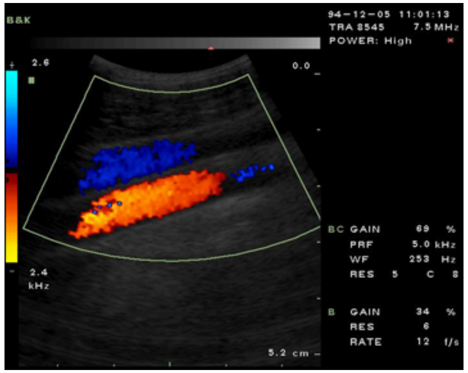
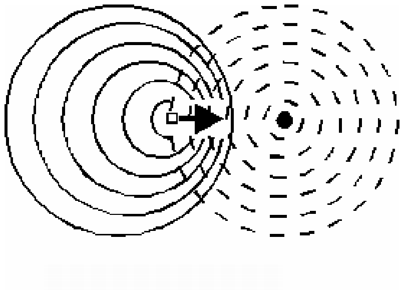
US imaging. Modes of sonography. Doppler-echo



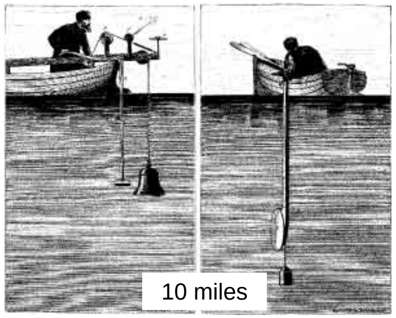


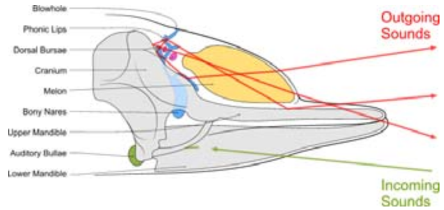
KAD 2013.02.20

Echo principle

1794 Spallanzani:
bat's navigation

1822 Colladen
measured the speed of
sound in water

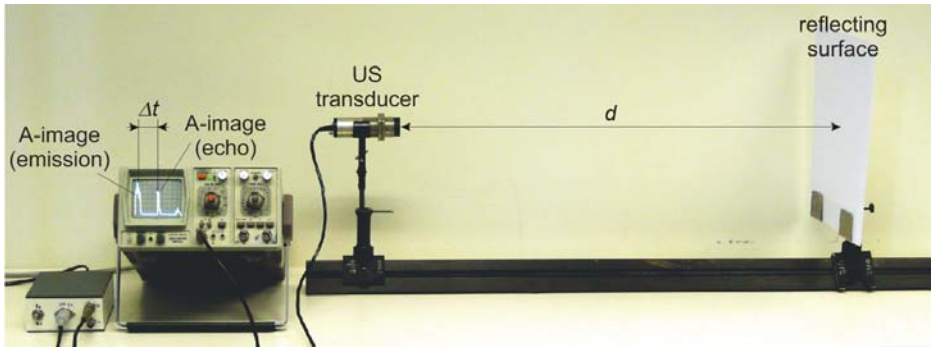




bottlenose dolphin

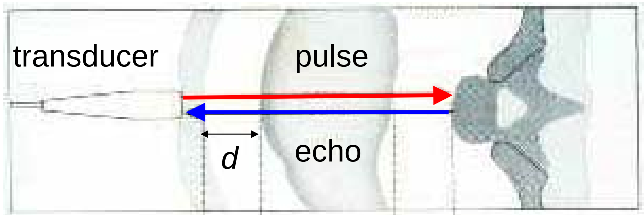
Echo principle

using a special US-head, short pulses are emitted in the air towards a reflecting surface, and the same US-head detects the echo signal

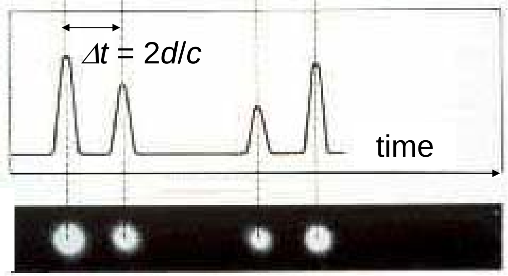


$c\Delta t = d + d = 2d$

Receiving the echos



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

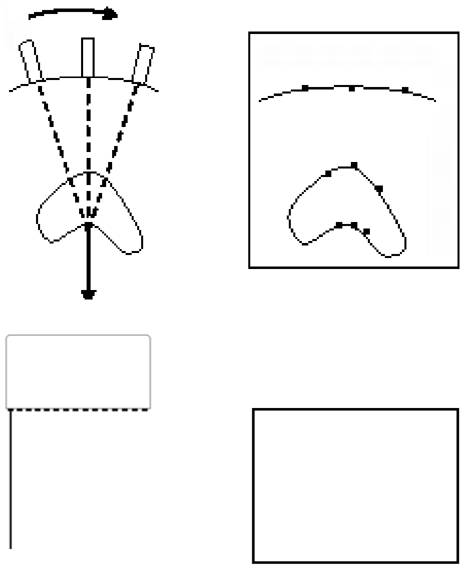


1-dimensional B-mode
(***B***rightness)

cf. Textbook Fig. VIII.33

2-dimensional B-mode

moving transducer

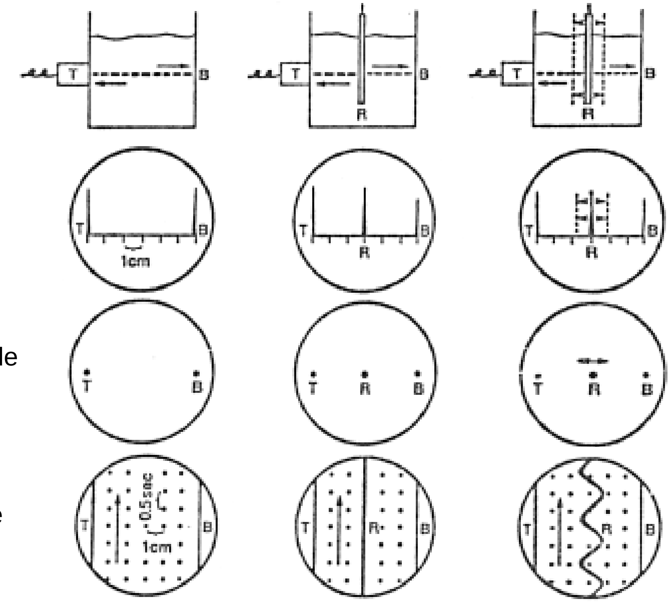


B-mode display

A- mode

1D B- mode

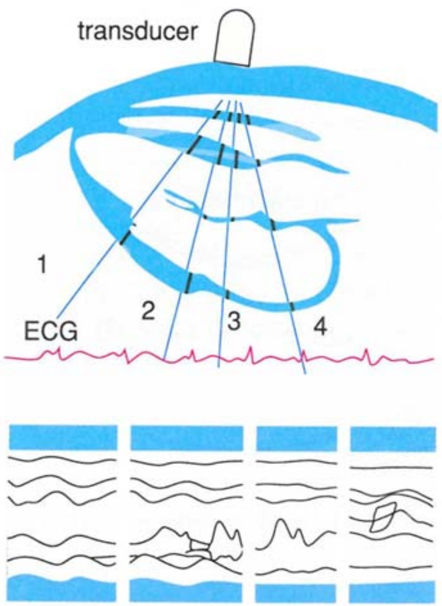
TM- mode



TM-mode

ECG signal for reference

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



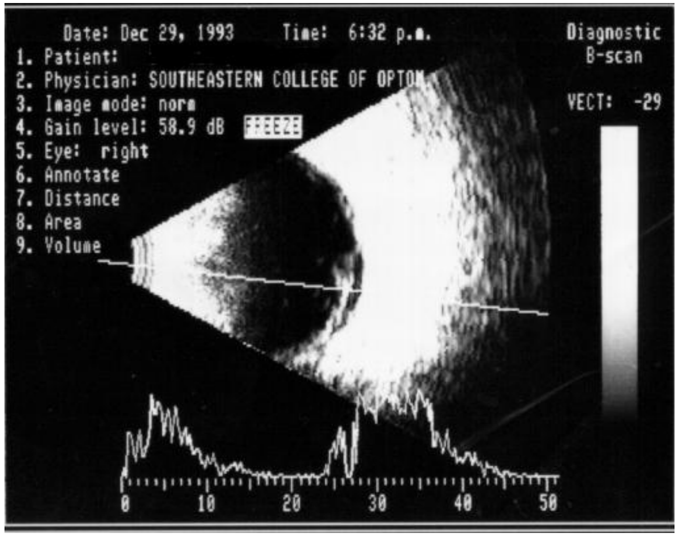
time →

(T)M-mode

***T**ime–*
***M**otion*

Textbook Fig. VIII.34

2-dimensional B-mode and A-mode
(used in opthamology)



real speed of propagation for the accurate determination of distances:

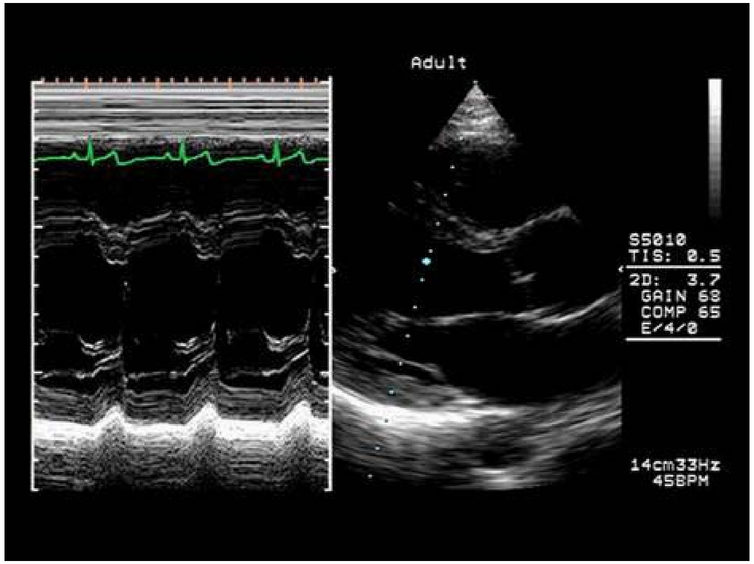
cornea: 1641 m/s

aqueos humour: 1532 m/s

crystalline lens: 1641 m/s

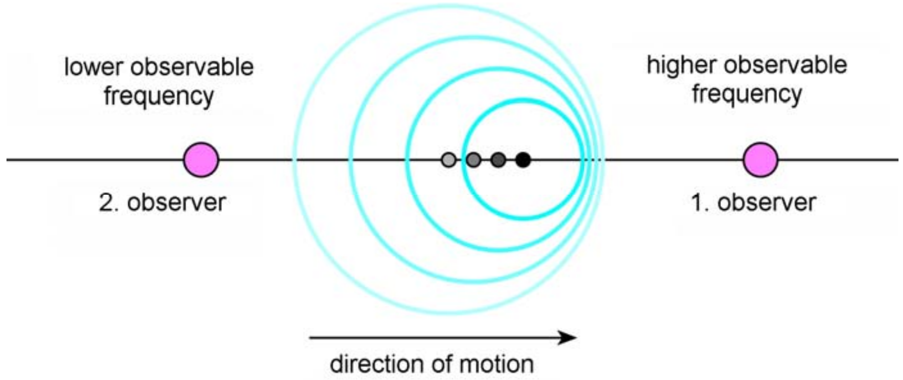
vitreous body: 1532 m/s

TM-mode B-mode



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

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))

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

(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 $v_R \ll c$)

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

Doppler frequency = frequency change = frequency shift

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

rearranging equation (a)
moving source or observer:

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

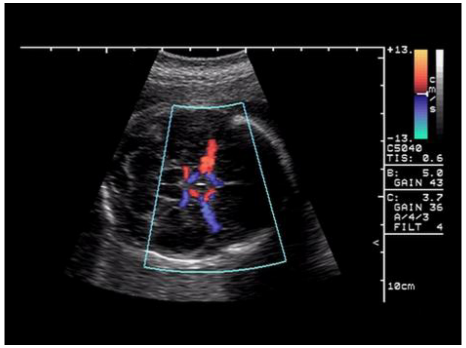
rearranging equation (d)
moving reflecting object or surface:

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

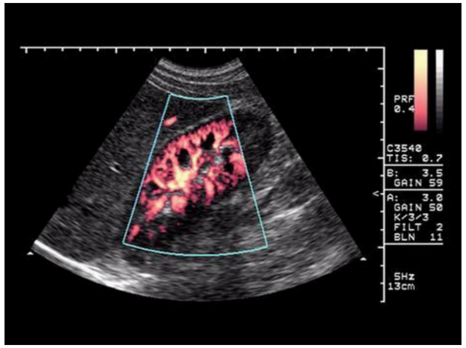
if v and c are not parallel, then $v \cos\Theta$ should be used instead of v (remark: if $\Theta = 90°$, $f_D = 0$)

Colour coding

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



BART: Blue Away Red Towards



power Doppler

1-dimensional CW Doppler apparatus for measuring average flow velocity. Red blood cells as sound scatterers

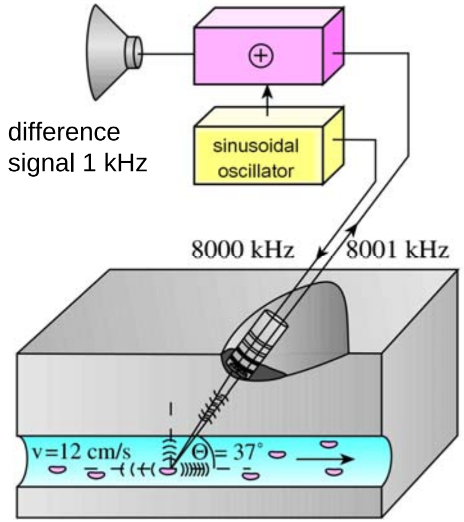
CW: continuous wave

source and detector are separated

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

e.g. f=8000 kHz
v=12 cm/s
c=1600 m/s
Θ = 37°

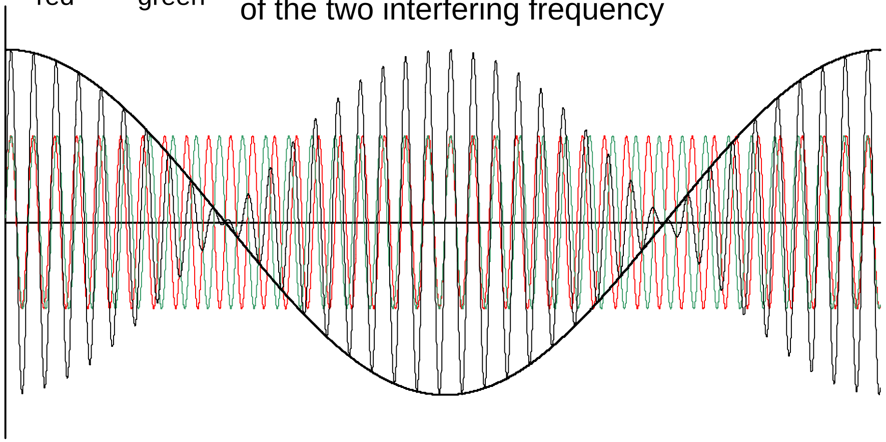
⇨f_D=1 kHz
(beating phenomenon)



Textbook Fig. VIII.41

Beating phenomenon

$f_{red} \geq f_{green}$ the beating frequency equals to the difference of the two interfering frequency

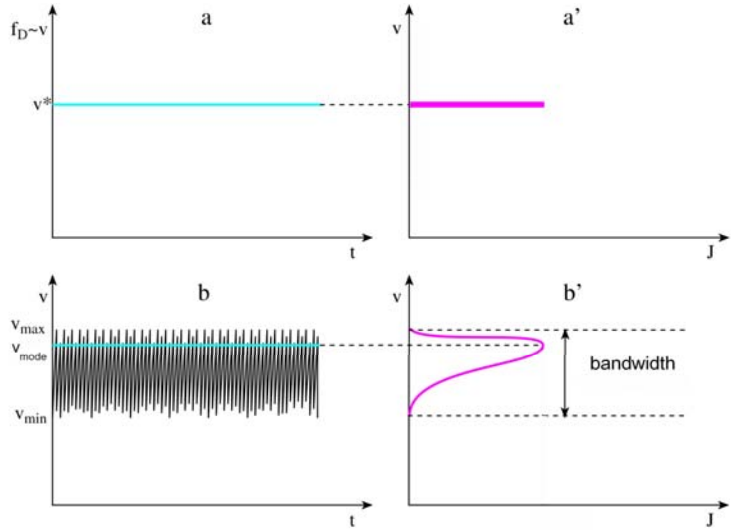


reminder: $\sin\alpha + \sin\beta = 2\sin\frac{\alpha+\beta}{2}\cos\frac{\alpha-\beta}{2}$

Doppler curves

one constant velocity (v*)

frequency distribution (with v_{mode})



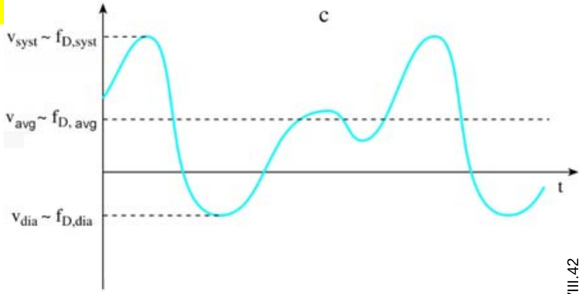
velocity distribution in TM-mode

velocity distribution at a certain time

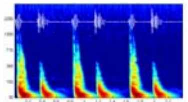
Textbook Fig. VIII.42

Doppler curves

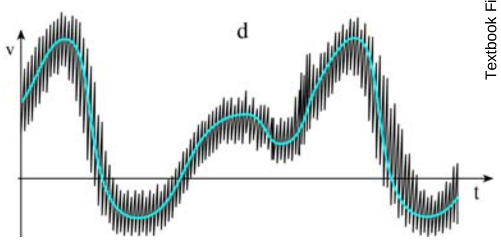
flow can be represented by one velocity in each moment



flow can be represented by a velocity distribution in each moment

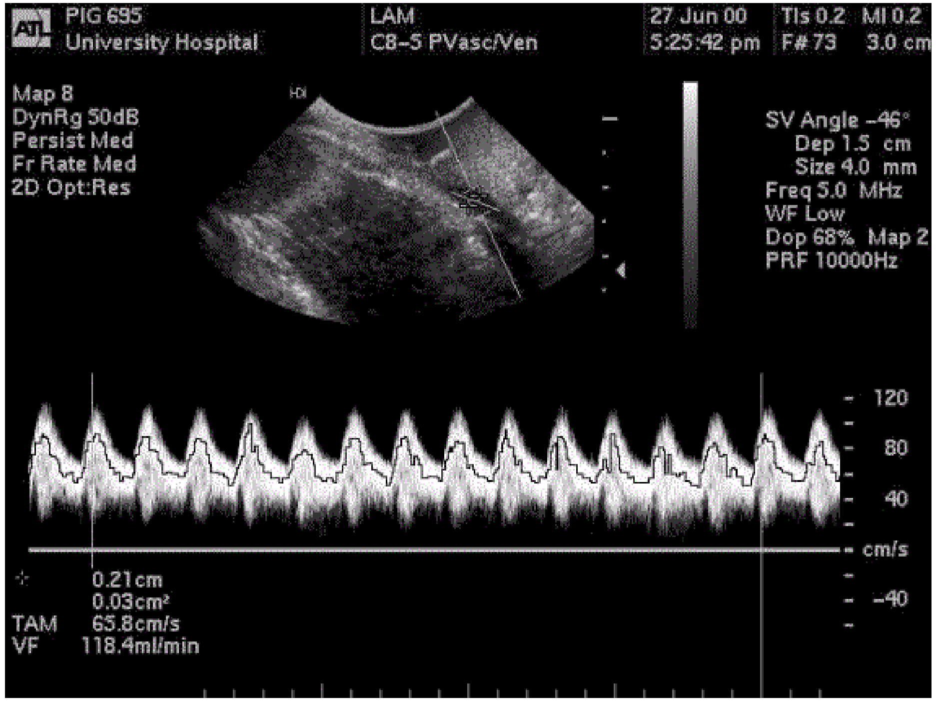


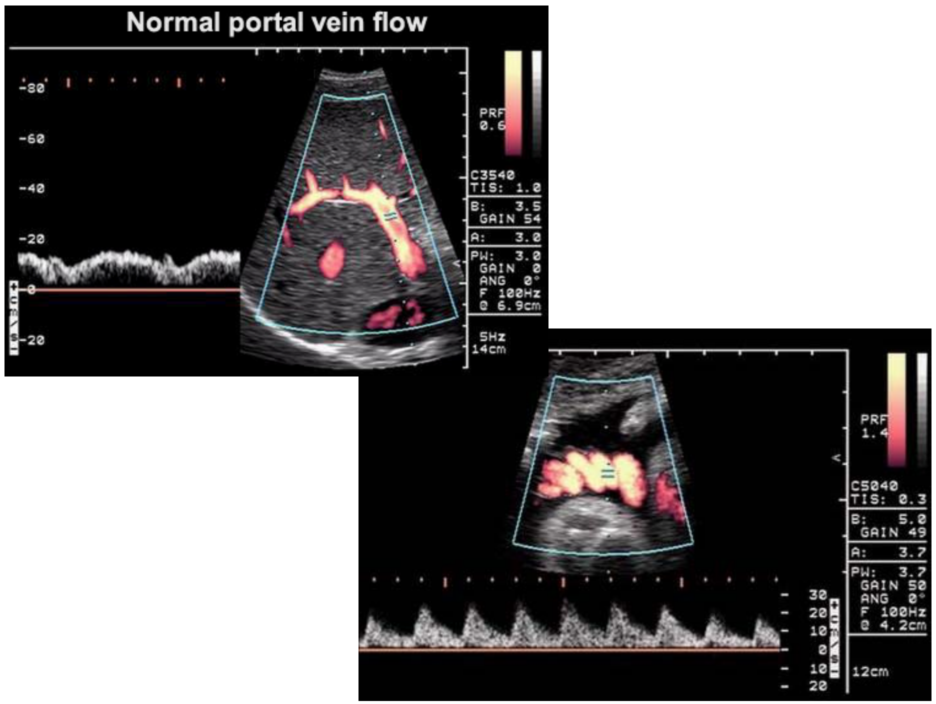
cf. voiceprint, music/heart beats in time-frequency representation



velocity distribution in TM-mode

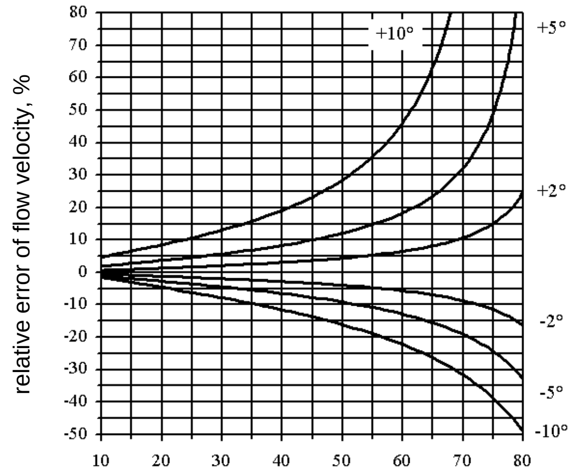
Textbook Fig. VIII.42





Supplementary material

Error of measuring the angle between the US-beam and axis of blood vessel influences the error of the flow velocity



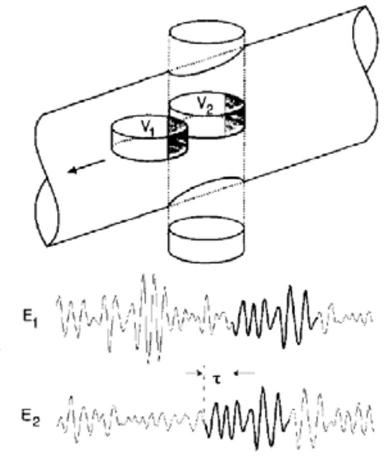
Φ (= angle between the US-beam and axis of blood vessel)

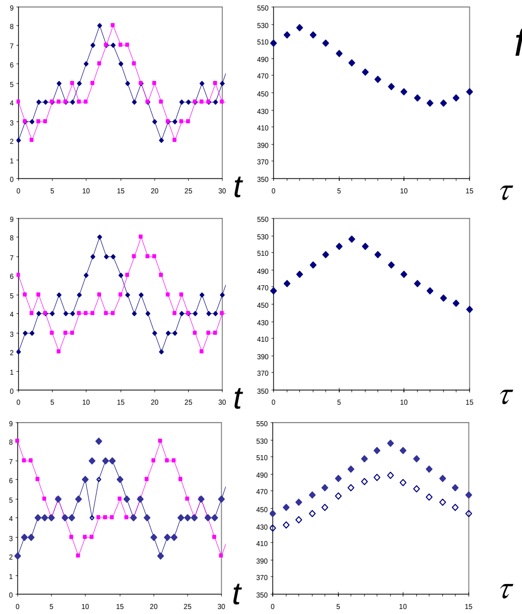
Time domain correlation method
(CVI = color velocity imaging)

If the reflecting surface and/ or the scatterer are moving then the US signal at a fixed position depends on time.

Similar US pattern can be measured at a certain distance from the earlier position (where the reflecting surface/scatterer moved).

How can be compared the similarity of different functions?





$$f_{\mathrm{blue}}(t) = f_{\mathrm{pink}}(t+\tau^*)$$

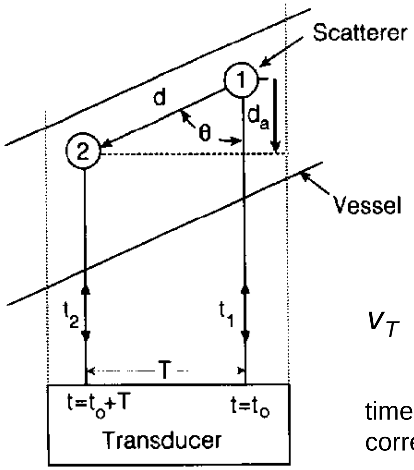
$$\tau^* = 2\ \mathrm{u}$$

$$\tau^* = 6\ \mathrm{u}$$

$$\tau^* = 9\ \mathrm{u}$$

$$f_{\mathrm{empty}}(t) \cong f_{\mathrm{blue}}(t)$$

Supplementary material



$$d_a = \frac{(t_1 - t_2)c}{2}$$

$$d = \frac{(t_1 - t_2)c}{2\cos\theta}$$

$$v_T = \frac{(t_1 - t_2)c}{2T\cos\theta} \qquad v_D = \frac{f_D c}{2f\cos\theta}$$

time domain correlation method

cf.: Doppler method

T : pulse repetition time

f : frequency of US

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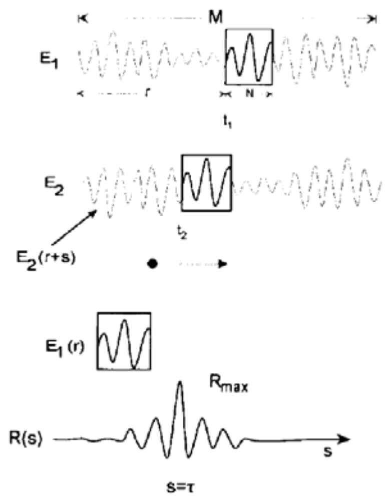
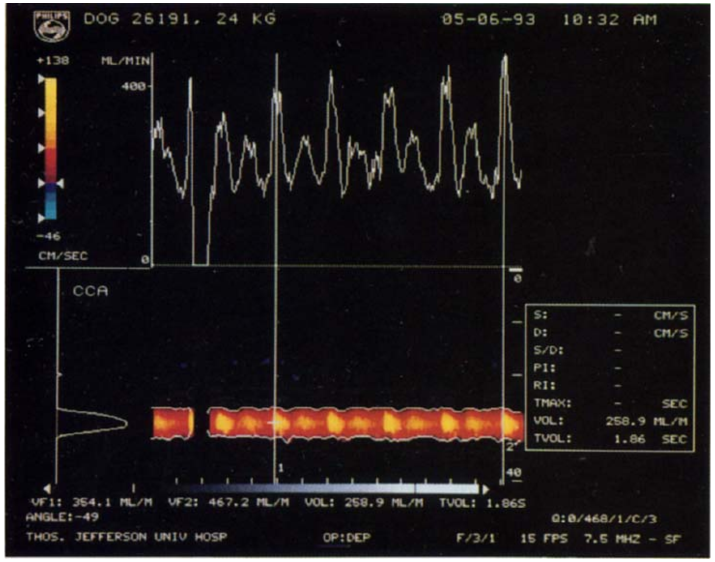
Supplementary material



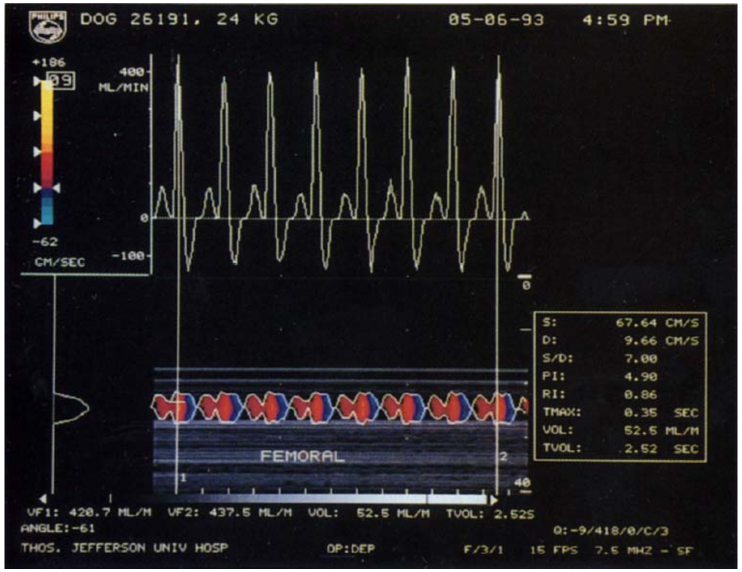
correlation procedure consists of removing a window of width N at desired range from on echo signal E_1

E_1 is correlated at different locations along another echo signal E_2

the value of s producing the maximum corresponds to s = τ



Ultrasound in Med. & Biol., Vol. 21, No. 8, pp. 1037–1045, 1995



Ultrasound in Med. & Biol., Vol. 21, No. 8, pp. 1037–1045, 1995

Sono-CT

image reconstruction from several multidirectional B-images

SonoCT yields better results than conventional B-mode sonography in terms of delineation, visualization of borders and artefact-free representation

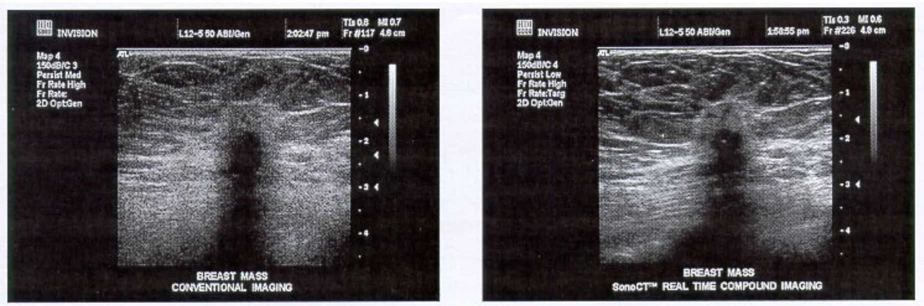
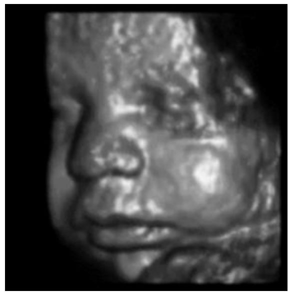


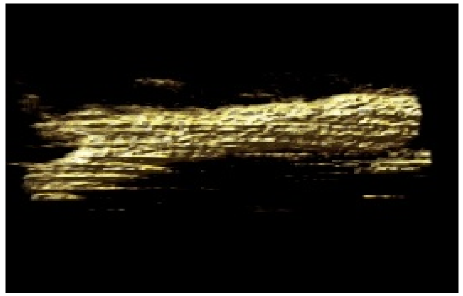
Figure 1. Breast fibroadenoma as shown on conventional ultrasound (left) and SonoCT ultrasound imaging (right).

3D reconstruction

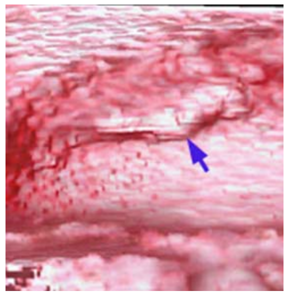
face of a fetus



carotis



bladder



Safety

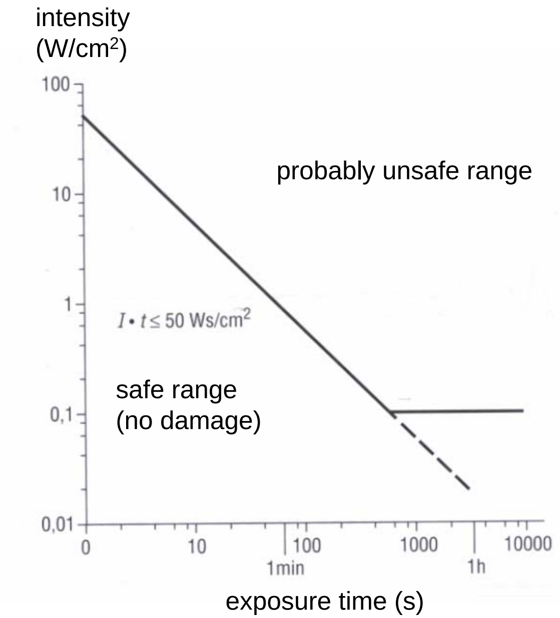
in the diagnostics:

10 mW/cm^2 = 100 W/m^2

cf. pain threshold: 10 W/m^2

in the therapy: 1 W/cm^2

spatial average temporal average (SATA) intensity;
spatial peak temporal peak (SPTP) intensity;
spatial peak temporal average (SPTA) intensity;
spatial peak pulse average (SPPA) intensity
spatial average pulse average (SAPA) intensity

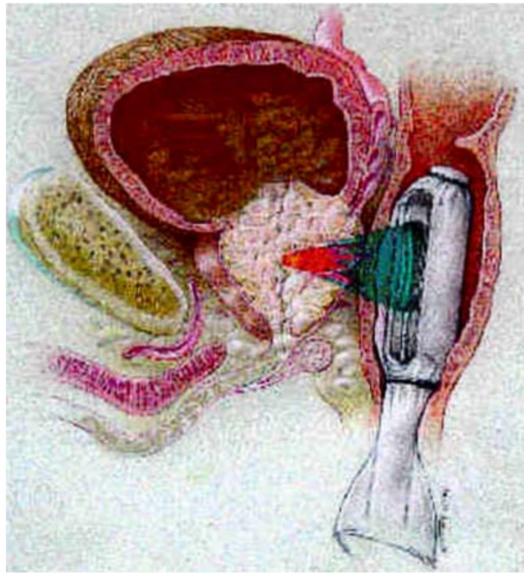


High Intensity Focused Ultrasound

by focusing US it is possibble to create suffciciently high intensities to trigger cavitation and local heating

cell damage only in the focal point

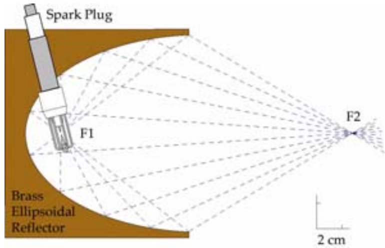
treatment of prostate tumour by HIFU using high energy, focused ultrasound source placed in the rectum

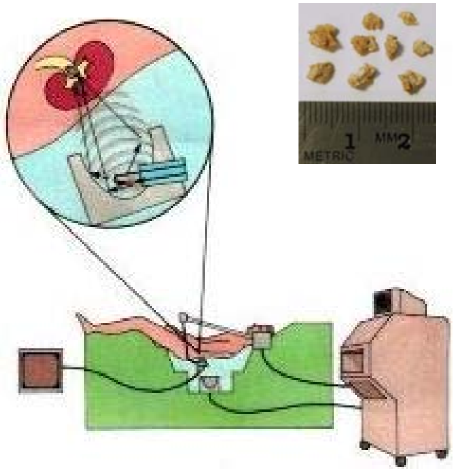


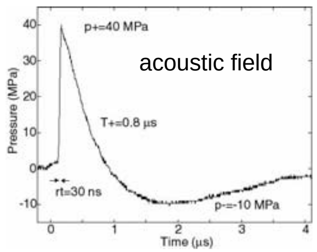
Textbook Fig.IX.27.

Extracorporeal Schockwave Lithotripsy, ESWL

kidney/urinary stone fragmentation caused by high local tensile and shear waves created by the focused shock waves hitting the stone







X-ray and/or US real-time monitoring of the disintegration process