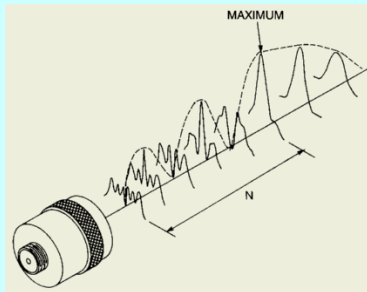
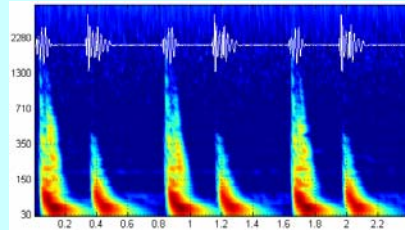
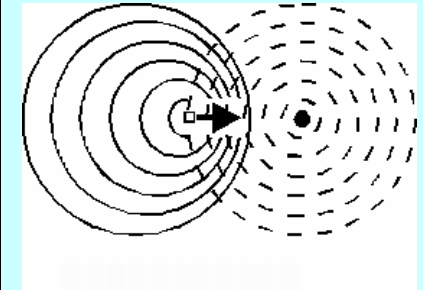
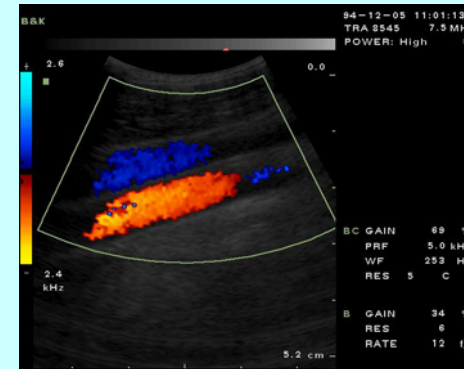


# Physics of ultrasonography



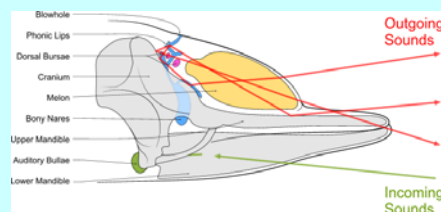
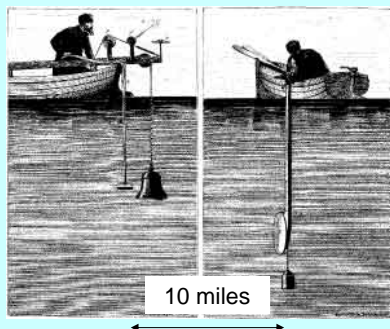
## US imaging. Modes of sonography. Doppler-echo.



## Echo principle

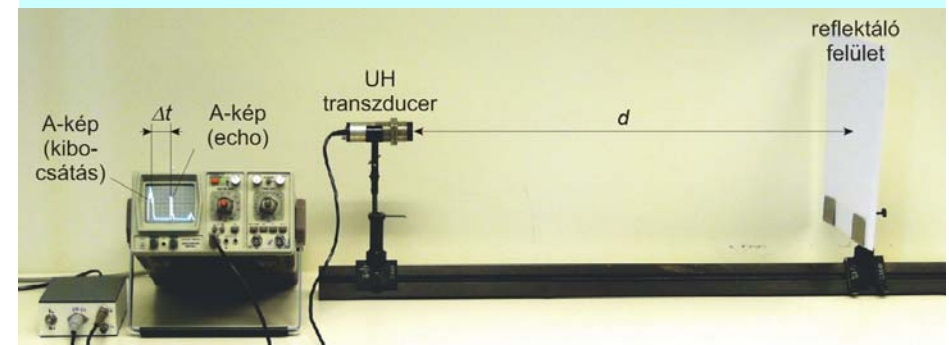
1794 - Spallanzani:  
bat's navigation

1822 - Colladen measured  
the speed of sound in water

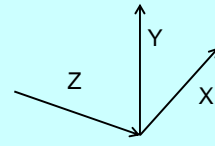
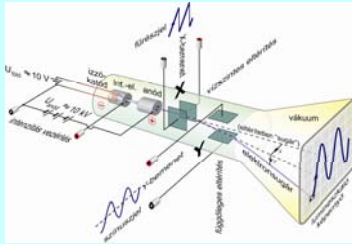


bottlenose dolphin

## Echo principle

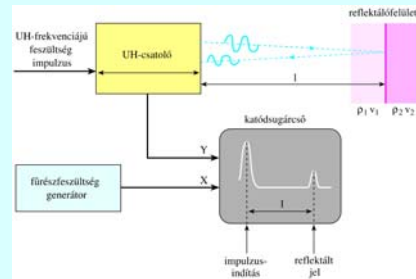


$$c\Delta t = d + d = 2d$$



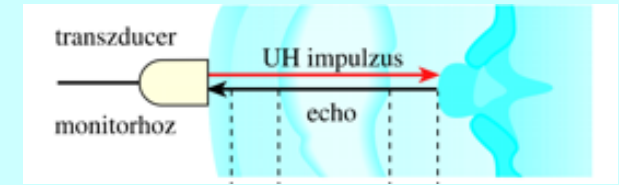
### Deflection / controlling

	A-image
X	Time ( $\rightarrow$ axial distance)
Y	Amplitude ( $\rightarrow I_{refl}$ )
Z	(Brightness)

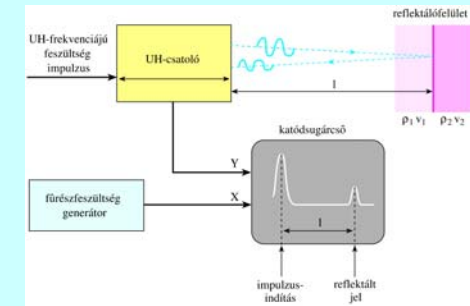


5

### A-image - Amplitúdó



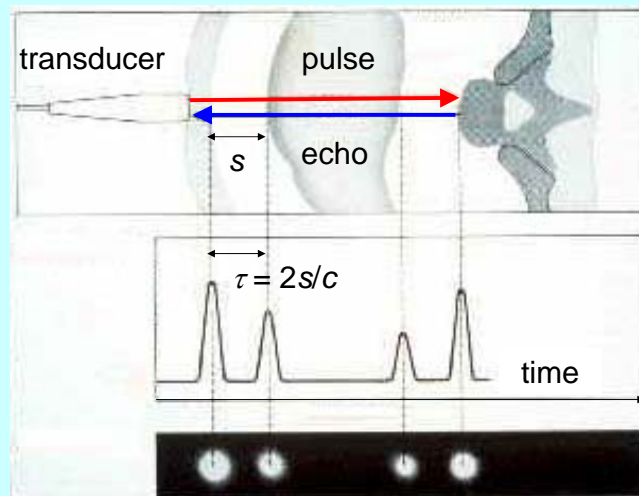
One-dimensional only



$$c\Delta t = d + d = 2d$$

6

### B-image - Brightness

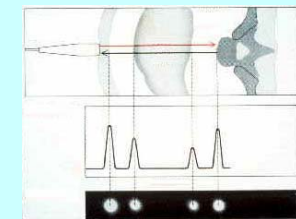
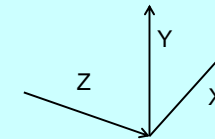


A-mode  
(Amplitude)  
only 1-dimensional

B-mode  
(Brightness)  
only 1-dimensional

7

cf. Textbook Fig. VIII.33



Eltérítés /  
szabályozás

A-kép

egydimenziós B-kép

X

Idő ( $\rightarrow$  axiális  
távolság)

Idő ( $\rightarrow$  axiális  
távolság)

Y

Amplitúdó ( $\rightarrow I_{refl}$ )

-

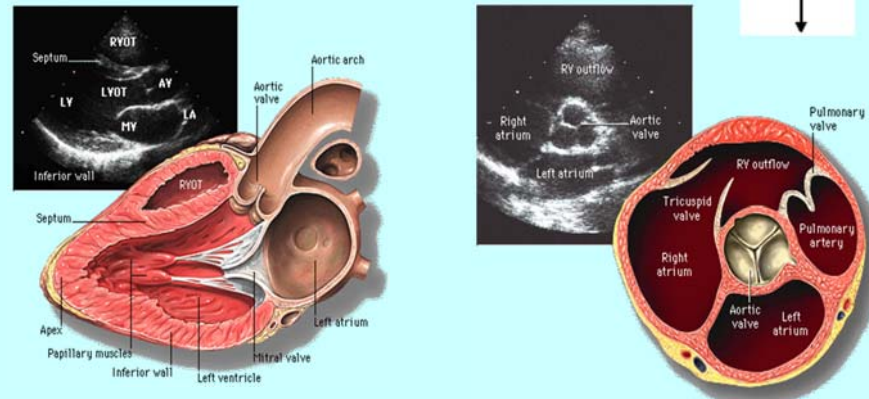
Z

(Fényesség)

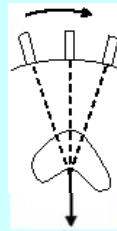
Fényesség ( $\rightarrow I_{refl}$ )

8

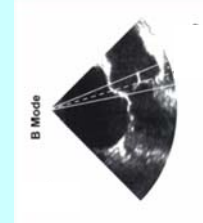
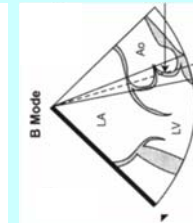
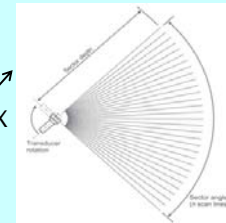
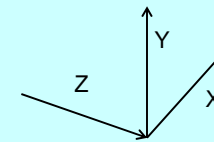
## 2-dimensional B-mode



moving  
transducer



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Eltérítés /  
szabályozás

X

Y

Z

kétdimenziós B-kép

Idő (→ axiális  
távolság)

Laterális távolság

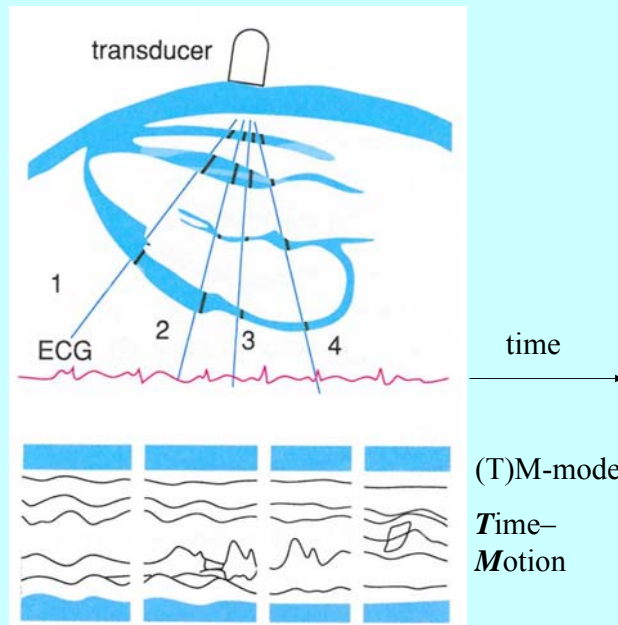
Fényesség (→  $I_{refl}$ )

10

## TM-mode

ECG signal  
for reference

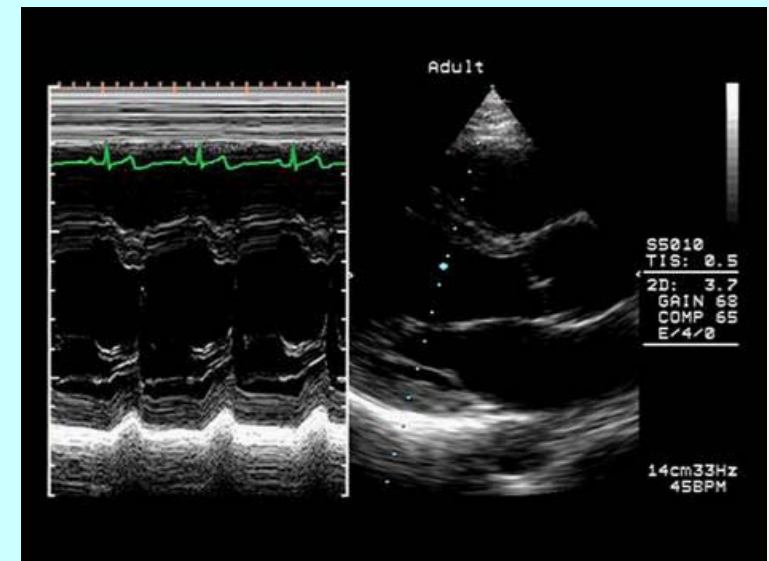
(vertical)  
time-dependent  
1-dimensional  
B-mode



11

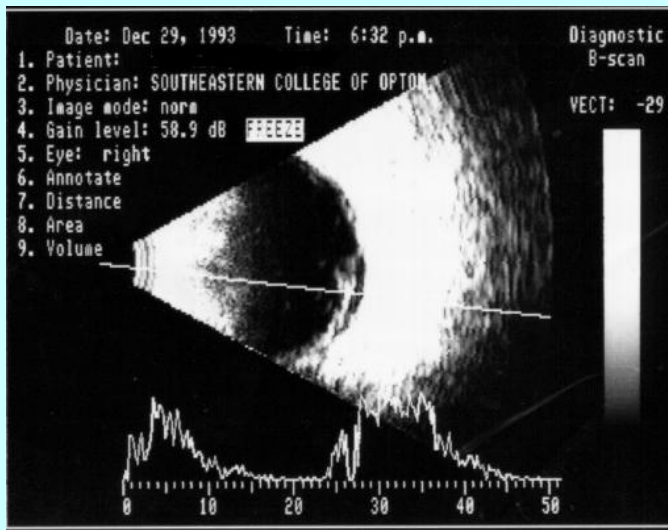
## TM-mode

## B-mode



12

## 2-dimensional B-mode and A-mode (used in ophthalmology)



real speed of propagation for the accurate determination of distances:

cornea: 1641 m/s

aqueous humour: 1532 m/s

crystalline lens: 1641 m/s

vitreous body: 1532 m/s

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## Resolving limit, resolution

**Resolving limit** is the distance between two object details which can be just resolved as distinct objects (the smaller the better).

**Resolution (resolving power):** the reciprocal of the resolving limit (the greater the better)

**Axial resolving limit** - is the minimum separation of two interfaces aligned along the ultrasound beam.

**Lateral resolving limit** - is the minimum separation of two interfaces aligned along a direction perpendicular to the ultrasound beam.

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## Resolving limit, resolution

**Axial resolving limit** depends on the pulse length.

Pulse length is inversely proportional to the frequency.

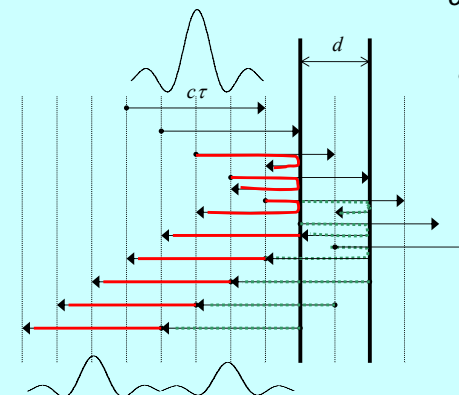
**Lateral resolving limit** depends on the beam width

### Typical parameters

frequency (MHz):	2	15
wavelength (in muscle) (mm):	0.78	0.1
penetration depth (cm):	12	1.6
lateral resolving limit (mm):	3.0	0.4
axial resolving limit (mm):	0.8	0.15

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## Axial resolving limit



$\tau$  : pulse duration

$c_1\tau \cong c_2\tau = c\tau$  pulse length

$\delta_{ax} = d = \frac{c\tau}{2}$  resolving limit

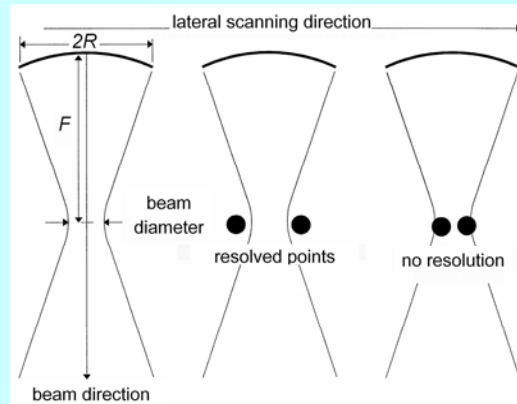
The axial resolving limit is the half of the pulse length. The echos from the adjacent surfaces in this case just hit another.

$$\tau \sim T = \frac{1}{f}$$

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## Lateral resolving limit



$$\left( \delta_{\text{lat}} \sim \frac{F}{2R} \cdot \lambda \right)$$

$F$ : focal length

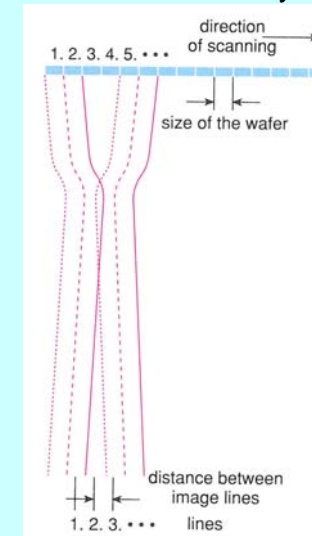
$2R$ : diameter of the transducer

$\lambda$ : wavelength

17

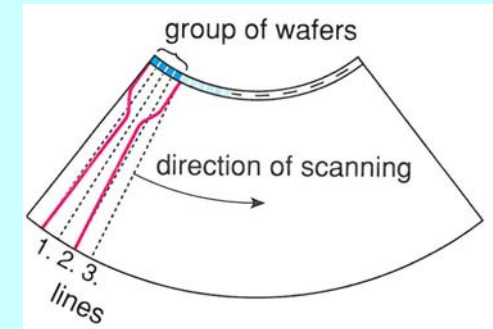
## Scanning

### multi unit linear array



cf. Textbook Fig. VII. 36-37

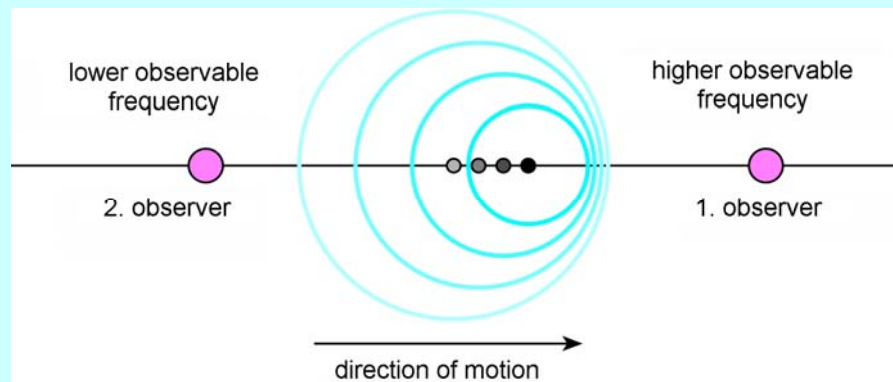
### multi unit curved array



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## Doppler phenomenon

„The pitch of a train whistle seems to get higher as it approaches, then seems to lower as the train whistle moves away.” (C. Doppler, 1842)



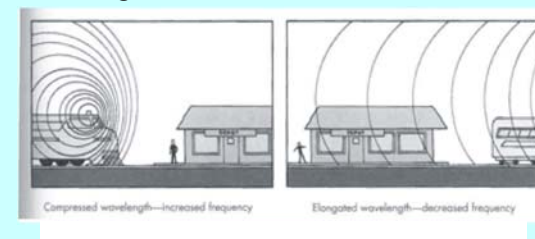
19

Textbook Fig. VIII.39

## Doppler phenomenon

„The pitch of a train whistle seems to get higher as it approaches, then seems to lower as the train whistle moves away.” (C. Doppler, 1842)

### Moving source

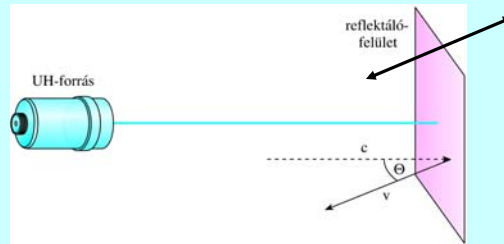


$$f' = f \cdot \left( 1 \pm \frac{v}{c} \right)$$

$f$ : initial frequency  
 $f'$ : altered frequency  
 $v$ : speed of source  
 $c$ : speed of US

20

### Moving reflecting object (surface),



$$f' = f_0 \cdot \left(1 \pm \frac{2v}{c}\right)$$

Doppler-shift

$$f_D = f' - f_0$$

Doppler shift is proportional to the speed of reflecting surface

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$f'$ : **observed frequency**,  $f$ : original frequency

- (a) standing source and moving observer ( $v_O$ )  
 +: observer approaches the source  
 -: observer moves away from the source

$$f' = f \left(1 \pm \frac{v_O}{c}\right)$$

- (b) moving source and standing observer  
 (if  $v_S \ll c$ , then „same” as (a))

$$f' = \frac{f}{1 \mp \frac{v_S}{c}}$$

- (c) moving source and moving observer

$$f' = f \frac{1 \pm \frac{v_O}{c}}{1 \mp \frac{v_S}{c}}$$

- (d) moving reflecting object (surface),  
 (if  $v_R \ll c$ )

$$f' = f \left(1 \pm \frac{2v_R}{c}\right)$$

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**Doppler frequency** = frequency change = frequency shift

if  $v_i, v_R \ll c$  (i= S or O)

rearranging equation (a)  
**moving source or observer:**

$$\Delta f = f_D = \pm \frac{v_i}{c} f$$

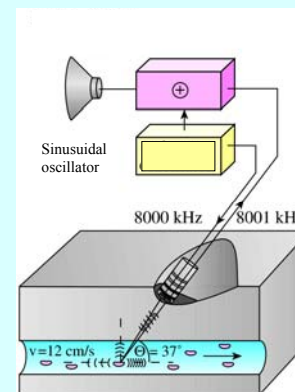
rearranging equation (d)  
**moving reflecting object or surface:**

$$\Delta f = f_D = \pm 2 \frac{v_R}{c} f$$

if  $v$  and  $c$  are not parallel, then  $v \cos \theta$  should be used instead of  $v$  (remark: if  $\theta = 90^\circ$ ,  $f_D = 0$ )

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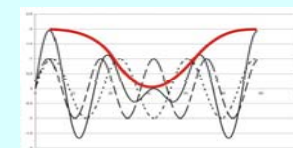
*1-dimensional Doppler apparatus for measuring average flow velocity.*



Tkv. VIII.41. ábra

CW: continuous wave  
 source and detector are separated

Red blood cells as sound scatterers.

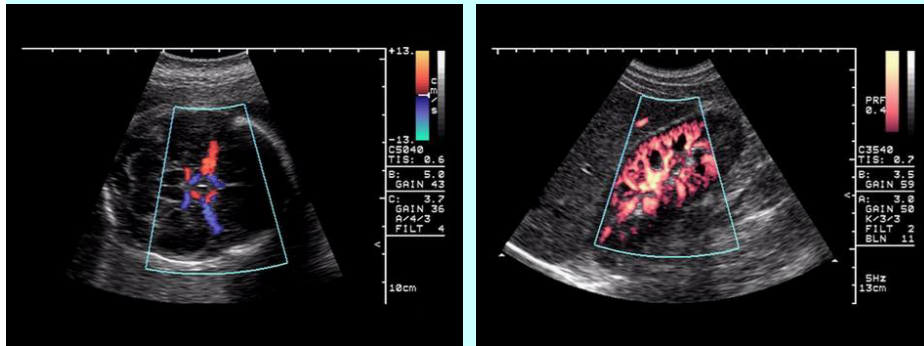


difference signal 1 kHz

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## Colour coding

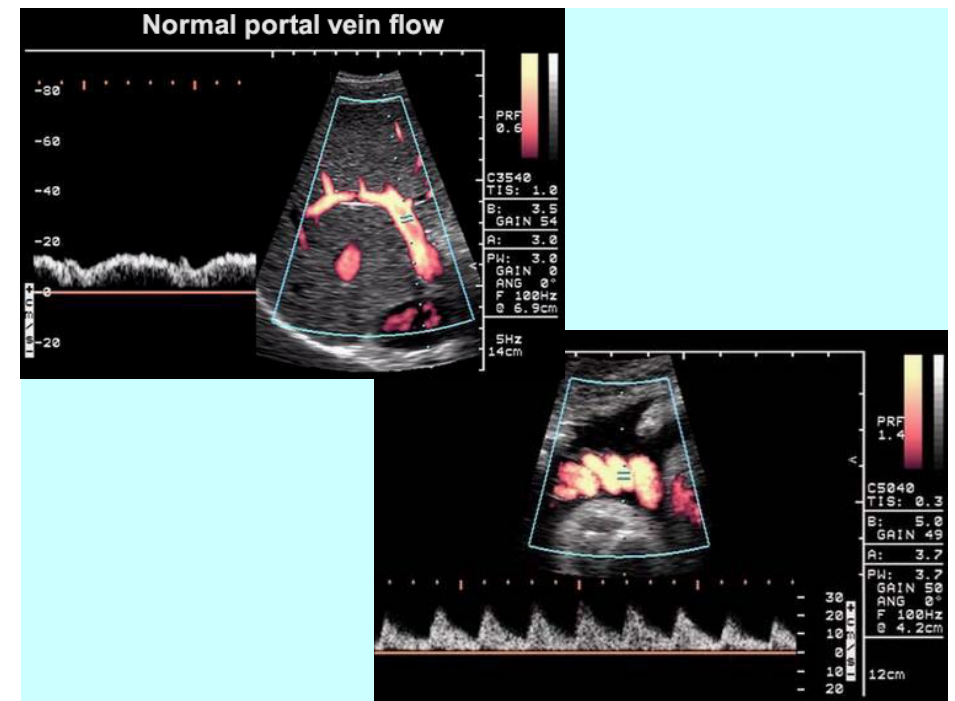
towards the transducer: warm colours  
away from the transducer: cold colours



BART: Blue Away Red Towards

power Doppler

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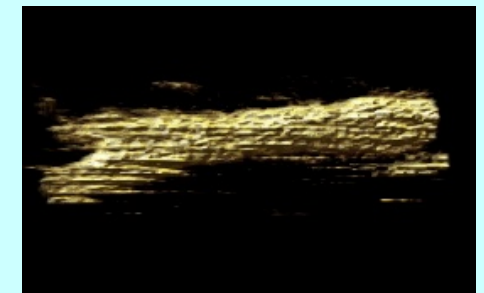
## Reconstruction of the face of a fetus



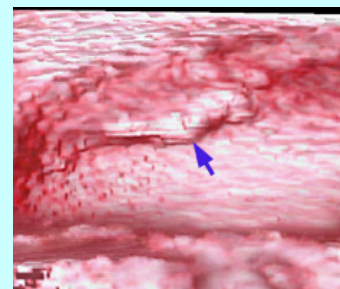
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## 3D reconstruction

carotis



bladder



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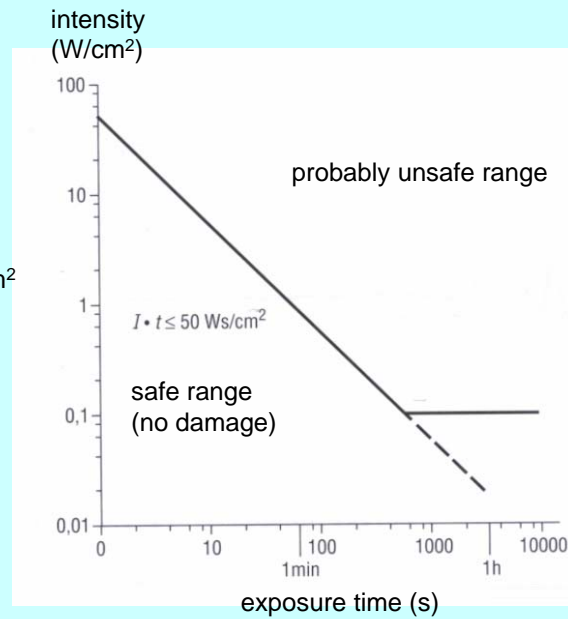
## Safety

in the diagnostics:

$$10 \text{ mW/cm}^2 = 100 \text{ W/m}^2$$

cf. pain threshold:  $10 \text{ W/m}^2$

in the therapy:  $1 \text{ W/cm}^2$



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## Question of the week

What is the function of couplant materials in US diagnostics?

30

Kapcsolódó fejezetek:

*Damjanovich, Fidy, Szöllősi: Orvosi Biofizika*

II. 2.4.

VIII. 4.2.

31