## Medical application of US

Therapy – due to absorption of US

Diagnostics – due to reflection of US

Physics of ultrasonography
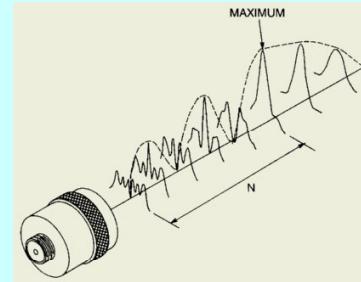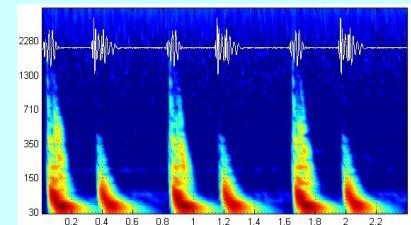
Reflection of US

material	ρ	κ	c	Z
	[kg/m^3]	[1/GPa]	[m/s]	[kg/(m^2·s)]
Air	1,3	7650	331	0,00043·10^6
Lung	400	5,92	650	0,26·10^6
Fat	925	0,51	1470	1,42·10^6
Soft tissue	1060	0,40	1540	1,63·10^6
Eye lens	1140	0,34	1620	1,84·10^6
Done merrow	970	0,36	1700	1,65·10^6
Bones (porous)	1380	0,08	3000	2,2 – 2,9·10^6
Bones (solid)	1700	0,05	3600	6,12·10^6

If $R \approx 1$ ⟶ Total reflection

interface	R
muscle/blood	0,0009
fat/liver	0,006
fat/muscle	0,01
bone/muscle	0,41
bone/fat	0,48
soft tissue/air	0,99

Reflection of US

material	c (m/s)	ρ (kg/m^3)	Z (kg/m^{2}s)
pulp	1570	1000	1,6 · 10^6
dentin	3800	2000	7,6 · 10^6
enamel	6250	3000	18,8 · 10^6
Al	6300	2700	17 · 10^6
borosilicate	5300	3570	18,9 · 10^6
amalgam	4350	7750	33,7 · 10^6

interface	R
enamel/dentin	0,18
dentin/pulp	0,43
amalgam/dentin	0,40

Reflection of US

Optimal coupling:

$$Z_{coup} = \sqrt{Z_1 \cdot Z_2}$$

$Z_{gele} \sim 6{,}5 \cdot 10^6$ kg/(m^{2}s)
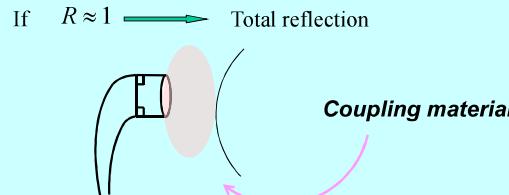
interface	R
muscle/blood	0,0009
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bone/muscle	0,41
bone/fat	0,48
soft tissue/air	0,99

If $\quad R \approx 1 \longrightarrow$ Total reflection

**Coupling material**

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US imaging. Modes of sonography. Doppler-echo.
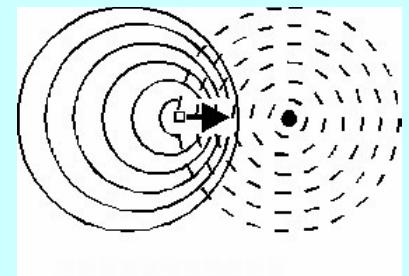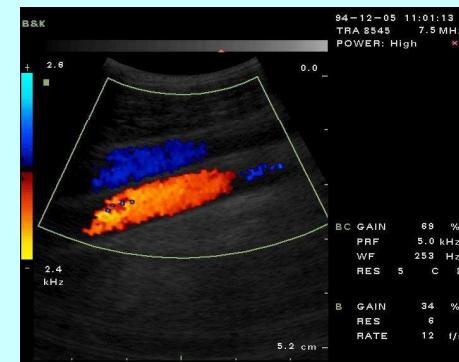
Echo principle

1794 - Spallanzani: bat's navigation

1822 - Colladen measured the speed of sound in water

10 miles
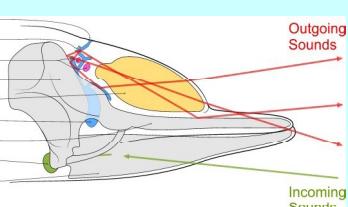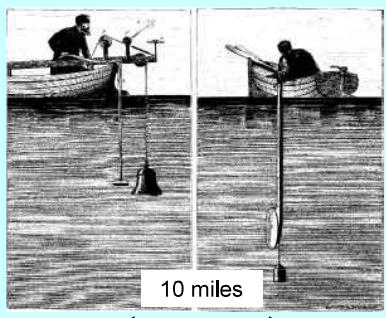

bottlenose dolphin

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Echo principle

emission Δt echo   US transducer d Reflection

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

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Deflection / controling — A-image

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

A-image - *A*mplitude

One-dimensional only

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

B-image - *Brightness*

transducer   pulse

echo

s

$\tau = 2s/c$

time

A-mode (*A*mplitude)
only 1-dimensional

B-mode (*B*rightness)
only 1-dimensional

cf. Textbook Fig. VIII.33

Deflection / controling	A-mode	1-dimensional B-mode
X	Time ($\rightarrow$ axial distance)	Time ($\rightarrow$ axial distance)
Y	Amplitude ($\rightarrow I_{refl}$)	–
Z	(Brightness)	Brightness ($\rightarrow I_{refl}$)

2-dimensional B-mode

moving
transducer

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multi unit linear array

multi unit curved array

direction
of scanning

1. 2. 3. 4. 5. • • •

size of the wafer

group of wafers

direction of scanning

1. 2. 3.
lines

distance between
image lines

1. 2. 3. • • •   lines

cf. Textbook Fig. VII. 36–37

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Y

Z

X

**Deflection /
controling**

2-dimensional B-mode

X

Time ($\rightarrow$ axial
distance)

Y

Lateral distance

Z

Brightness ($\rightarrow I_{refl}$)

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TM-mode

transducer
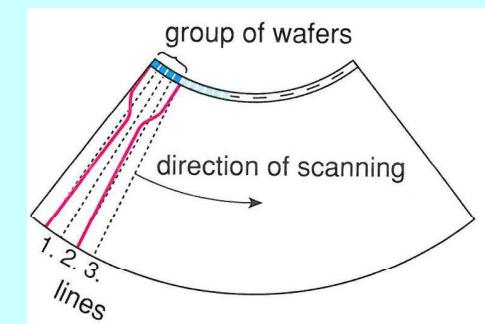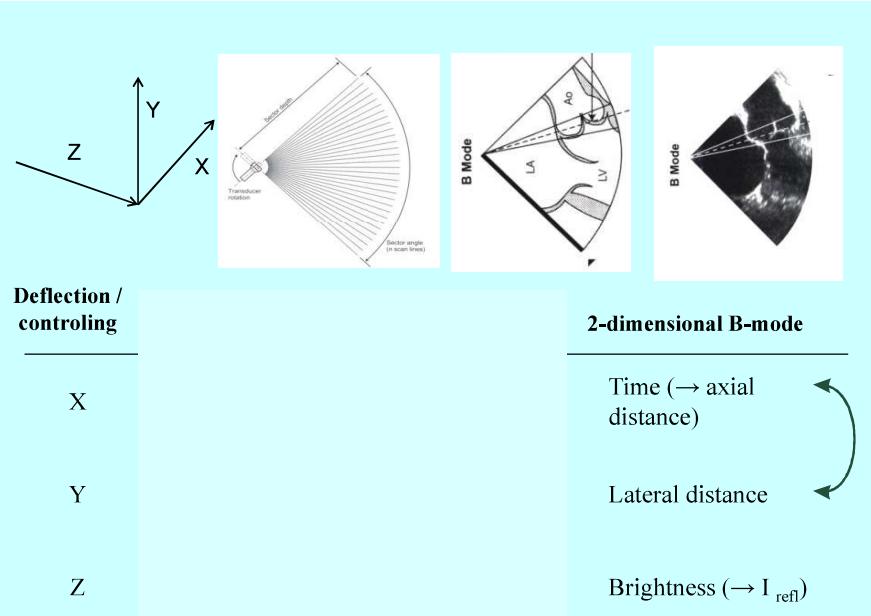
ECG signal
for reference

1

ECG

2   3   4

time

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

(T)M-mode

*T*ime–
*M*otion
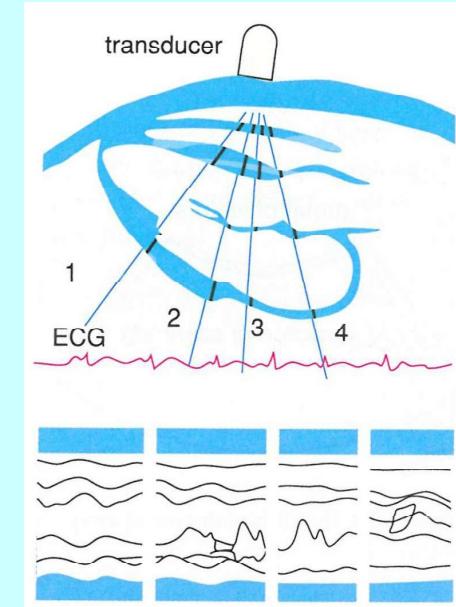
Textbook Fig. VIII.34

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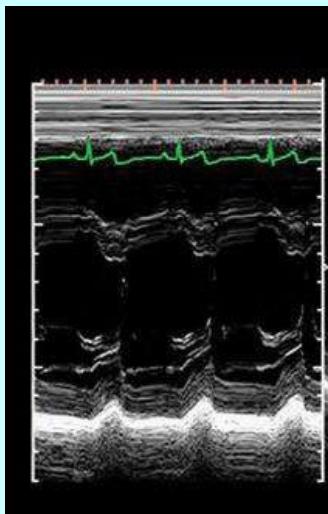
TM-mode   B-mode

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2-dimensional B-mode and A-mode
(used in opthamology)
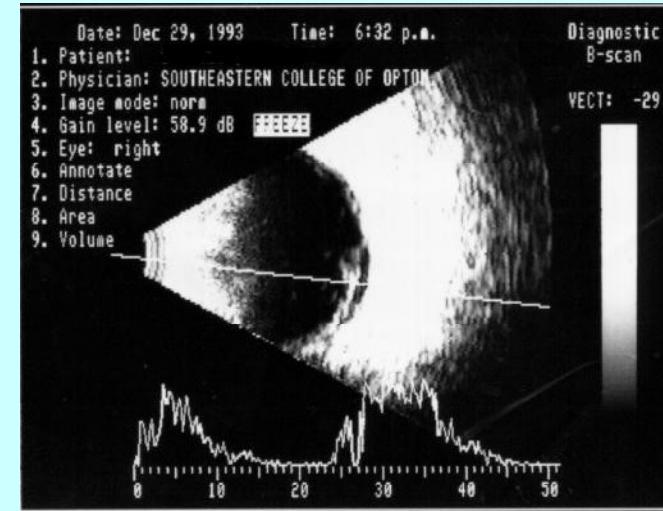
real speed of propagation for the accurate determination of distances:

cornea: 1641 m/s

aqueos humour: 1532 m/s

crystalline lens: 1641 m/s

vitreous body: 1532 m/s

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The object and the image


The object

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## The object and the image
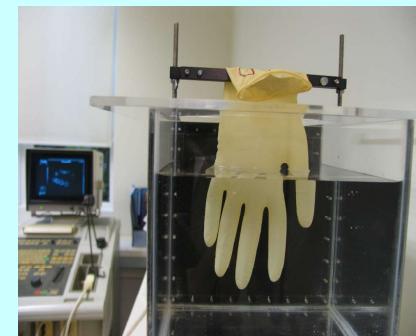
Imaging

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The object and the image

Watrer inside and outside
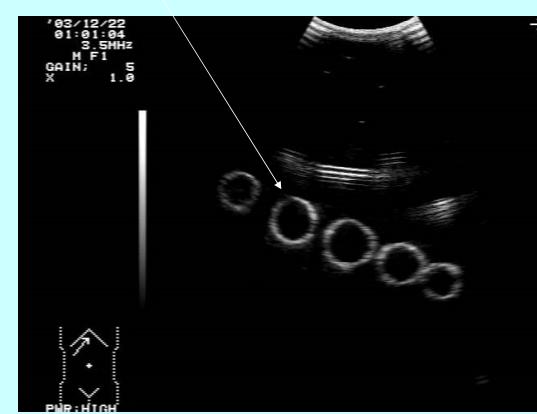
Cross-section

The image

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The object and the image

Glicerin inside
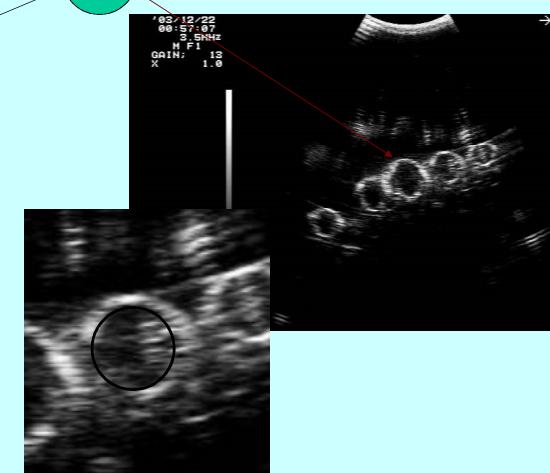
Cross-section

The image

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The object and the image

Alcohol inside

Cross-section

The image

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The object and the image

Air inside

Cross-section
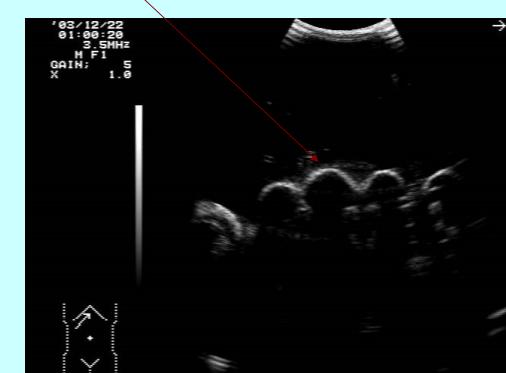
The image

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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)

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

## Resolving limit, resolution

Axial resolving limit - is the minimum separation of two interfaces aligned along the ultrasound beam.
Achieving good axial resolution requires that the returning echoes be distinct without overlap
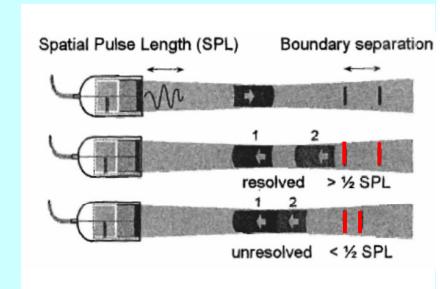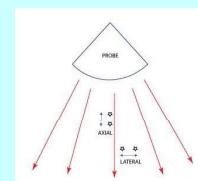
The minimal required separation distance between two boundaries is ½ SPL (about ½ λ) to avoid overlap of returning echoes

SPF inversely proportional to f

Resolving limit, resolution

Lateral resolving limit - is the minimum separation of two interfaces aligned along a direction perpendicular to the ultrasound beam determined by beam width, beam density and axial position of the object.

Typical values

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

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)
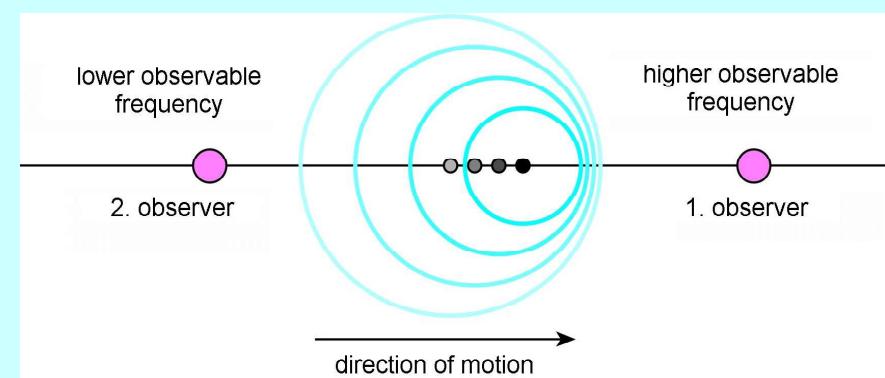
Teextbook Fig. VIII.39

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

Compressed wavelength—increased frequency   Elongated wavelength—decreased frequency
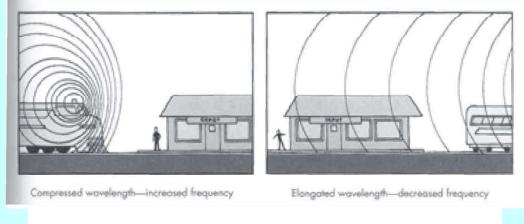
$$f' = f \cdot \left(1 \pm \frac{v}{c}\right)$$

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

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Moving reflecting object (surface),

reflektáló-felület
UH-forrás
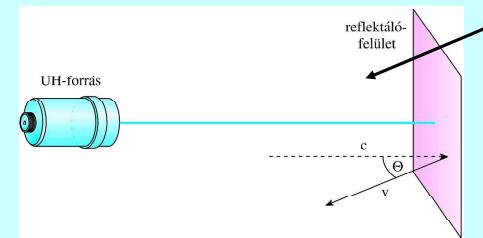
$$f' = f_0 \cdot \left(1 \pm \frac{2v}{c}\right)$$

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 approches 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))

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

(c) moving source and moving observer

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

(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 $\Theta = 90°$, $f_D = 0$)

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Slide 33

1-dimensional Doppler apparatus for measuring average flow velocity.

CW: continuous wave

source and detector are separated

Sinusuidal oscillator

8000 kHz   8001 kHz

$v = 12$ cm/s $\Theta = 37°$
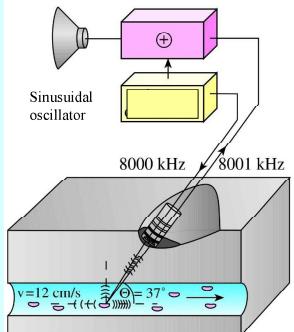
Tkv. VIII.41. ábra

Red blood cells as sound scatterers.
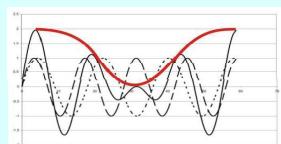
difference signal 1 kHz

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Slide 34

An artery of 9 mm inner diameter is examined by Doppler ultrasound method. The frequency of the ultrasound is 8 MHz. The average frequency audible for the examiner is 1200 Hz. Calculate the average velocity of blood in the artery. The velocity of the ultrasound in the body is 1500 m/s and we suppose that it propagates parallel to the axis of the blood vessel.

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

$$\left|f_D\right| = 2\frac{v_R\cos\theta}{c}f$$

$$\frac{1200*1500}{2*8*10^6} = v$$

$$\frac{\left|f_D\right|*c}{2f\cos\Theta} = v_R$$

$$v = 11{,}25\,m/s$$

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Slide 35

Colour coding

towards the transducer: warm colours
away from the transducer: cold colours
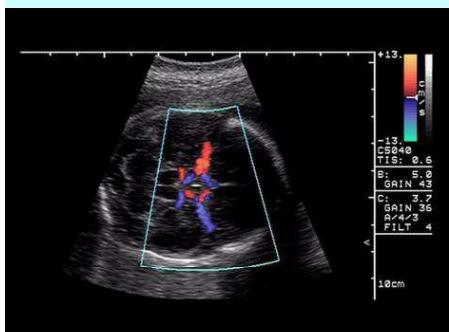
BART: Blue Away Red Towards   power Doppler

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Slide 36
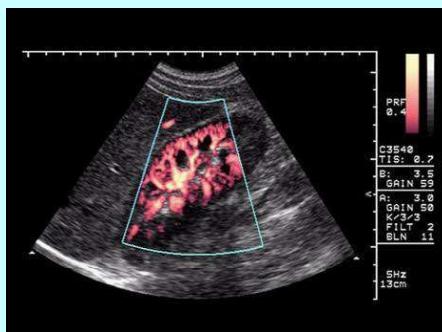
Normal portal vein flow
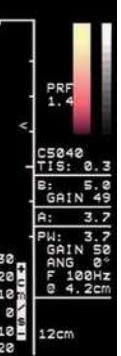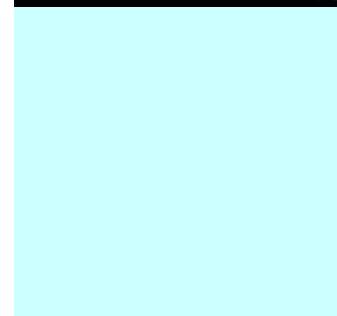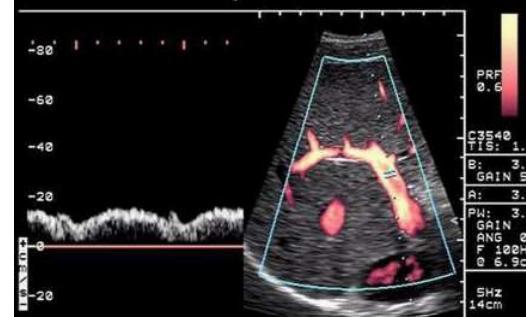
Reconstruction of the face of a fetus

3D reconstruction

carotis

bladder
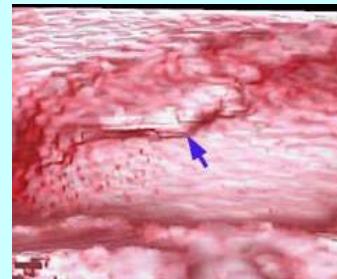
Safety

in the diagnostics:

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

cf. pain threshold: 10 W/m^2

in the therapy: 1 W/cm^2

intensity (W/cm²)

probably unsafe range

$I \cdot t \le 50 \text{ Ws/cm}^2$

safe range (no damage)

exposure time (s)
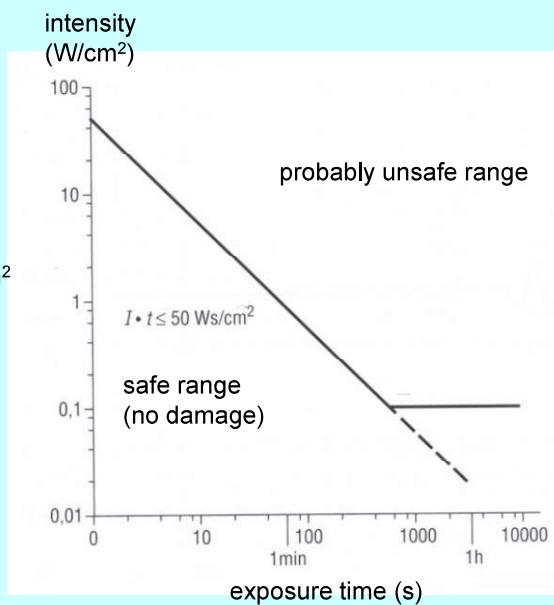
Question of the week

What does Doppler-shift mean?

Related chapters
Damjanovich, Fidy, Szöllősi: Orvosi Biofizika

II. 2.4.
VIII. 4.2.