
36
40 mm Hg


MR
7 m/s
196 mmHg
196
0 mm Hg


Courbes de pression
AP et VD
AP
VD
Gradient AP-VD
Onde a
Flux d'insuffisance
pulmonaire


NO:
15 OCT 92
17:46
ANGLE 0
CORRIG.
DC
2.25 MHZ
CRB2
FILT PAR
A 400 HZ
NORMAL
DC
M/SEC
CA.ECH
25000 HZ
GAIN
50%
PUISS %
100.0
NYQUIST
4.16
b


P1
V
P2


RPR = 32 mmHg / t (s)
t
A
-1m/s
32 mmHg
B
-3m/s

Conclusions

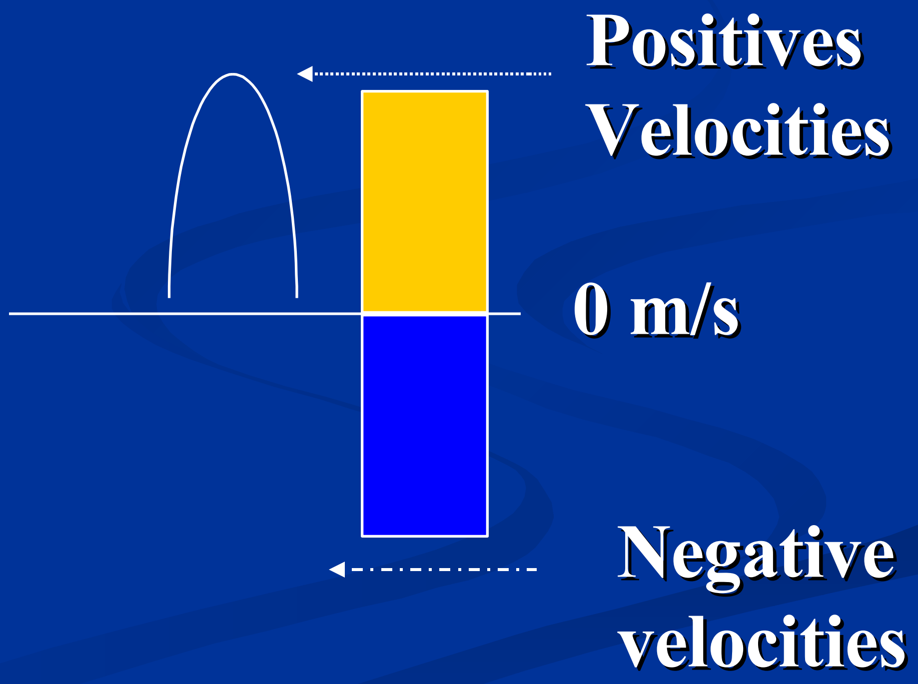
- Echocardiography : image
- Pulsed and continuous Doppler : hemodynamics
- Color Doppler : flows
- Tissue Doppler : myocardial function

Other Techniques

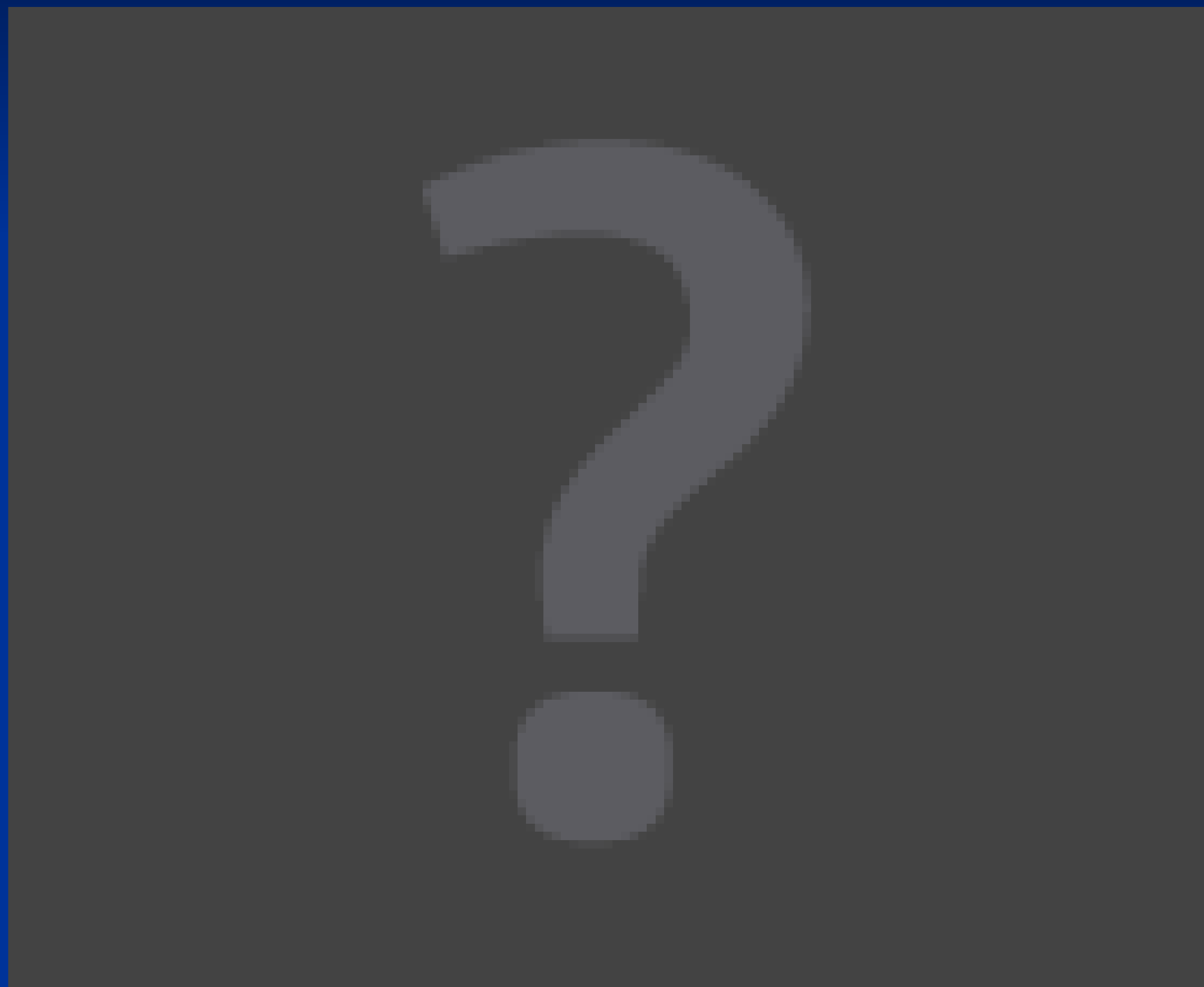
- DTI
- Contraste
- Color kinesis

Different Doppler techniques

- Pulsed Doppler
- Continuous Doppler
- Color Doppler

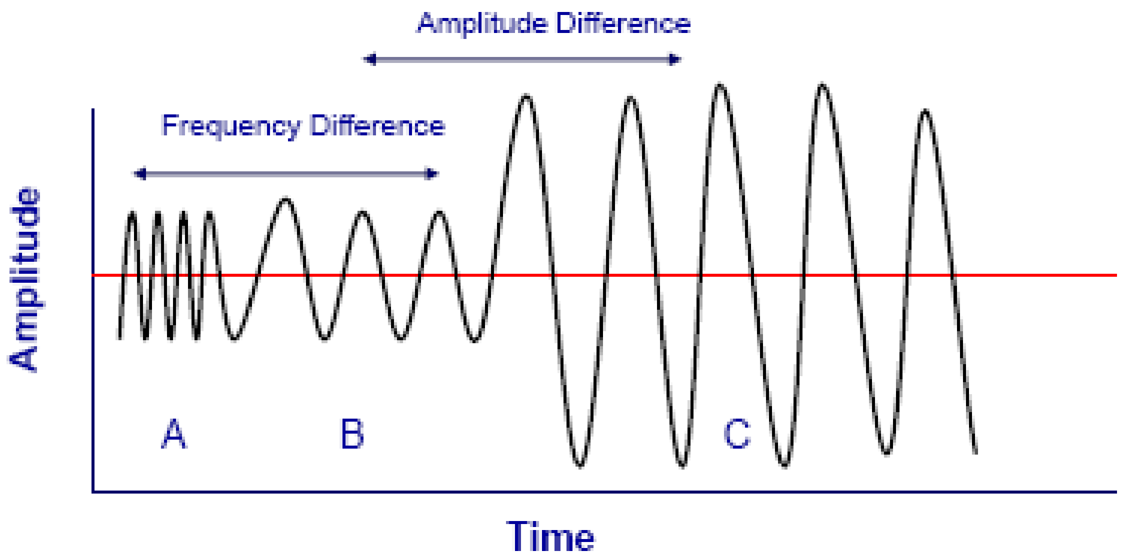


Doppler Pulsé



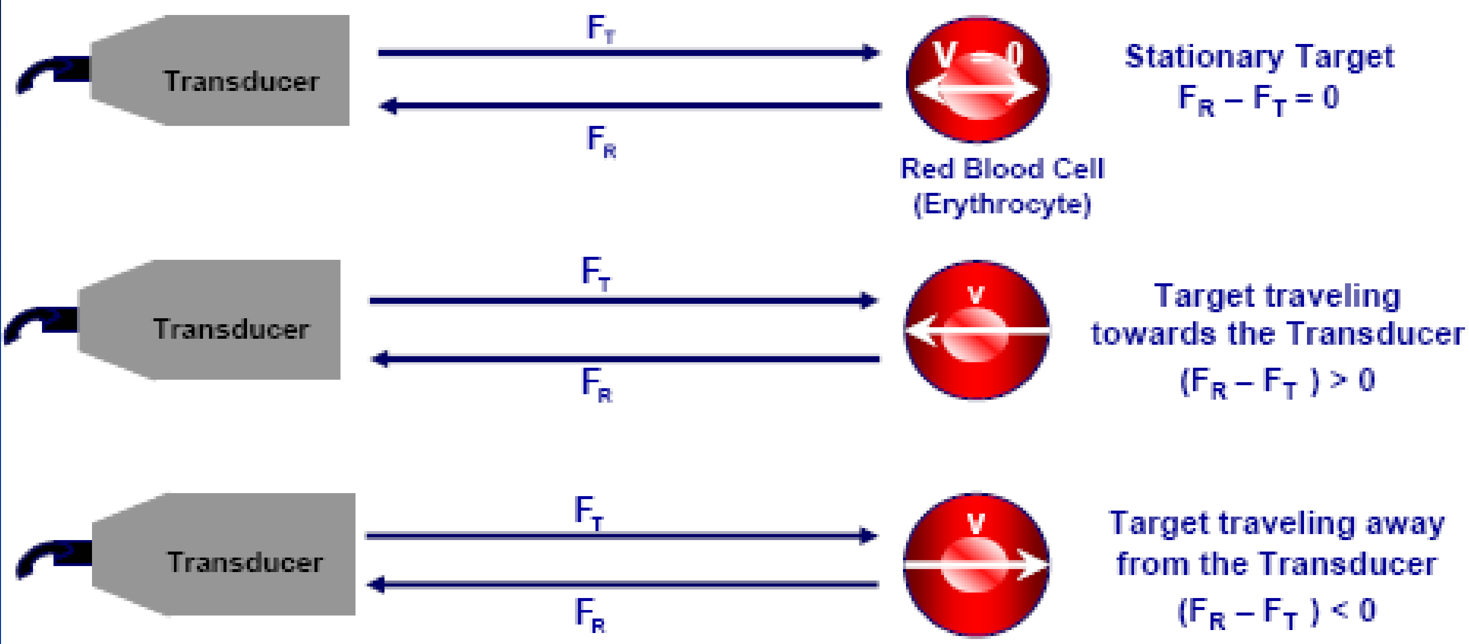
Doppler Continu

Doppler Ultrasound



This diagram shows the frequency differences that form the basis of Doppler ultrasound. The back scattered ultrasound signal contains amplitude, phase and frequency information. Signals B and C differ in amplitude but have the same frequency. Signals A and B have different frequencies, but the same amplitude. It is the **frequency differences** that are the basis of Doppler ultrasound.

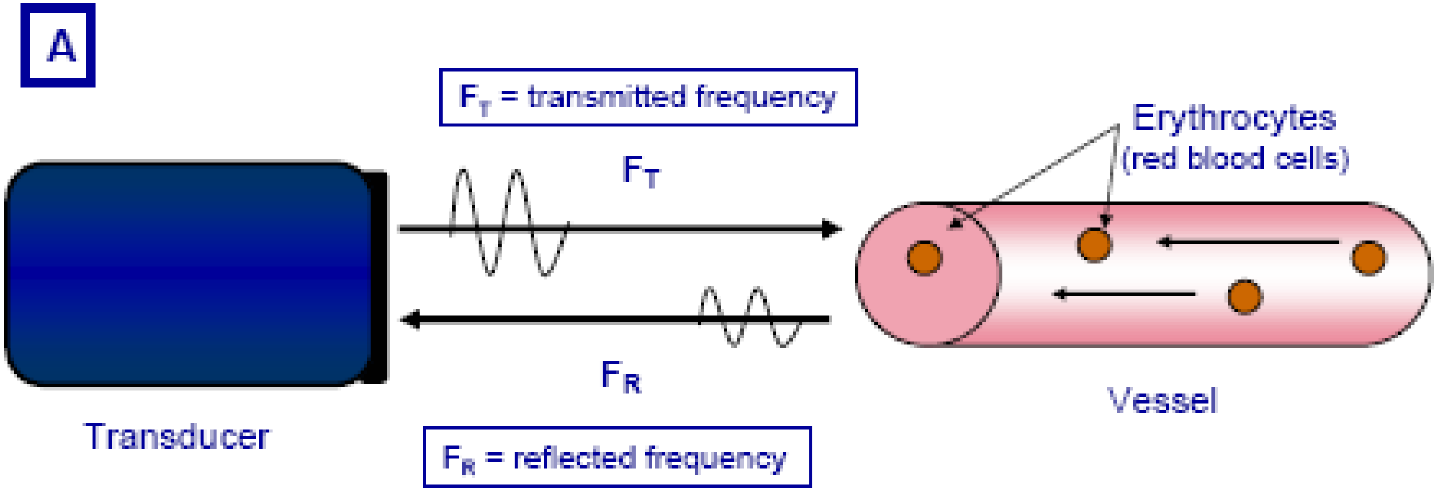
Doppler Effect



If the target is stationary then the reflected ultrasound has the same frequency as the transmitted sound, so there is no difference between the transmitted (F_T) and the reflected (F_R) frequencies. When the target is moving there is a change in the frequency of the sound scattered by the target interface. The change in frequency is directly proportional to the velocity of the moving target and can be calculated using the Doppler equation (see over page).

The Doppler Equation

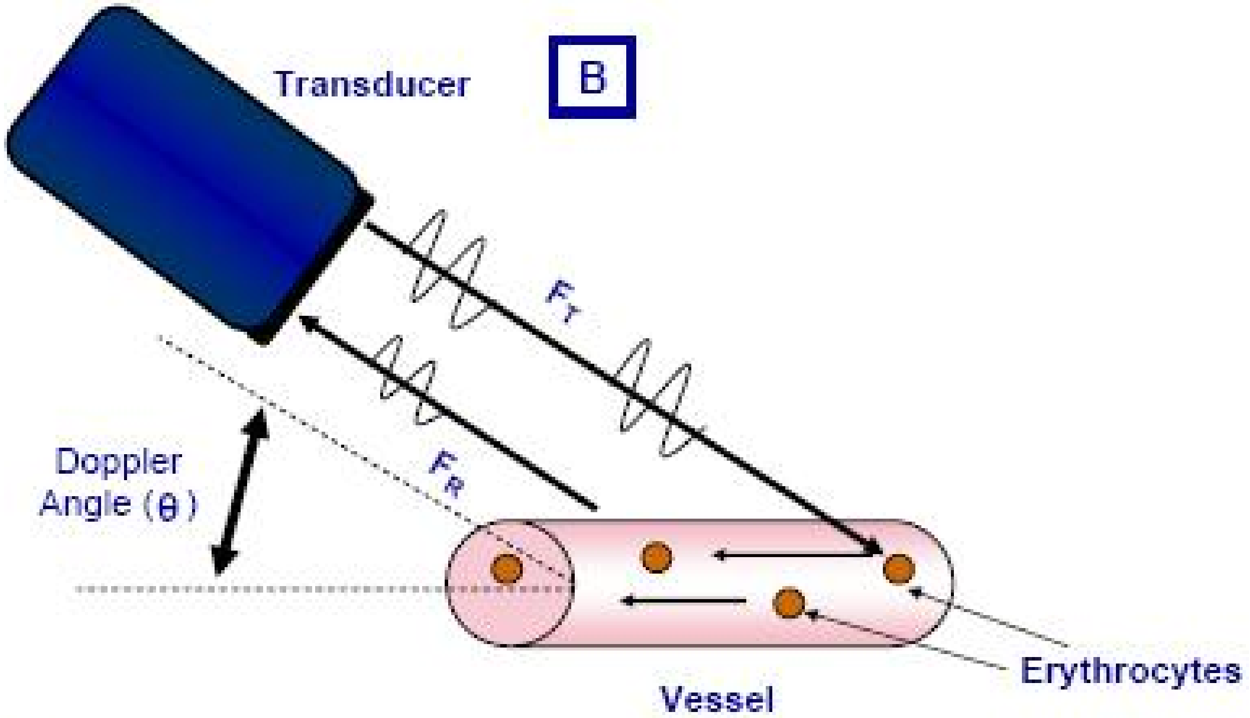
The Doppler Equation describes the relationship of the Doppler frequency shift to target velocity. The frequency difference is equal to the reflected frequency (F_R) minus the originating frequency (F_T). If the resulting frequency is higher, then there is a positive Doppler shift and the object is moving toward the transducer, but if the resulting frequency is lower, there is a negative Doppler shift and it is moving away from the transducer. In its simplest form it would be calculated as if the ultrasound was parallel to the target's direction, as shown in diagram **A** below.



However, this would be a rare occurrence in clinical practice, because the transducer is rarely pointed head on to a blood vessel. In real life, the ultrasound waves would approach the target at an angle, called the Doppler angle (θ). On the following page, diagram B shows the Doppler equation used in general clinical situations, which includes the Doppler angle.

Continued

The Doppler Angle



The ultrasound beam usually approaches the moving target at an angle called the *Doppler angle* (θ). This reduces the frequency shift in proportion to the cosine of this angle. If this angle is known then the flow velocity can be calculated. The equation used is:

$$\Delta F = (F_R - F_T) = \frac{2F_T V \cos\theta}{C}$$

(See over page for description)

Continued

The Doppler Equation

The Doppler Equation

$$\Delta F = (F_R - F_T) = \frac{2F_T V \cos\theta}{C}$$

Where:

ΔF ≡ Doppler shift frequency (the difference between the transmitted and received frequencies)

F_T ≡ transmitted frequency

F_R ≡ reflected frequency

V ≡ velocity of the blood flow towards the transducer

C ≡ velocity of sound in tissue

θ ≡ the angle between the sound beam and the direction of moving blood

The Doppler Angle

- The Doppler angle (θ) is also known as the angle of insonation. It is estimated by the sonographer by a process known as angle correction, which involves aligning an indicator on the duplex image along the longitudinal axis of the vessel.

- There are a few considerations that affect the performance of a Doppler examination that are inherent in the Doppler equation, which are:

  – The cosine of 90° is zero, so if the ultrasound beam is perpendicular to the direction of blood flow, there will be no Doppler shift and it will appear as if there is no flow in the vessel.

  – Appropriate estimation of the angle of insonation, or angle correction, is essential for the accurate determination of Doppler shift and blood flow velocity. The angle of insonation should also be less than 60° at all times, since the cosine function has a steeper curve above this angle, and errors in angle correction will be magnified.

Doppler Signal Processing and Display

As ultrasound developed different modes to display information from tissue interfaces (A-mode, B-Mode etc.), so did different Doppler ultrasound techniques develop, each with its own strengths and weaknesses. All Doppler techniques display flow information, but some are optimized to display certain characteristics of blood flow.

For example, conventional Doppler imaging produces a wave form that can be used to calculate the actual flow rate in a vessel, whereas colour flow Doppler displays the same information by superimposing the image of moving blood in colour on the usual real time image.

The colour flow immediately draws the operator's attention to areas of high flow or disturbed flow, which can then be examined more thoroughly and quantitatively with conventional Doppler imaging.

In the following pages the different techniques will be described in more detail.

Doppler frequency shifts in most clinical situations are audible to the human ear and flow characteristics can be identified by sound alone to a trained ear, but they are usually displayed on a screen as a frequency spectrum of the returning signal over time.

These frequencies are analyzed using spectral analysis, which separates the signal into individual components and assigns a relative importance. Fast Fourier transformation (which does not need to be understood for this course) is the most popular method of spectral analysis.

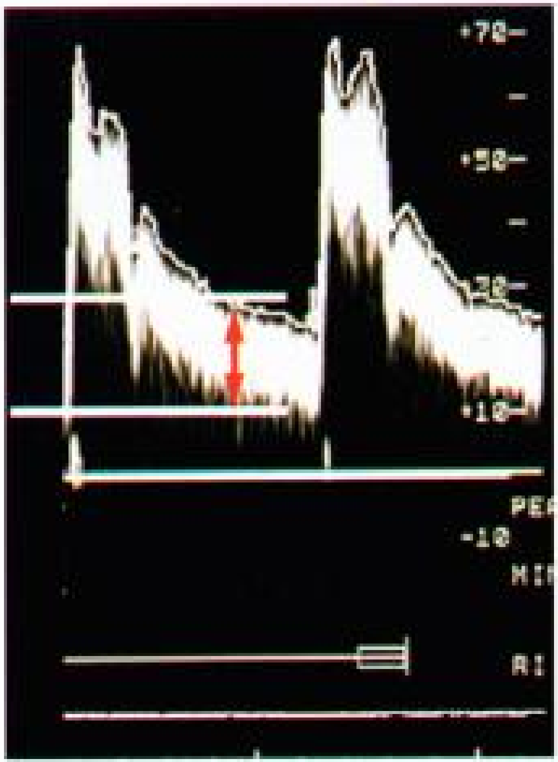
Continued

Doppler Frequency Spectrum

The figure on the right shows changes in the flow velocity and direction in the cardiac cycle by deflections in the waveform above and below the baseline. The height of the waveform indicates the velocity while time is measured along the horizontal axis. So with each contraction of the heart the blood flow increases speed initially and then slows until the next pulse.

Spectral broadening results when there are a mixture of different velocities in the sample at any one time. This is shown by the red arrow, which shows a shaded area below the peak velocity value.

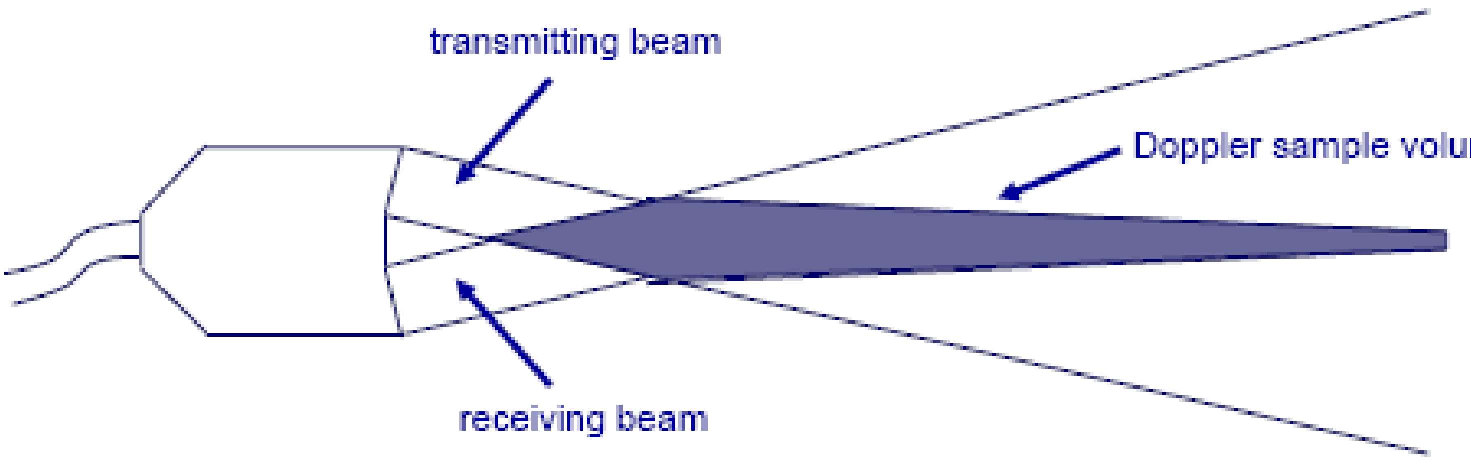
There are two main types of Doppler ultrasound transducers: Continuous Wave (CW Doppler) and Pulsed Wave Doppler.



Doppler Frequency Spectrum Display

Continuous Wave Doppler (CW Doppler)

The simplest Doppler devices use continuous wave (CW Doppler), rather than the pulsed wave used in more complex devices. CW Doppler uses two transducers (or a dual element transducer) that transmit and receive ultrasound continuously. The transmit and receive beams overlap in a Doppler sample volume some distance from the transducer face, as shown in the diagram below.



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