Základní principy a historie ultrazvukového vyšetřování

Tomáš Jůza

Klinika radiologie a nukleární medicíny FN Brno
Biofyzikální ústav LF MU

Kurz UZ techniky
čejkovice 2019

Ultrazvuk

Lazzaro Spallanzani 1794 – echolokace netopýrů mechanickým vlněním o vyšší než slyšitelné frekvenci

Mechanické vlnění, f >20kHz
(v praxi k diagnostice 2-18MHz)

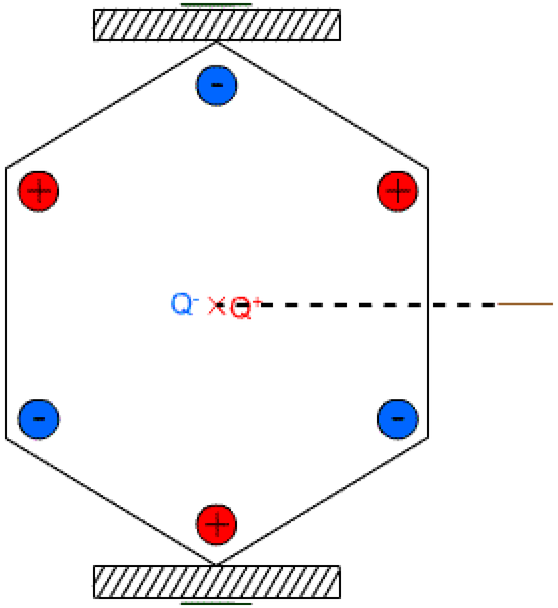
Podélné (zahušťování a zřeďování)
Příčné (pružné pevné látky, povrchy kapalin)

Prostředí	Rychlost [$m.s^{-1}$]
Vzduch	330
Destilovaná voda	1480
Sklivec	1532
Játra	**1550**
Měkké tkáně	1550
Ledviny	1560
Kost	3500

Piezoelektrický jev

Pierre a Jacques Curie, 1880

- schopnost krystalu generovat elektrické napětí při jeho deformování (pouze krystaly, které nemají střed symetri



nepřímý piezoelektrický jev

- deformace krystalu ve vnějším elektrickém poli
- (Elektrostrikce…)

Deformací se ionty opačných nábojů posunou v krystalové mřížce tak, že elektrická těžiště záporných a kladných iontů, která se v nezdeformovaném krystalu nacházejí ve stejném bodě, se od sebe vzdálí. Na určitých plochách krystalu se objeví elektrický náboj.

Sonar

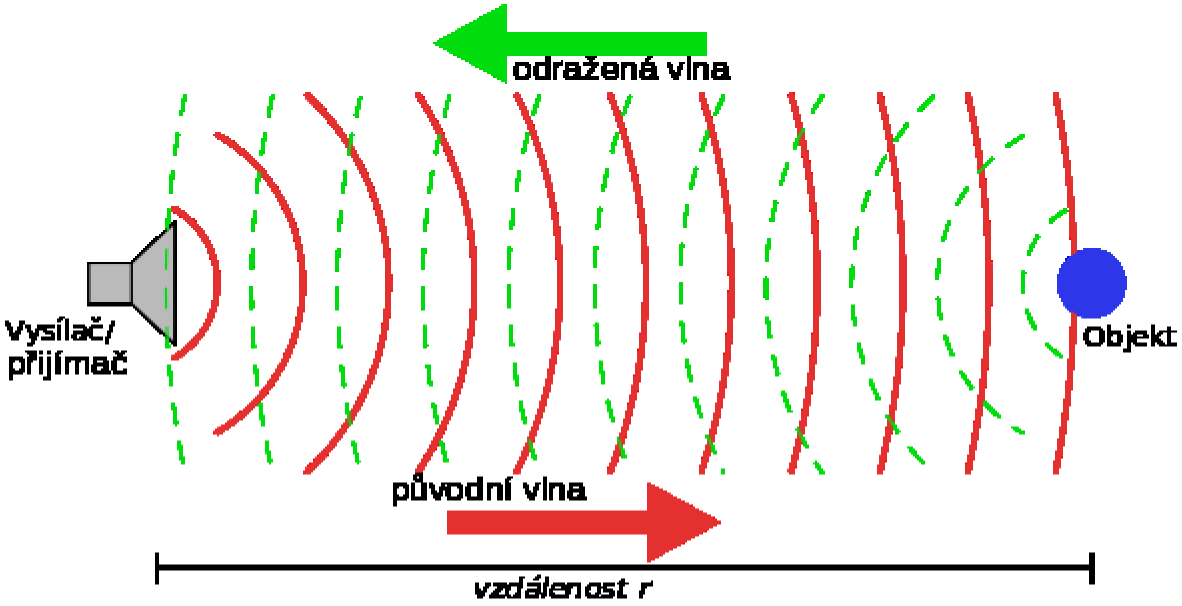
Sound Navigation And Ranging

1914

Aktivní sonar

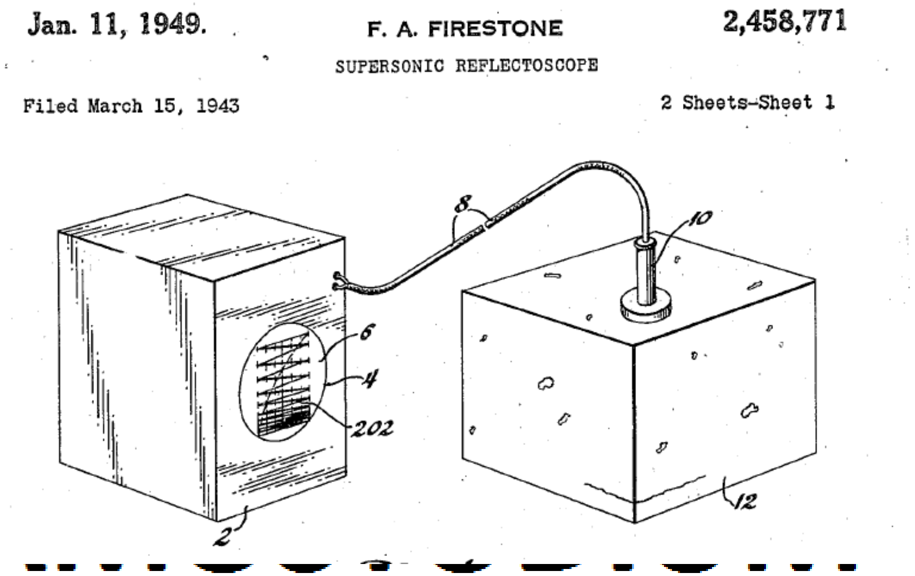
Pulse-echo princip

„hydrophone“



Ultrazvuk v praxi

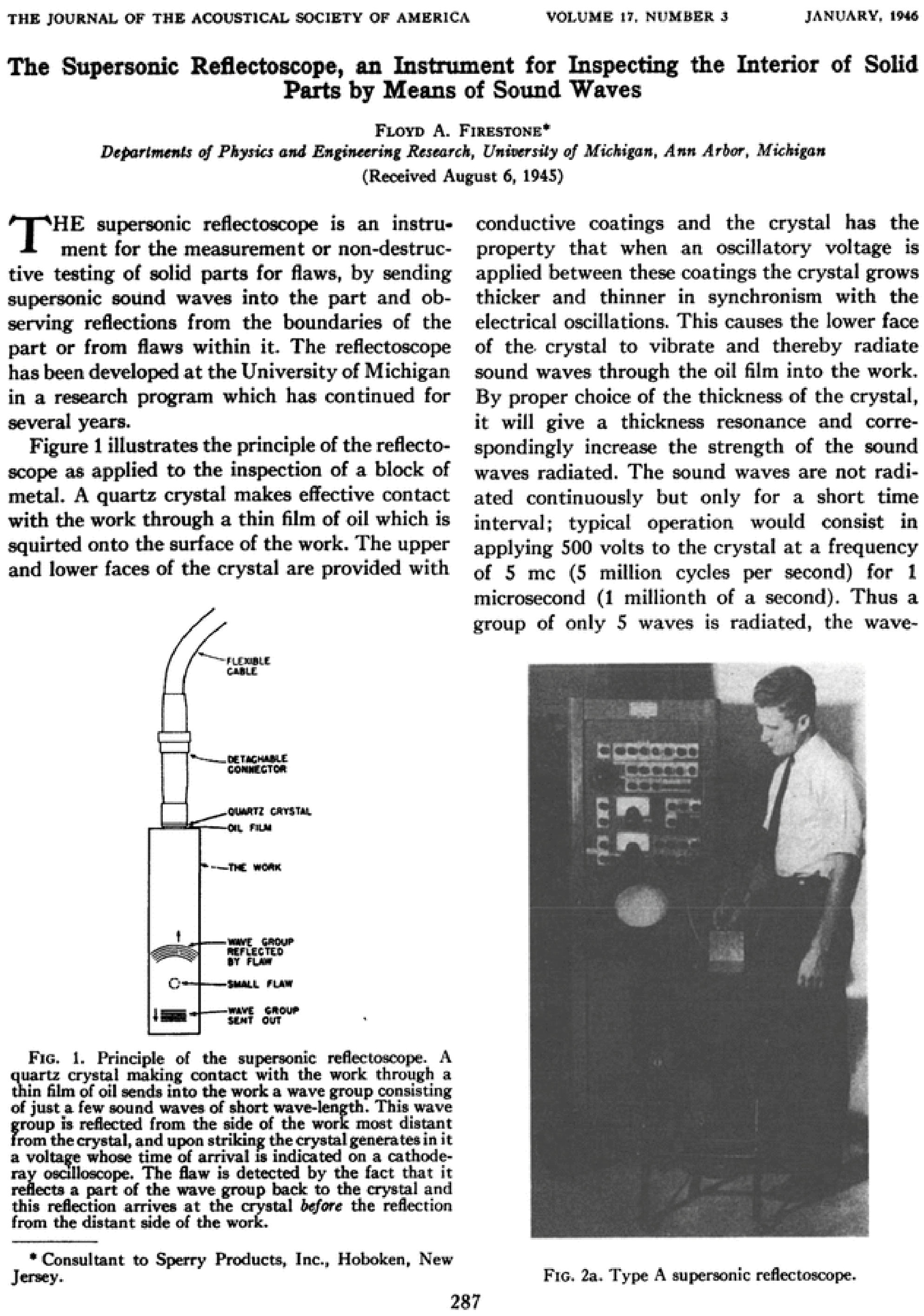
- První praktické využití - 1941
- detekce vad kovových materiálů
- „supersonic reflectoscope“



Jan. 11, 1949. F. A. FIRESTONE 2,458,771

SUPERSONIC REFLECTOSCOPE

Filed March 15, 1943 2 Sheets-Sheet 1



THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA VOLUME 17, NUMBER 3 JANUARY, 1946

The Supersonic Reflectoscope, an Instrument for Inspecting the Interior of Solid Parts by Means of Sound Waves

Floyd A. Firestone*
Departments of Physics and Engineering Research, University of Michigan, Ann Arbor, Michigan

(Received August 6, 1945)

THE supersonic reflectoscope is an instrument for the measurement or non-destructive testing of solid parts for flaws, by sending supersonic sound waves into the part and observing reflections from the boundaries of the part or from flaws within it. The reflectoscope has been developed at the University of Michigan in a research program which has continued for several years.

Figure 1 illustrates the principle of the reflectoscope as applied to the inspection of a block of metal. A quartz crystal makes effective contact with the work through a thin film of oil which is squirted onto the surface of the work. The upper and lower faces of the crystal are provided with conductive coatings and the crystal has the property that when an oscillatory voltage is applied between these coatings the crystal grows thicker and thinner in synchronism with the electrical oscillations. This causes the lower face of the crystal to vibrate and thereby radiate sound waves through the oil film into the work. By proper choice of the thickness of the crystal, it will give a thickness resonance and correspondingly increase the strength of the sound waves radiated. The sound waves are not radiated continuously but only for a short time interval; typical operation would consist in applying 500 volts to the crystal at a frequency of 5 mc (5 million cycles per second) for 1 microsecond (1 millionth of a second). Thus a group of only 5 waves is radiated, the wave-

Fig. 1. Principle of the supersonic reflectoscope. A quartz crystal making contact with the work through a thin film of oil sends into the work a wave group consisting of just a few sound waves of short wave-length. This wave group is reflected from the side of the work most distant from the crystal, and upon striking the crystal generates in it a voltage whose time of arrival is indicated on a cathode-ray oscilloscope. The flaw is detected by the fact that it reflects a part of the wave group back to the crystal and this reflection arrives at the crystal *before* the reflection from the distant side of the work.

Fig. 2a. Type A supersonic reflectoscope.

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* Consultant to Sperry Products, Inc., Hoboken, New Jersey.

Průkopníci v medicíně

Karl Theodore a Friederich Dussik - 1937 (mozkové nádory)

George Ludwig – 1949 (lokalizace žlučových kamenu, rychlost šíření UZ)

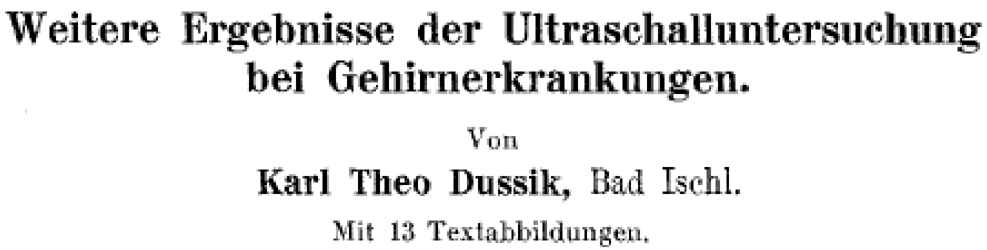
John Julian Wild - 1950 (ileus) A-mód

Douglas Howry - 1949 B-mód skener (somaskop)

Ian Donald - 1958 (gynekologie) A-mód, B-mód

Inge Edler a Carl Hellmuth Hertz 1954 -M- mód echokardiografie

Karl Theodore Dussik

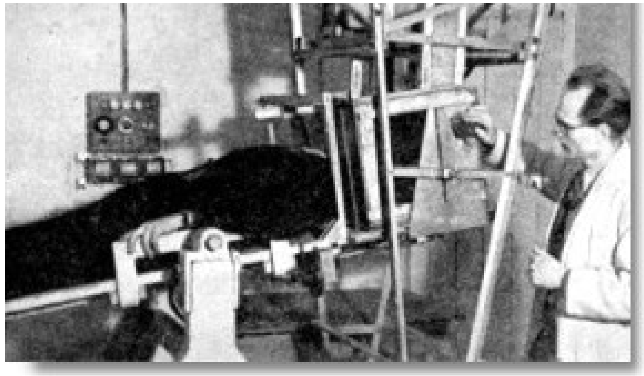


Weitere Ergebnisse der Ultraschalluntersuchung bei Gehirnerkrankungen.

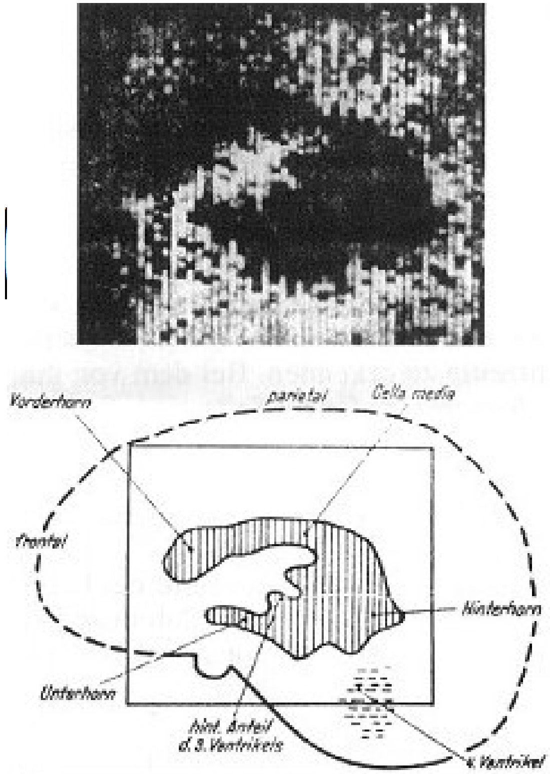
Von

Karl Theo Dussik, Bad Ischl.

Mit 13 Textabbildungen.

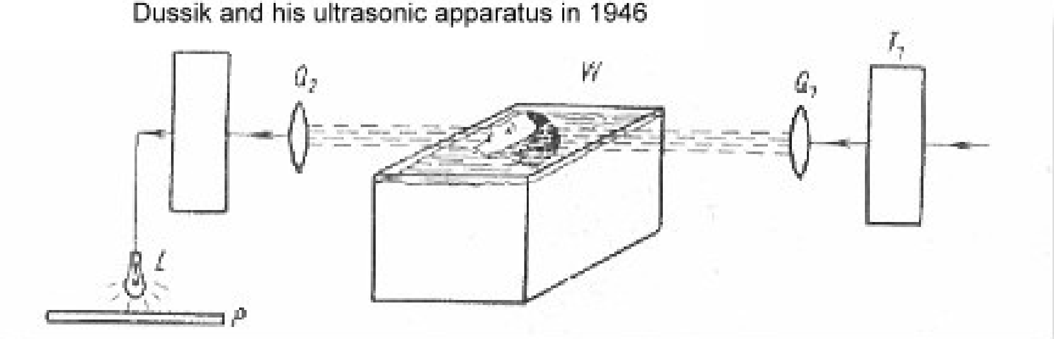


Dussik and his ultrasonic apparatus in 1946



The hyperphonogram was thought to depict the ventricles

Karl Theo (Theodore) Dussik
1908 - 1968



T1 -- ultrasonic generator, Q1-- transmitter, Q2 -- receiver, T2 -- converter amplifier, W -- waterbath,
L -- light, P -- photographic/ heat-sensitive paper *

•from "Ultraschall" by Lieselott Herforth and Herbert Winter. B.G. Teubner Verlagsgesellschaft, Leipzig, 1958.

George Döring Ludwig

THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA VOLUME 22, NUMBER 6 NOVEMBER, 1950

The Velocity of Sound through Tissues and the Acoustic Impedance of Tissues

George D. Ludwig*
Naval Medical Research Institute, Bethesda, Maryland

(Received August 11, 1950)

The velocity of sound through various animal organ tissues and through living human tissues is measured. using an ultrasonic pulse method, at 1.25 and 2.5 Mc. The effect of anisotropy (fiber direction) on velocity determined with beef muscle. Values obtained with the beam traversing the tissue perpendicularly to the lon axis of the muscle bundles do not differ significantly from those found with the energy directed parallel wit the muscle fibers.

Velocity through living human tissues, consisting mostly of muscle, is measured by transmitting th ultrasound through various thicknesses of the arm, leg, and thigh.

Specific gravities of the tissues are measured. The characteristic acoustic impedances (ρc values), calculated from the density and velocity data, vary between 1.5×10^5 and 1.7×10^5 g/cm²/sec. The imaginar component of tissue impedance is calculated and found to be negligible at the frequencies at which thes measurements are made.

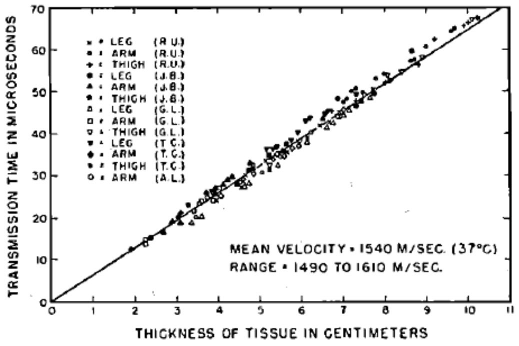
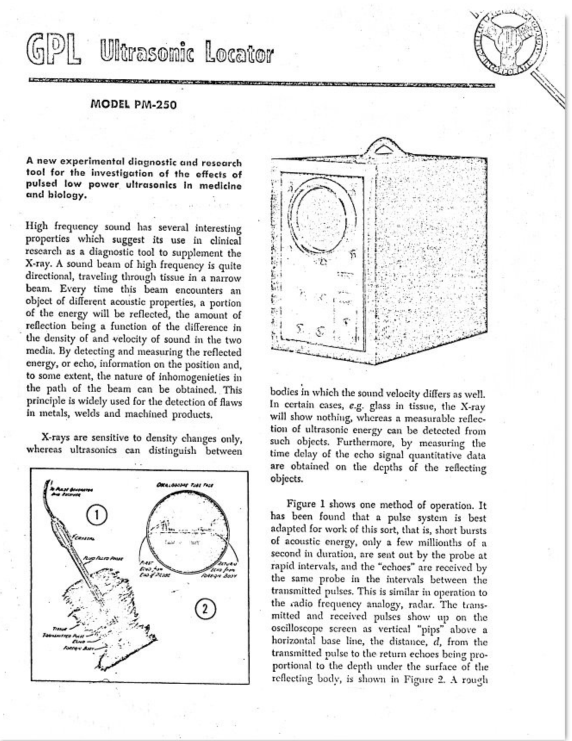


FIG. 4. Transmission time *vs.* thickness for living human tissue consisting principally of muscle. The line is the best straight-line fit of all data taken on living human tissues.



GPL Ultrasonic Locator

MODEL PM-250

A new experimental diagnostic and research tool for the investigation of the effects of pulsed low power ultrasonics in medicine and biology.

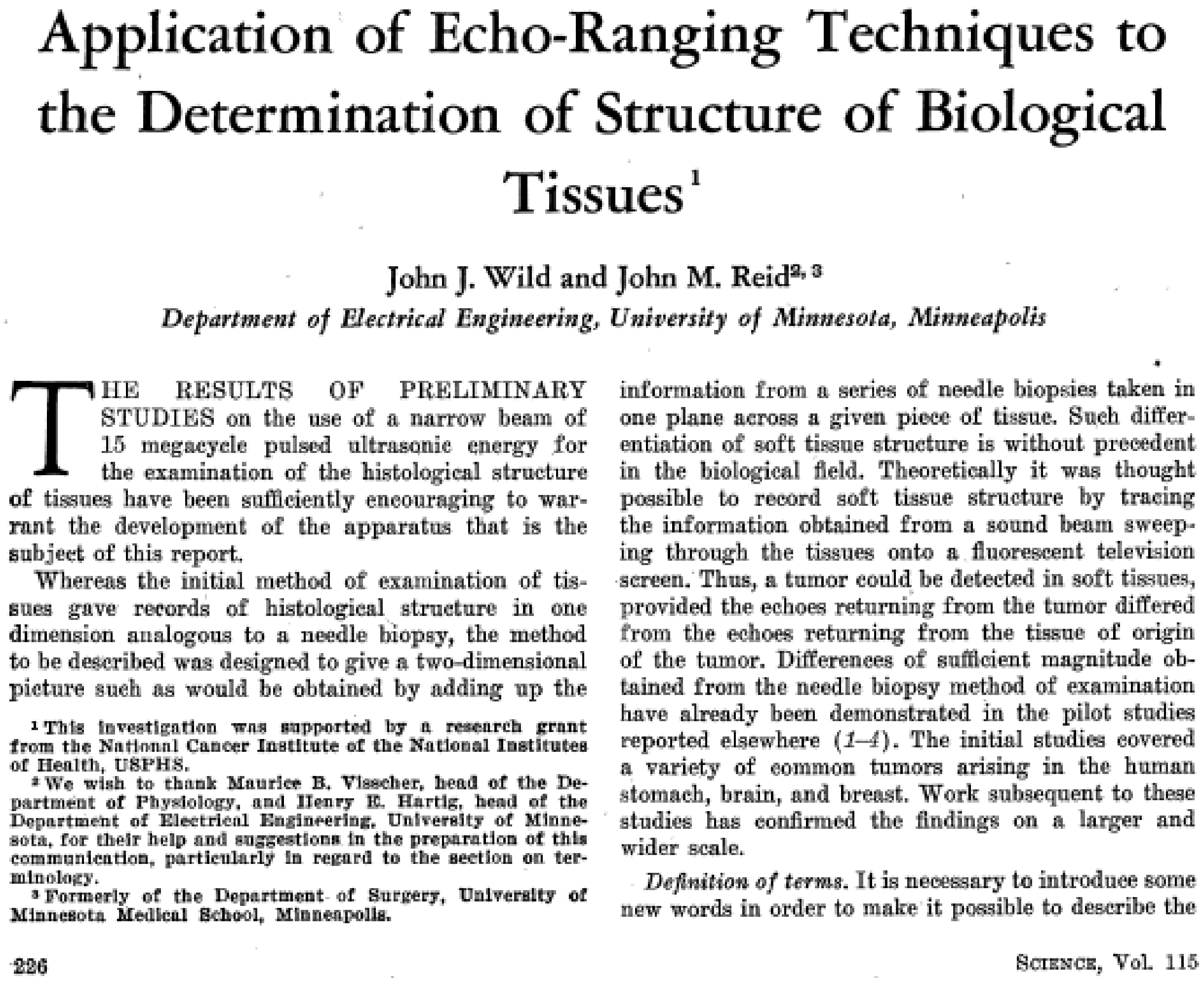
High frequency sound has several interesting properties which suggest its use in clinical research as a diagnostic tool to supplement the X-ray. A sound beam of high frequency is quite directional, traveling through tissue in a narrow beam. Every time this beam encounters an object of different acoustic properties, a portion of the energy will be reflected, the amount of reflection being a function of the difference in the density of and velocity of sound in the two media. By detecting and measuring the reflected energy, or echo, information on the position and, to some extent, the nature of inhomogenieties in the path of the beam can be obtained. This principle is widely used for the detection of flaws in metals, welds and machined products.

X-rays are sensitive to density changes only, whereas ultrasonics can distinguish between bodies in which the sound velocity differs as well. In certain cases, *e.g.* glass in tissue, the X-ray will show nothing, whereas a measurable reflection of ultrasonic energy can be detected from such objects. Furthermore, by measuring the time delay of the echo signal quantitative data are obtained on the depths of the reflecting objects.

Figure 1 shows one method of operation. It has been found that a pulse system is best adapted for work of this sort, that is, short bursts of acoustic energy, only a few millionths of a second in duration, are sent out by the probe at rapid intervals, and the "echoes" are received by the same probe in the intervals between the transmitted pulses. This is similar in operation to the radio frequency analogy, radar. The transmitted and received pulses show up on the oscilloscope screen as vertical "pips" above a horizontal base line, the distance, *d*, from the transmitted pulse to the return echoes being proportional to the depth under the surface of the reflecting body, is shown in Figure 2. A rough

George Ludwig c. 1972

John Julian Wild



Application of Echo-Ranging Techniques to the Determination of Structure of Biological Tissues[1]

John J. Wild and John M. Reid[2, 3]
Department of Electrical Engineering, University of Minnesota, Minneapolis

THE RESULTS OF PRELIMINARY STUDIES on the use of a narrow beam of 15 megacycle pulsed ultrasonic energy for the examination of the histological structure of tissues have been sufficiently encouraging to warrant the development of the apparatus that is the subject of this report.

Whereas the initial method of examination of tissues gave records of histological structure in one dimension analogous to a needle biopsy, the method to be described was designed to give a two-dimensional picture such as would be obtained by adding up the information from a series of needle biopsies taken in one plane across a given piece of tissue. Such differentiation of soft tissue structure is without precedent in the biological field. Theoretically it was thought possible to record soft tissue structure by tracing the information obtained from a sound beam sweeping through the tissues onto a fluorescent television screen. Thus, a tumor could be detected in soft tissues, provided the echoes returning from the tumor differed from the echoes returning from the tissue of origin of the tumor. Differences of sufficient magnitude obtained from the needle biopsy method of examination have already been demonstrated in the pilot studies reported elsewhere (*1–4*). The initial studies covered a variety of common tumors arising in the human stomach, brain, and breast. Work subsequent to these studies has confirmed the findings on a larger and wider scale.

Definition of terms. It is necessary to introduce some new words in order to make it possible to describe the

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[1] This investigation was supported by a research grant from the National Cancer Institute of the National Institutes of Health, USPHS.

[2] We wish to thank Maurice B. Visscher, head of the Department of Physiology, and Henry E. Hartig, head of the Department of Electrical Engineering, University of Minnesota, for their help and suggestions in the preparation of this communication, particularly in regard to the section on terminology.

[3] Formerly of the Department of Surgery, University of Minnesota Medical School, Minneapolis.

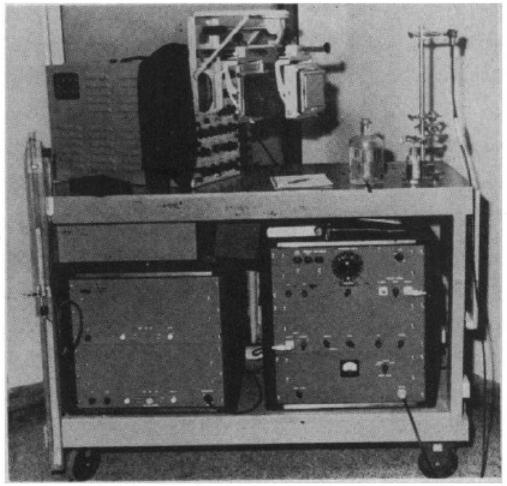


FIG. 3. The complete echographic apparatus as used in hospital. The unidimensional echoscope can be seen clamped to a stand on the right, connected to the transmitter-receiver unit. The cathode-ray screen with the camera in the recording position is to the left on the table.

John J Wild c. 1953

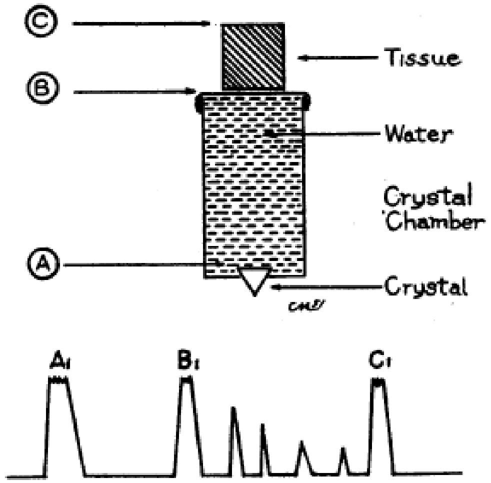


FIG. 2. Cross section of crystal chamber and tissue under examination (top) and a typical unidimensional echogram obtained from the arrangement (bottom).

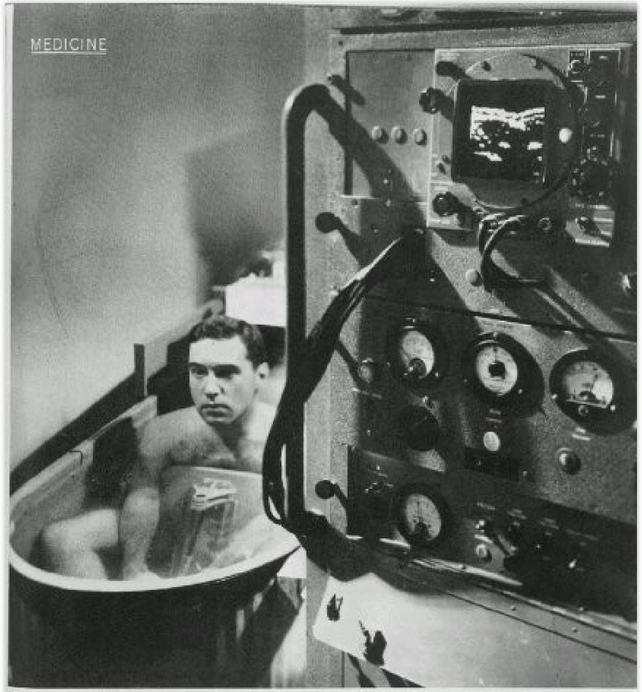
Douglass Howry

THE ULTRASONIC VISUALIZATION OF CARCINOMA OF THE BREAST AND OTHER SOFT-TISSUE STRUCTURES

DOUGLASS H. HOWRY, M.D., DOROTHY A. STOTT, M.D., AND W. RODERIC BLISS, B.S.

WE HAVE PREVIOUSLY REPORTED[10, 11] on the development of an original ultrasonic instrument that makes possible th of numerous soft-tissue structur bodies that cannot be demonst roentgenographic methods. Ou is to report on the in vitro app instrument for the visualization malignant tumors, the determ extent of tumor involvement other structures, and the localiz tases in distant sites.

of sound is transferred into an electrical signal that is amplified and presented as a single



SOMASCOPE SUBJECT SITS ON STOOL IN TUB AS SOUND WAVES, STREAMING INTO HIM FROM BEHIND, RECORD HIS BACK'S INNER TISSUES ON SCOPE (TOP)

SOUND-WAVE PORTRAIT IN THE FLESH

A sonarlike device produces pictures of the human body's soft tissues which are invisible to X-rays

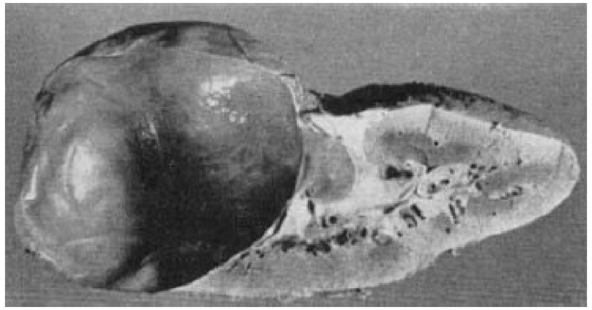


FIG. 2. Kidney with cyst; longitudinal section.

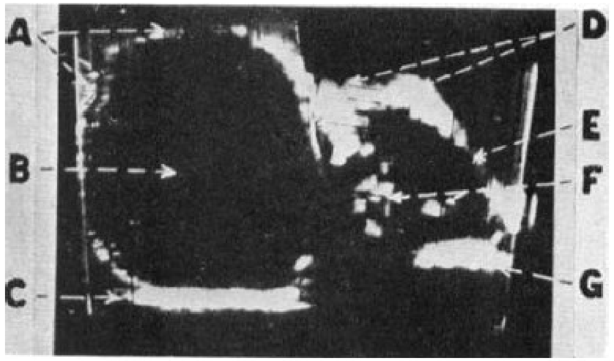
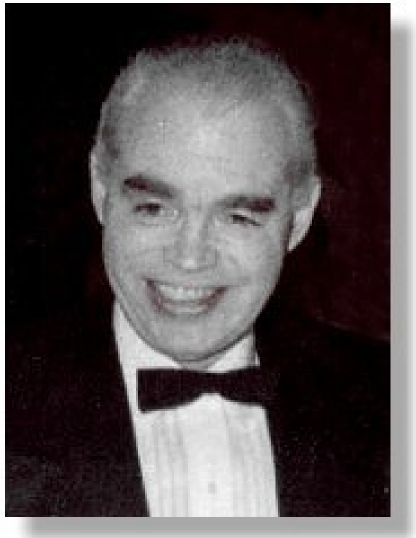


FIG. 3. Somagram of kidney specimen. A, Wall of cyst; B, homogeneous fluid; C, sonic reflector behind cyst; D, attached perirenal fat; E, kidney surface; F, calyxes and blood vessels; G, deep surface of kidney and perirenal fat.



Douglass Howry, late 1960s

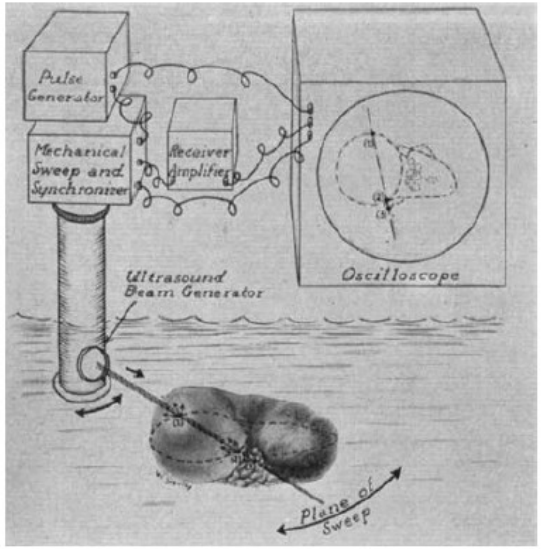
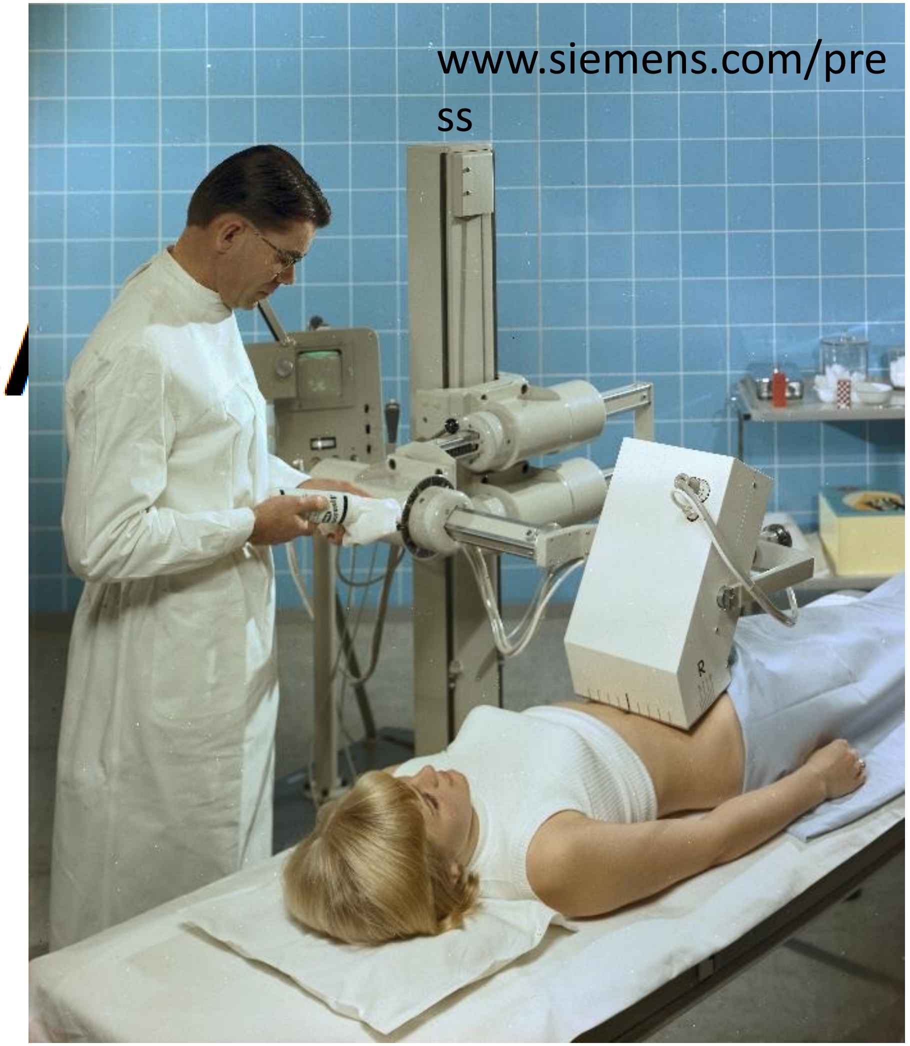


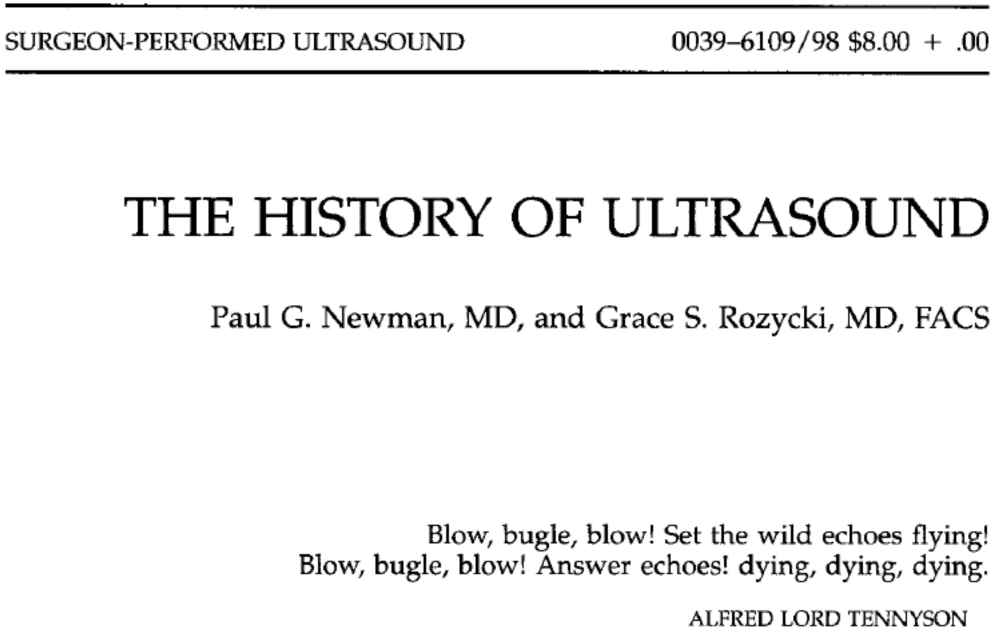
FIG. 1. Diagram of somascope scanning tissue specimen.



www.siemens.com/press

Vidoson 635, Siemens

První B-mód v reálném čase komerčně dostupný, 1967



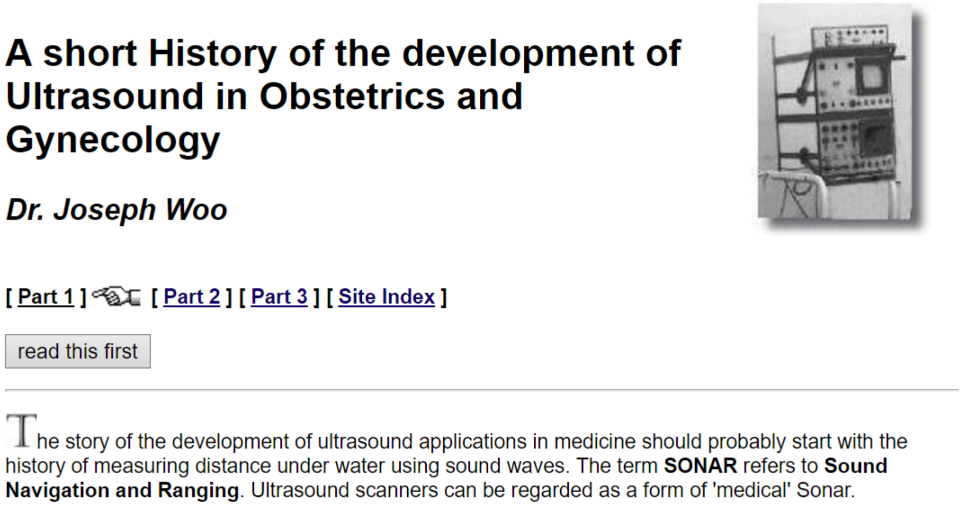
SURGEON-PERFORMED ULTRASOUND 0039–6109/98 $8.00 + .00

THE HISTORY OF ULTRASOUND

Paul G. Newman, MD, and Grace S. Rozycki, MD, FACS

> Blow, bugle, blow! Set the wild echoes flying!
> Blow, bugle, blow! Answer echoes! dying, dying, dying.
>
> ALFRED LORD TENNYSON

http://www.ob-ultrasound.net/history1.html



A short History of the development of Ultrasound in Obstetrics and Gynecology

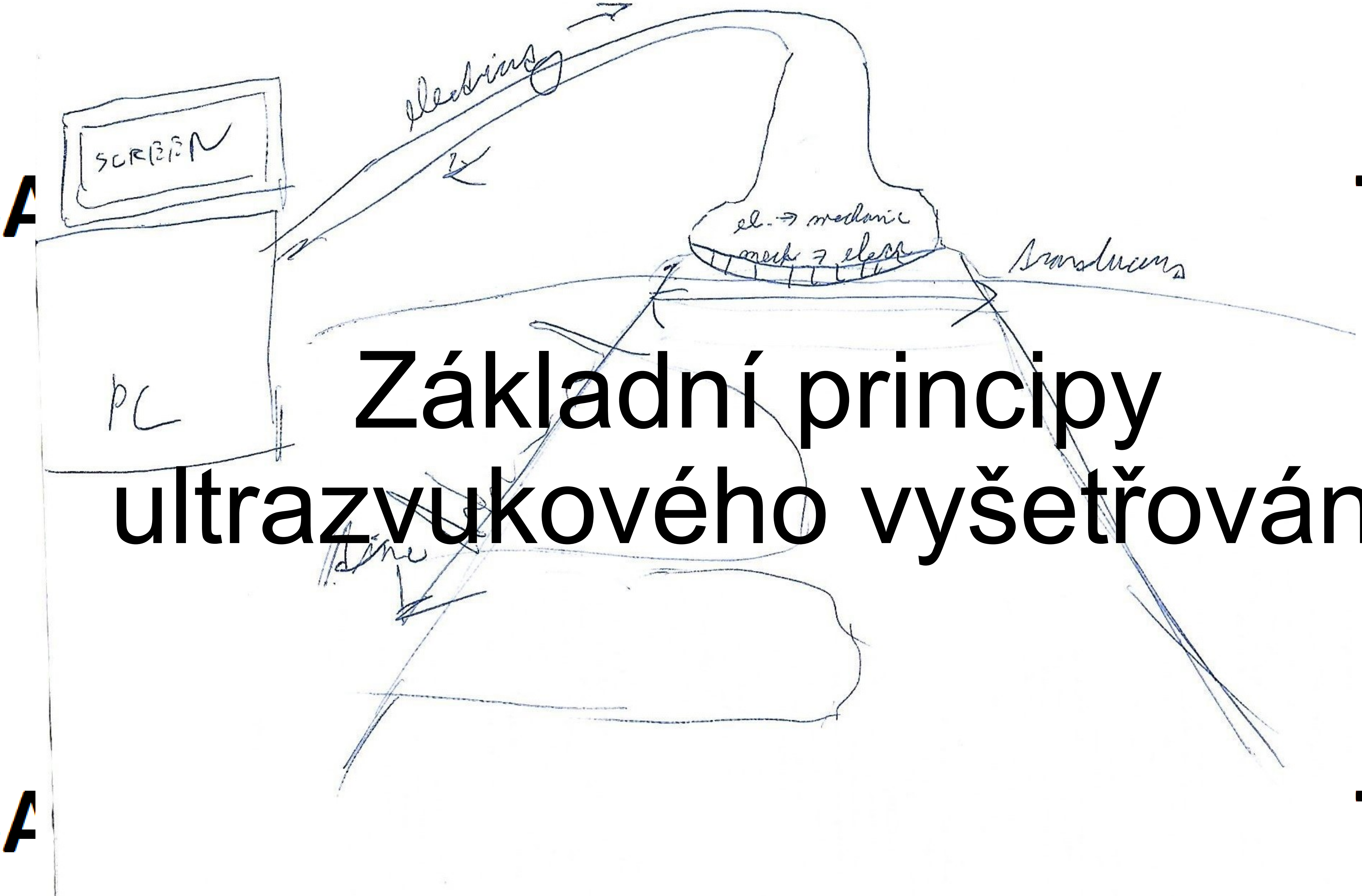
Dr. Joseph Woo

[Part 1] [Part 2] [Part 3] [Site Index]

read this first

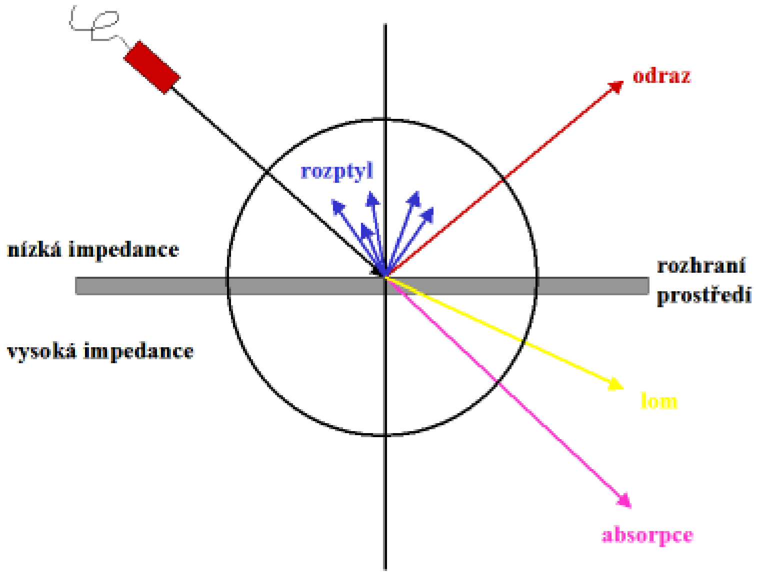
The story of the development of ultrasound applications in medicine should probably start with the history of measuring distance under water using sound waves. The term **SONAR** refers to **Sound Navigation and Ranging**. Ultrasound scanners can be regarded as a form of 'medical' Sonar.

Základní principy ultrazvukového vyšetřování



Šíření ultrazvuku prostředním

- odraz
  - na rozhraní dvou prostředí s výrazně rozdílnou impedancí
- rozptyl
  - na mikroskopických rozhraních, jejichž velikost je <u>menší než vlnová délka</u> vysílaného ultrazvuku
- ohyb, lom
  - na rozhraní dvou prostředí, když vlnění nedopadá kolmo (vznik UZ artefaktů)
- absorpce
  - <u>postupná</u> ztráta energie při průchodu prostředním (formou tepelné energie)
  - roste s frekvencí a hustotou



Principy ultrazvukového zobrazování

- Odražené akustické vlnění na rozhraní prostřední s rozdílnou akustickou impedancí
- Čas a intenzita
- Akustická impedance - odpor, který klade prostředí ultrazvuku
  - Rozhodující veličina při odrazu a lomu UZ vln na akustických rozhraních

Možnosti rekonstrukce obrazu

- **A mód (Amplitude)**
  - jednorozměrný UZ paprsek
- **B mód (Brightness)**
  - 2D zobrazení v reálném čase
  - Horizontální poloha – směr odrazu
  - Vertikální poloha – čas resp. hloubka
  - Jas – intenzita odrazu
- **(3D, 4D)**
- **M mód (Motion)**
  - Jednorozměrný B-mód + čas

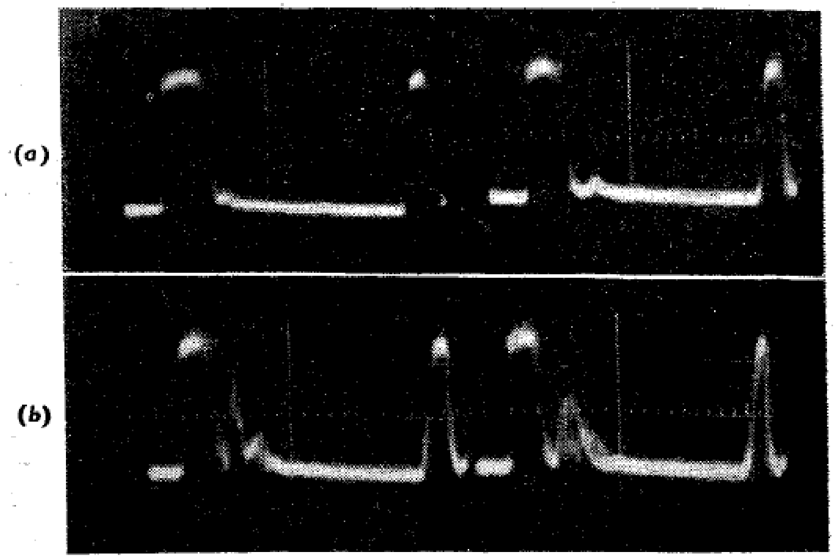
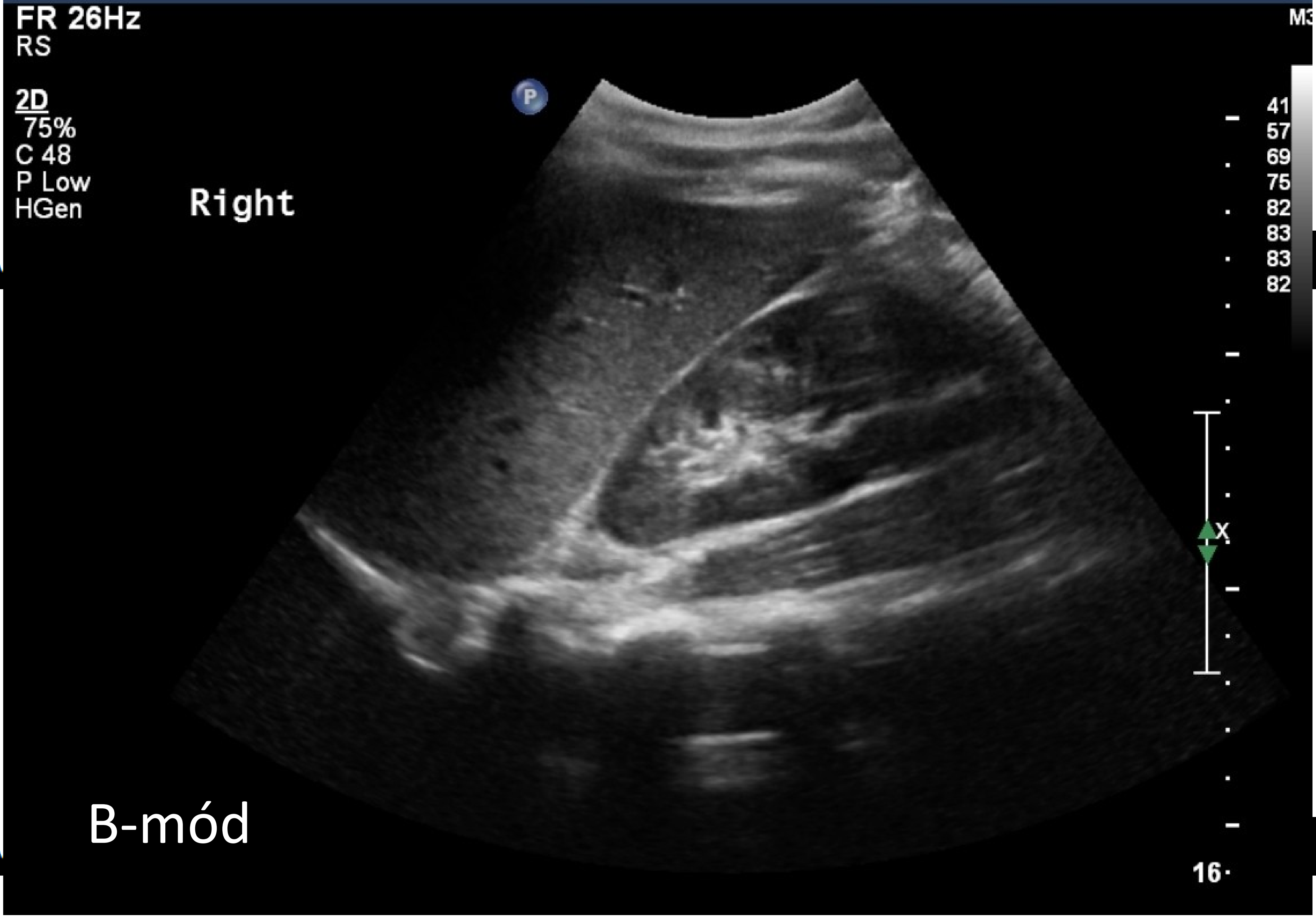


Fig. 5(*a*)—Two typical ultrasonograms of normal human breast in case I. The saturated peak to the left is given by the rubber membrane on the ultrasonograph. The peak to the right is an artefact inherent in the machine and is considered to be due to "ringing" of the pulses within the apparatus. Note that almost no echoes are returned from the base-line between the two "landmarks."

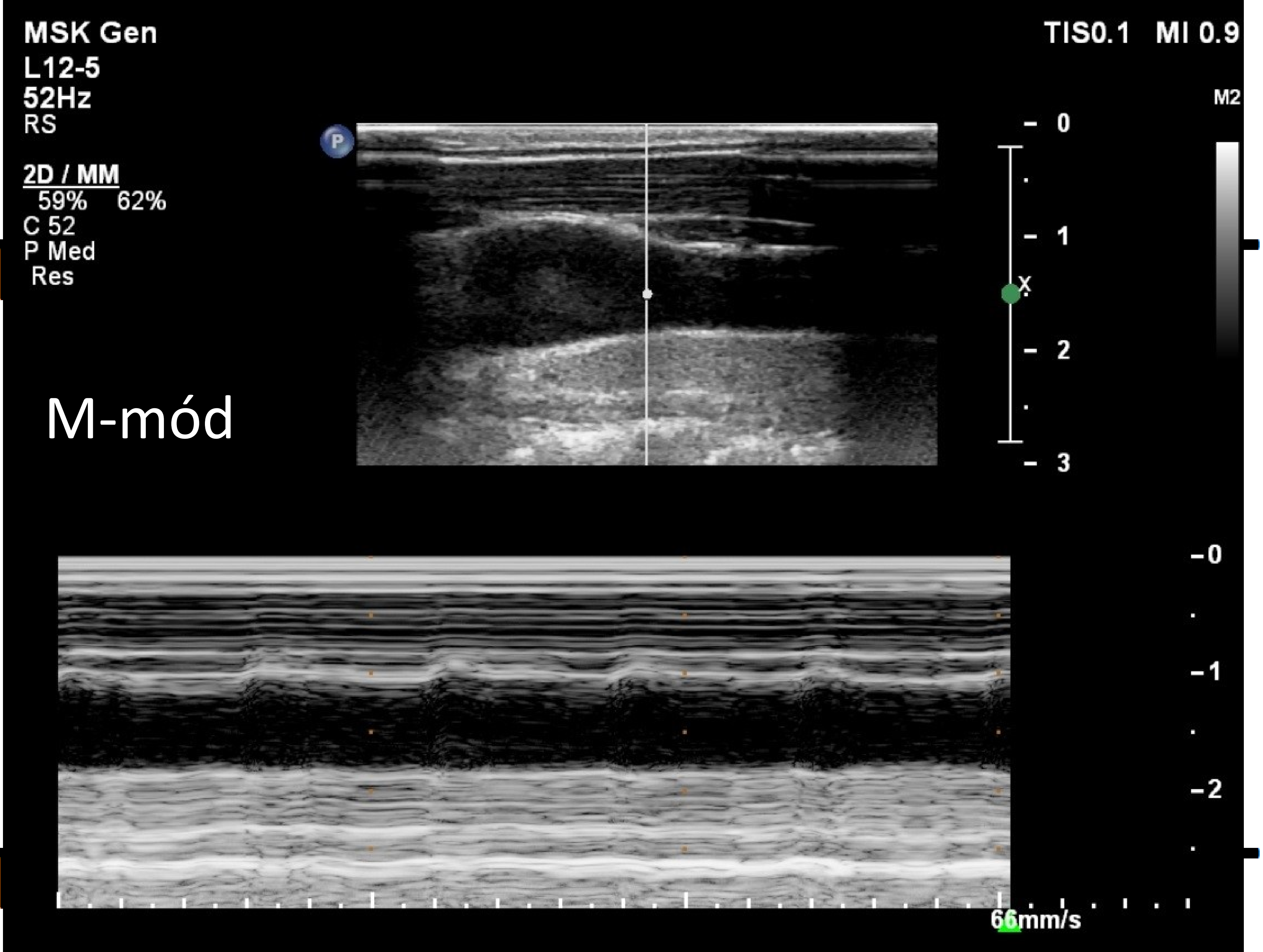
Fig. 5(*b*)—Two representative ultrasonograms of carcinoma of breast As in Fig. 5(*a*) the two "landmarks" can be seen. The strong return signals rising from the base-line indicate echoes returning from the tumour.

A – mód, J. Wild, Reid 1952

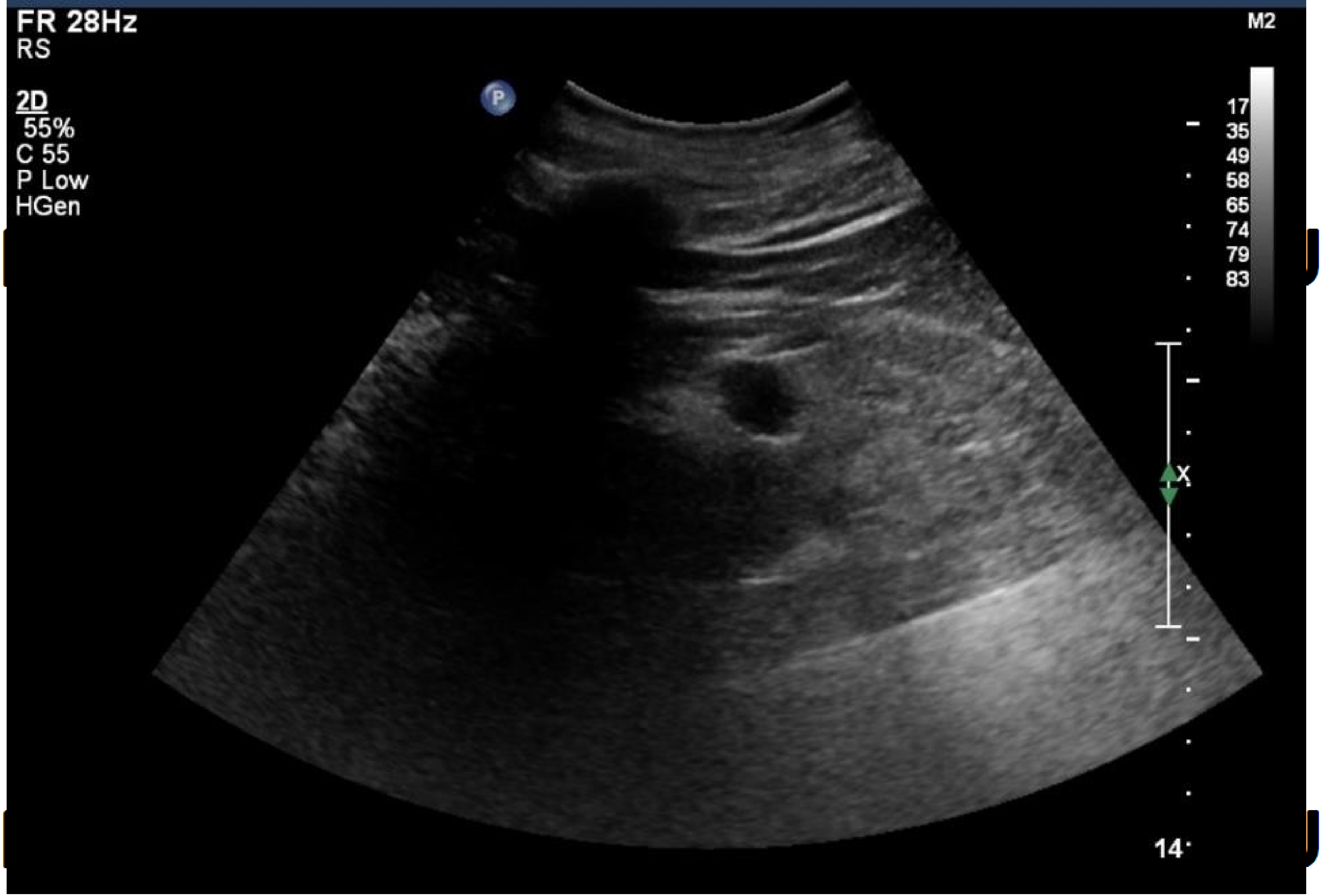


B-mód


C+ / Surface:Surface Smooth / 3D Rotation:90
3D


MSK Gen
L12-5
52Hz
RS
2D / MM
59% 62%
C 52
P Med
Res
TIS0.1 MI 0.9
M2
P
0
1
2
3
X
–0
–1
–2
66mm/s

M-mód


FR 28Hz
RS
2D
55%
C 55
P Low
HGen
M2
17
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74
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X
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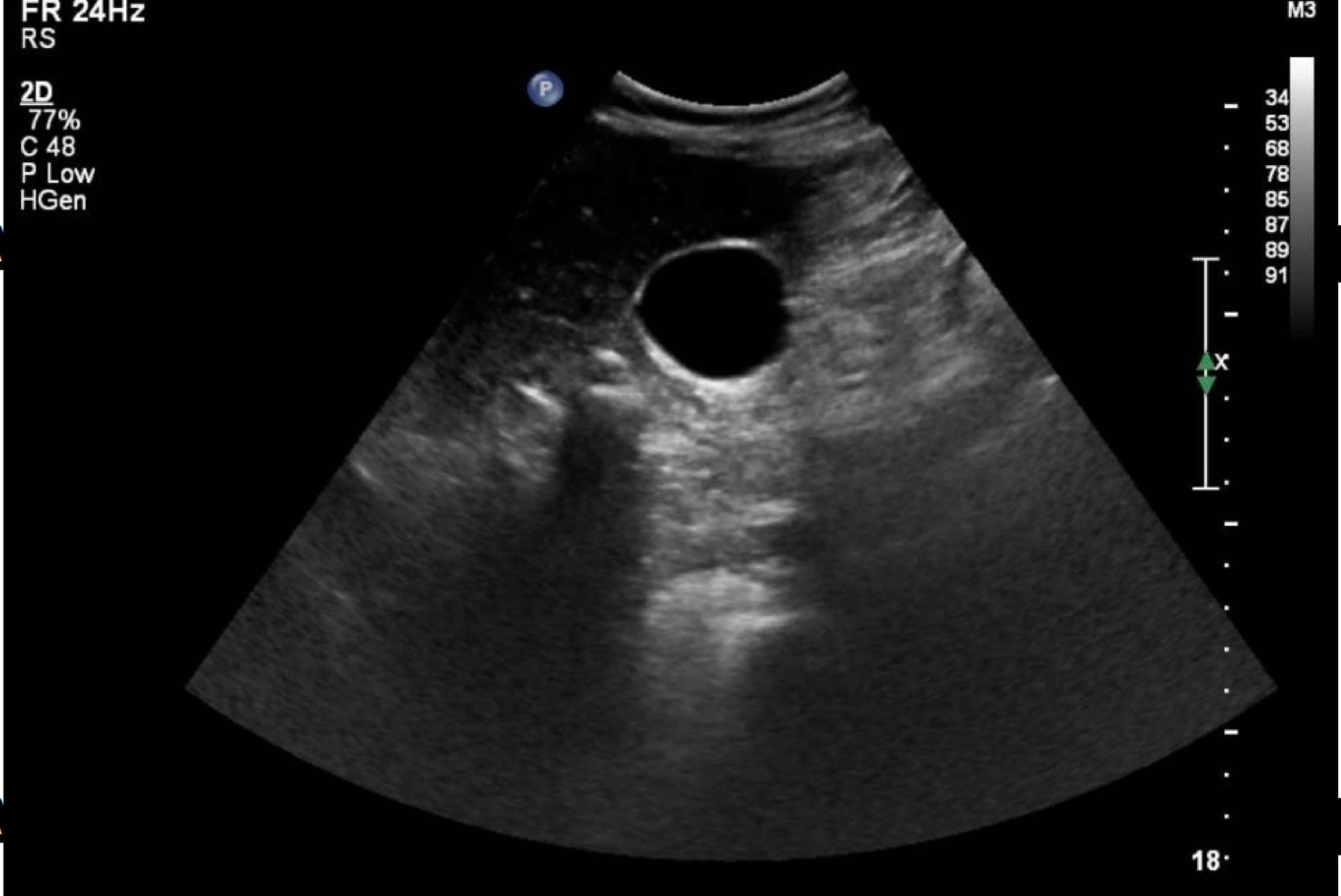
FR 24Hz
RS
2D
77%
C 48
P Low
HGen
P
M3
34
53
68
78
85
87
89
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X
18


,28 cm
R

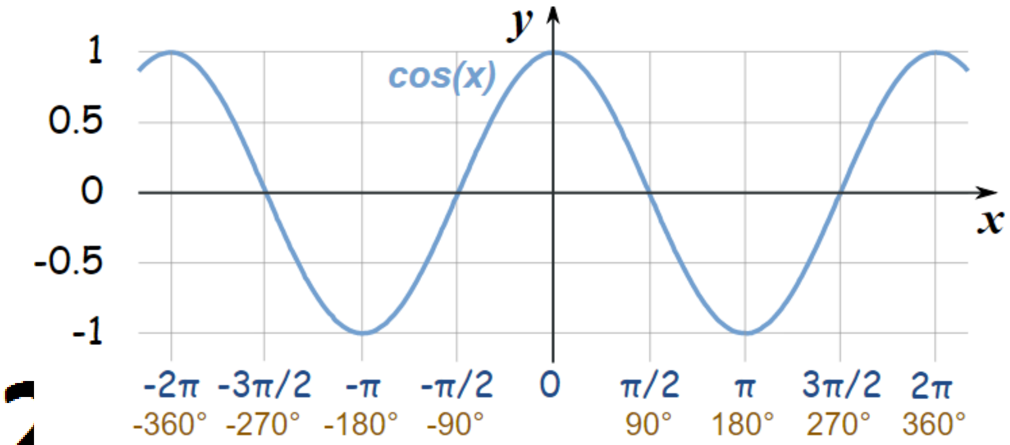
Dopplerův jev

Johann Christian Doppler 1845

Přibližuje-li se zdroj zvuku o konstantní výšce (frekvenci) tónu směrem k pozorovateli, vnímá pozorovatel výšku tónu vyšší, rozdíl mezi frekvencemi záleží na rychlosti pohybu.

- velikost frekvenčního posuvu je přímo úměrná frekvenci, rychlosti krevního toku a kosinu úhlu, který svírá směr UZ vln a tok krve
    - kritická mez nad 60°

$$\Delta f = \frac{2 f_0 v \cos\alpha}{c}$$



Dopplerovské techniky

Kontinuální doppler

- kontinuální nosnou vlnou (CW)
- nelze určit hloubka, ze které signál přichází

Pulzní doppler

- jeden elektroakustický měnič, který střídavě ultrazvukové vlnění vysílá a přijímá
- doba mezi vysláním a příjmem ultrazvukového impulzu je úměrná vzdálenosti cévy od ultrazvukové sondy
- umožňuje záznam rychlostního spektra toku krve v cévě

Barevný doppler

- v B-obrazu je definovaná výseč, ze které je dopplerovská informace o rychlosti a směru toku analyzována a zobrazena v podobě barevných pixelů (BART)

Spektrální záznam

- Graf závislosti rychlosti na čase

Duplexní

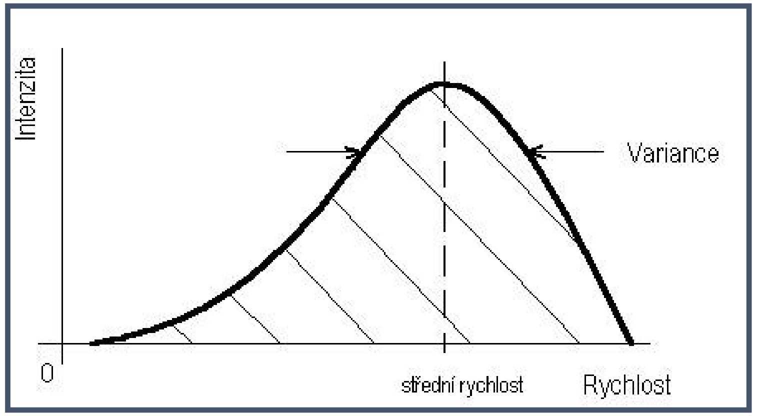
- kombinace dvojrozměrného dynamického zobrazení (B-mode) a pulsního dopplerovského měření

Triplexní

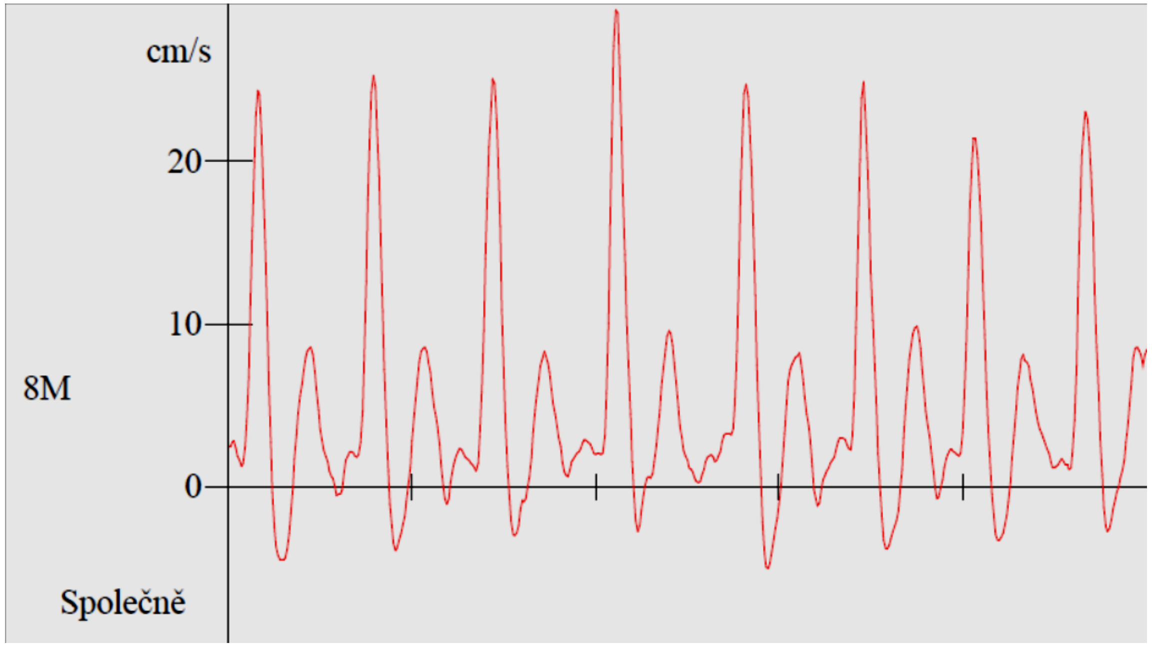
- kombinace B zobrazení se spektrální křivkou a barevným dopplerem

Energetický doppler

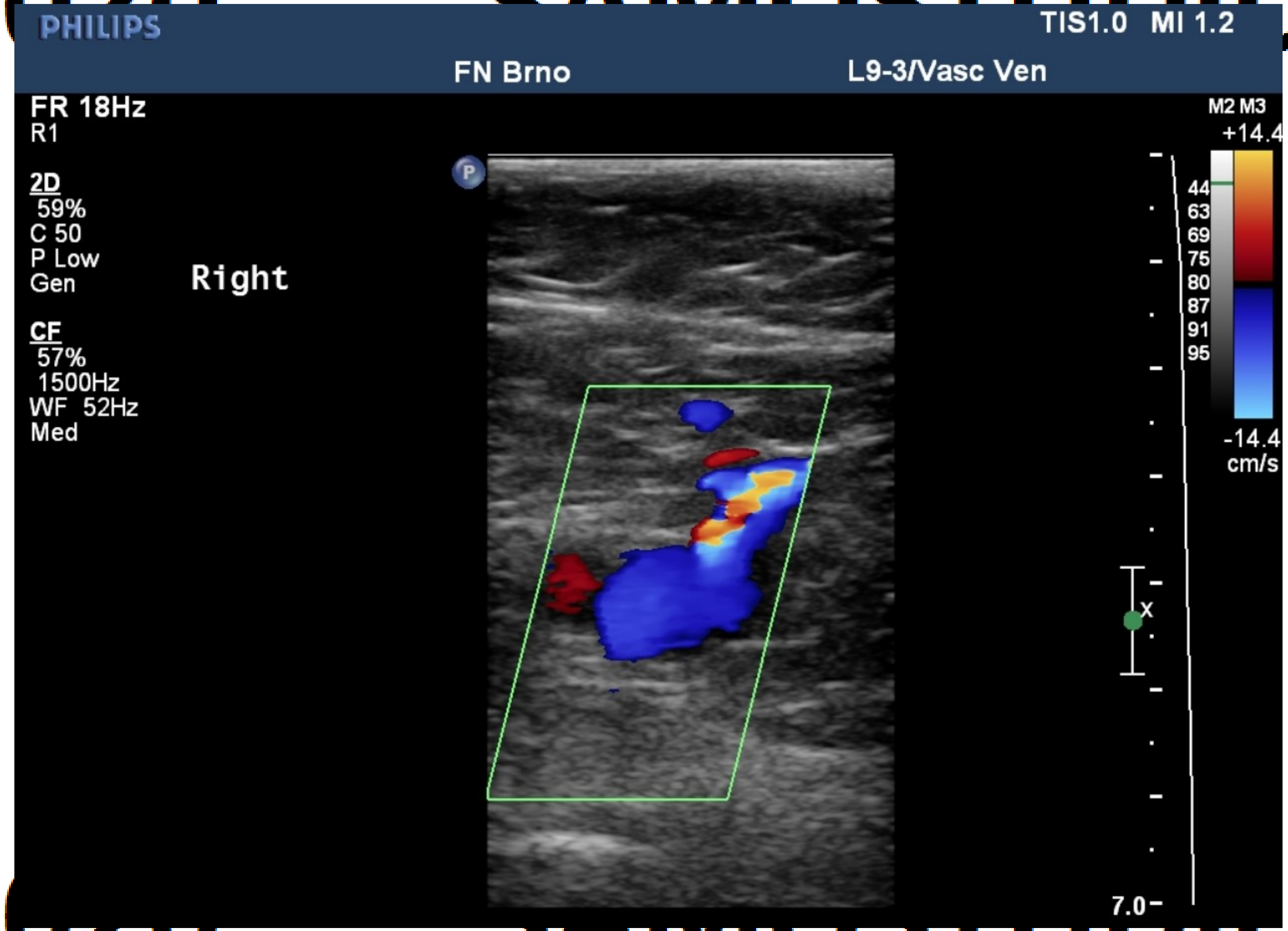
- zobrazuje celou energii dopplerovského signálu
- úměrná ploše vymezené spektrální křivkou



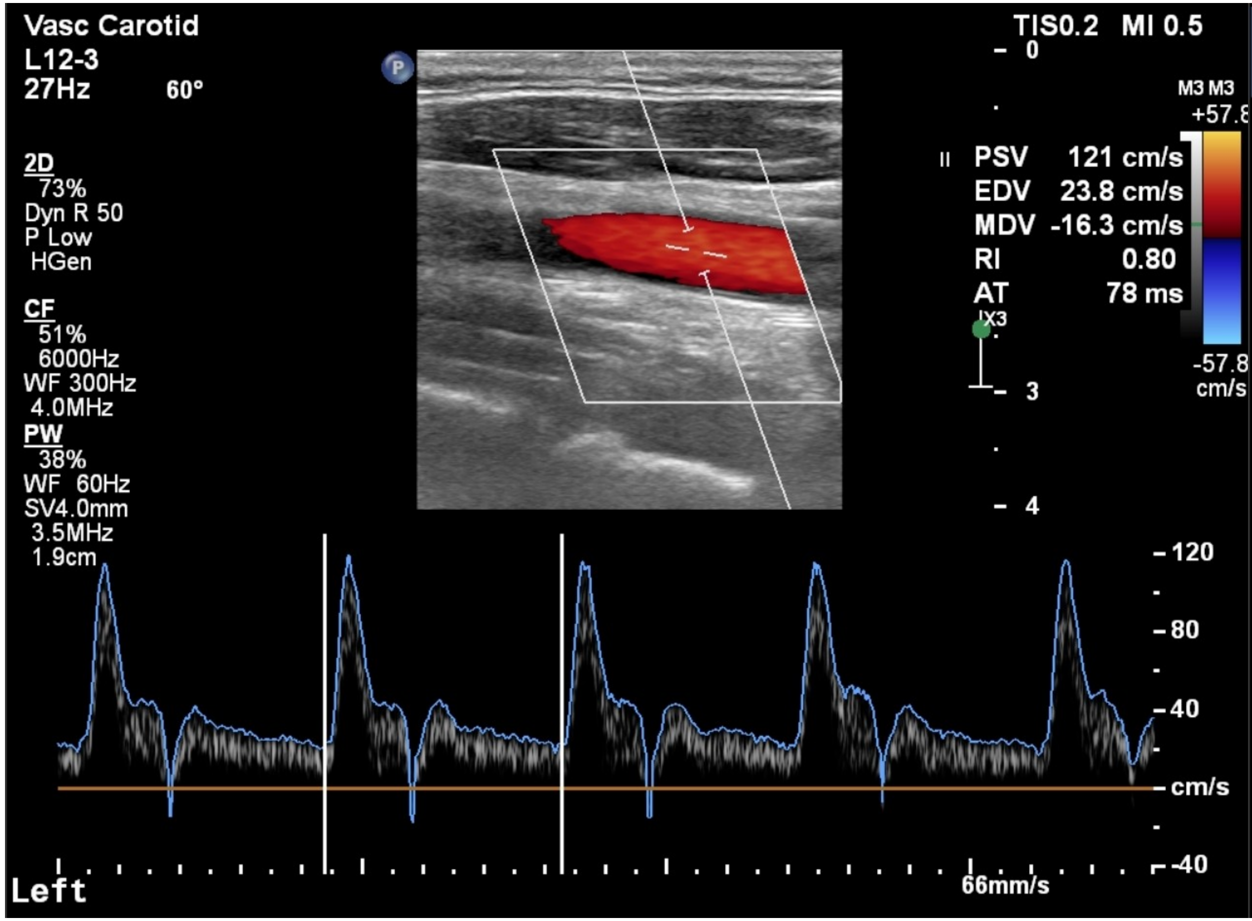
Spektrální záznam z kontinuálního „doppleru“



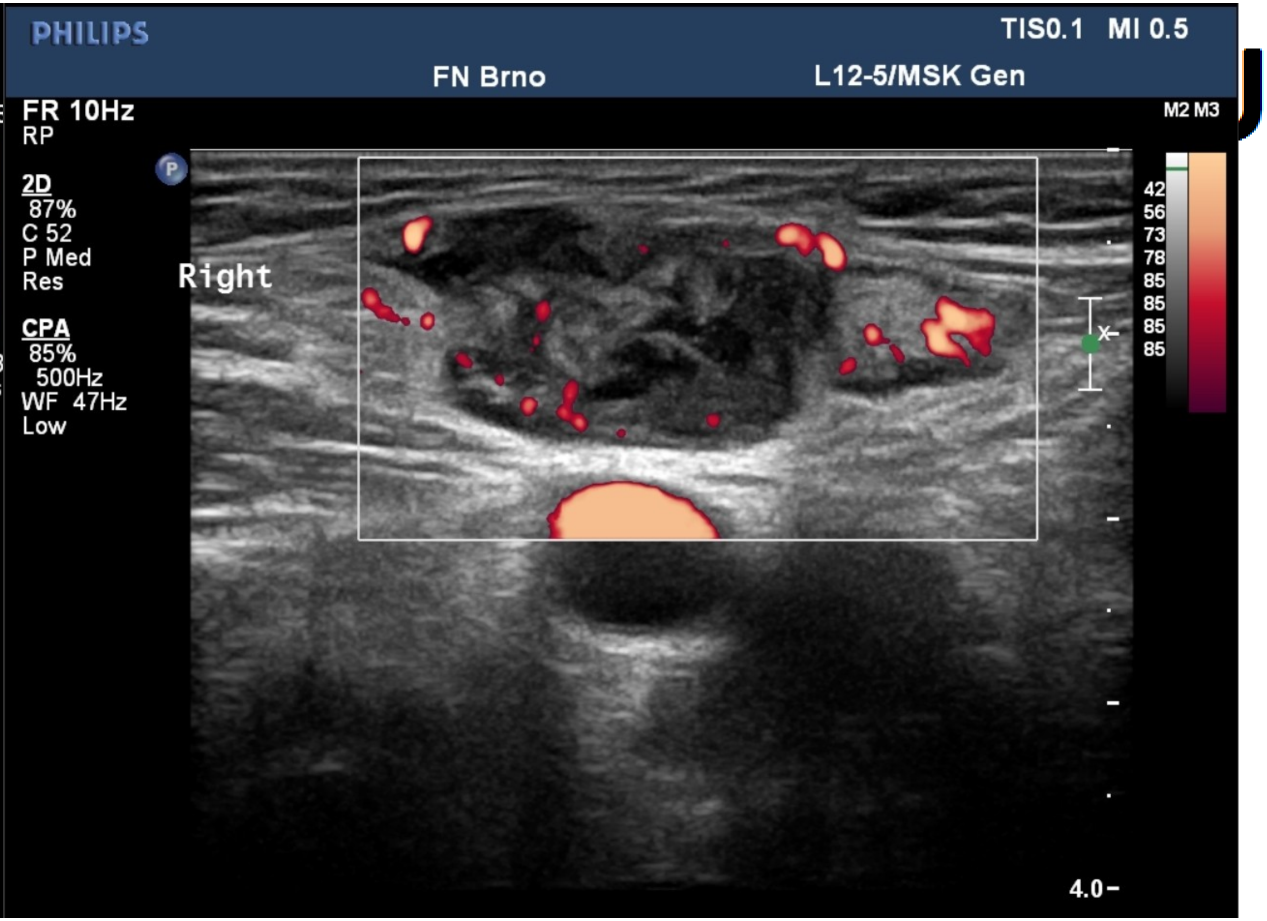
Barevný mód



Triplexní zobrazení



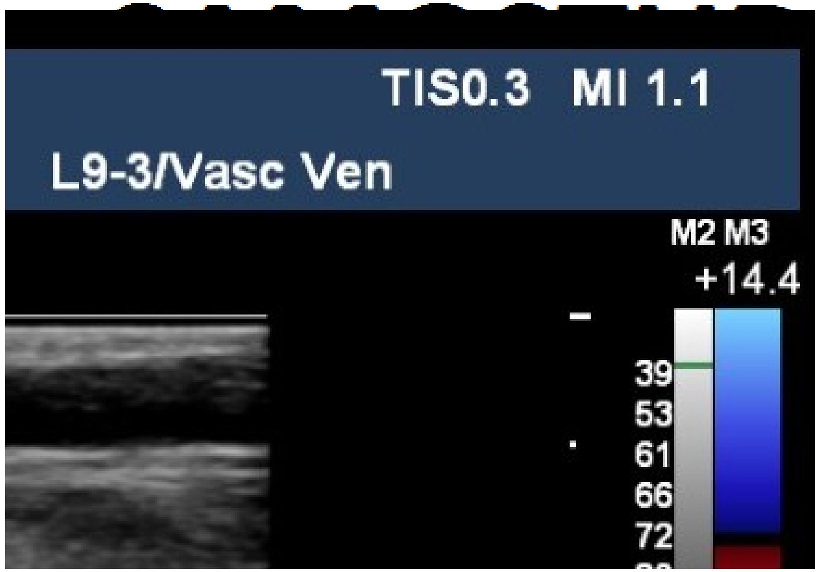
Power doppler



Bezpečnost ultrazvukového vyšetřování

Mechanický index (MI)

- s kavitací spojené bioefekty
- Závisí na akustickém tlaku a frekvenci
- MI < 1,9



Tepelný index (TI)

- poměr aktuálního výkonu k hodnotě která by zvýšila teplotu o 1°C
- TIS – „soft tissue“, TIB – „bone“, TIC – „cranial bone“

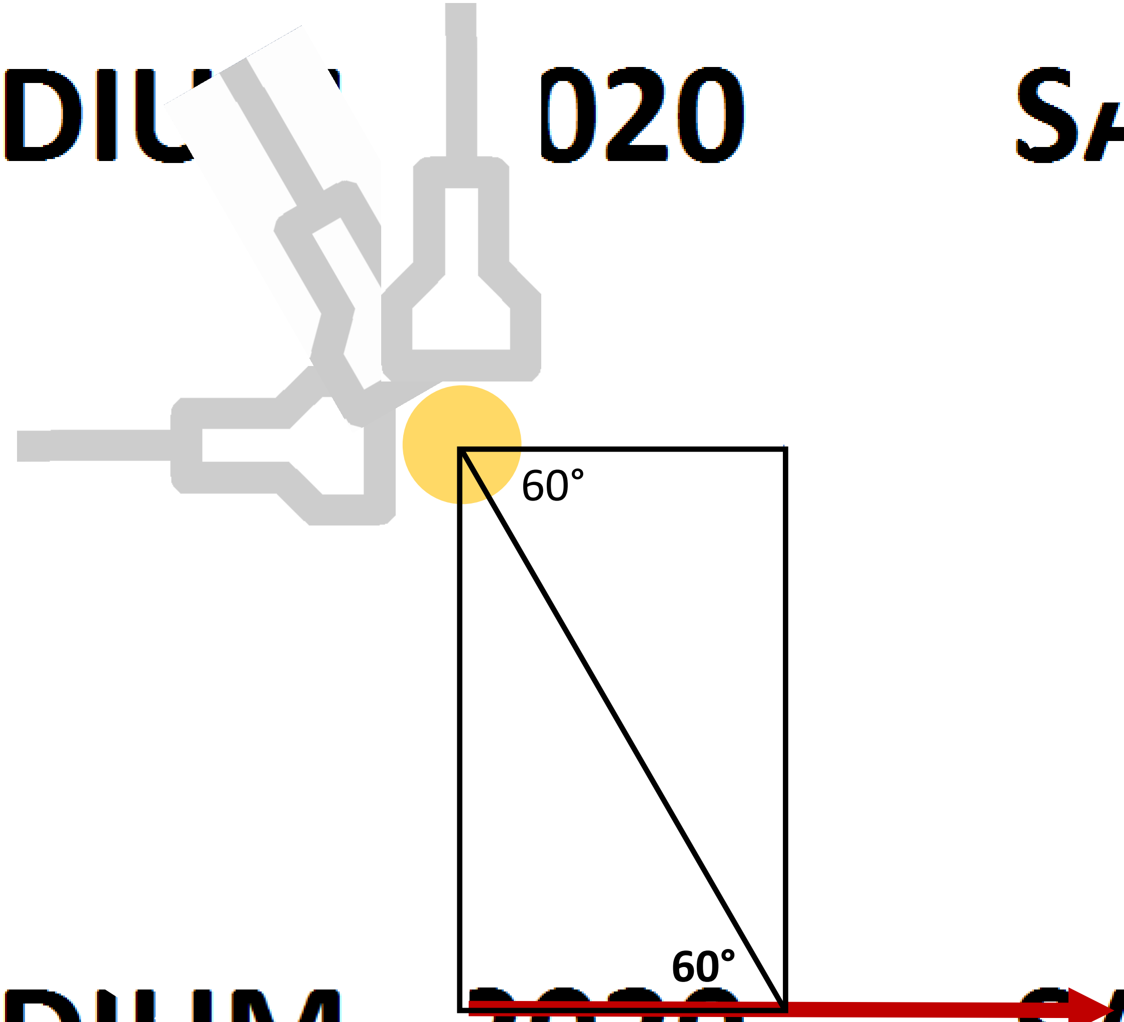
Dopplerův jev

Zdroj dopplerovského posunu

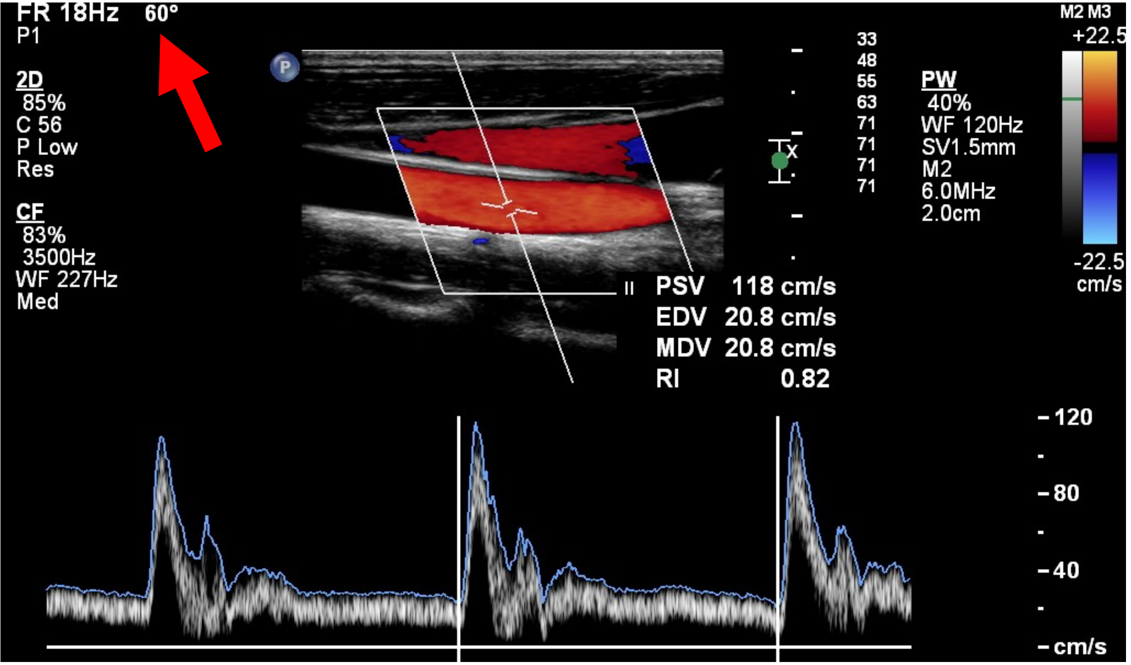
Matematický základ

$$\Delta f = \frac{2 f_0 v \cos\alpha}{c}$$

$$\Delta f = \frac{\cancel{2 f_0} v \cos\alpha}{\cancel{c}}$$

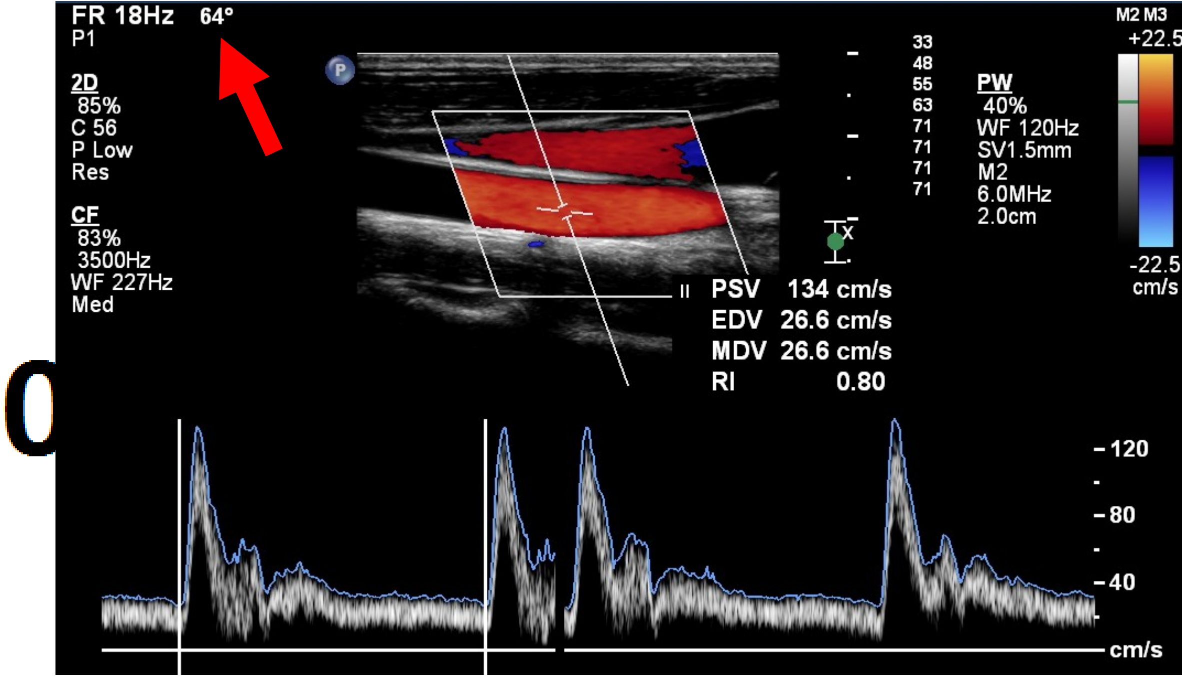


$\Delta f = (f_0 v)/c$

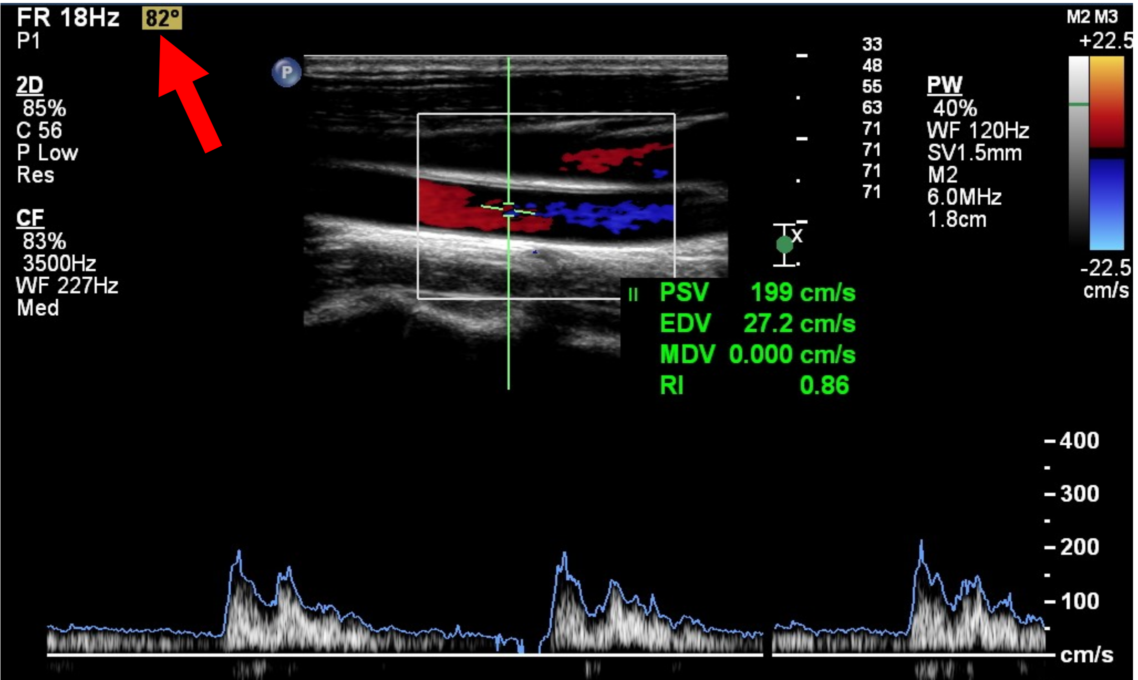


PSV 118 cm/s
EDV 20.8 cm/s
MDV 20.8 cm/s
RI 0.82

2020

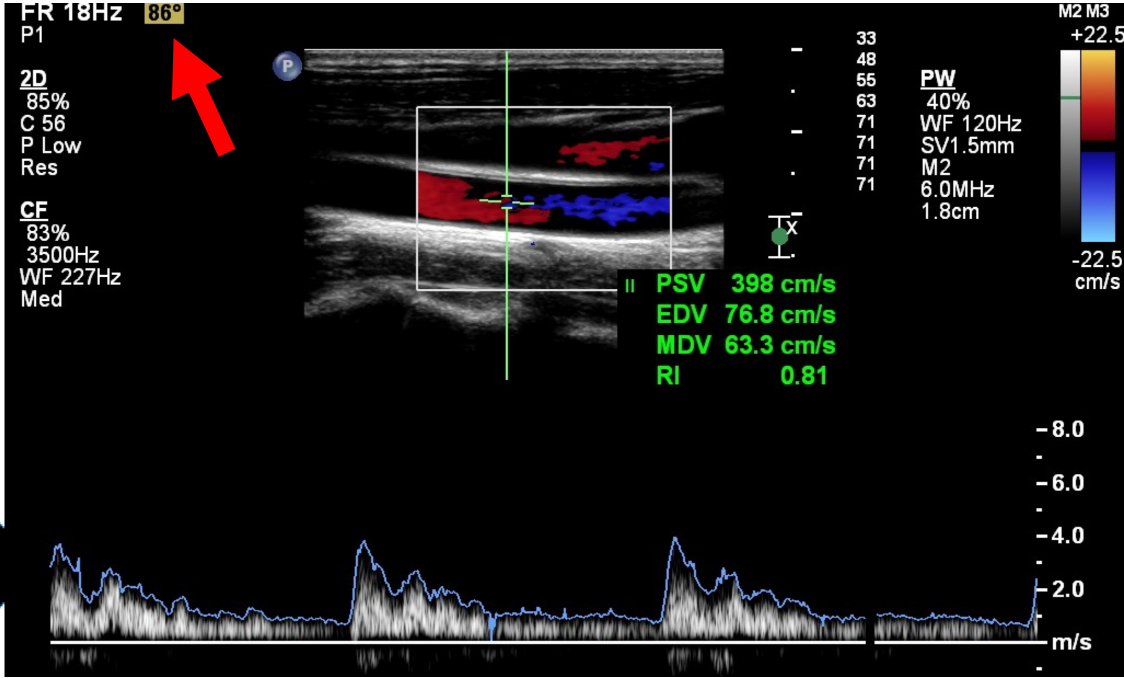


PSV 134 cm/s
EDV 26.6 cm/s
MDV 26.6 cm/s
RI 0.80

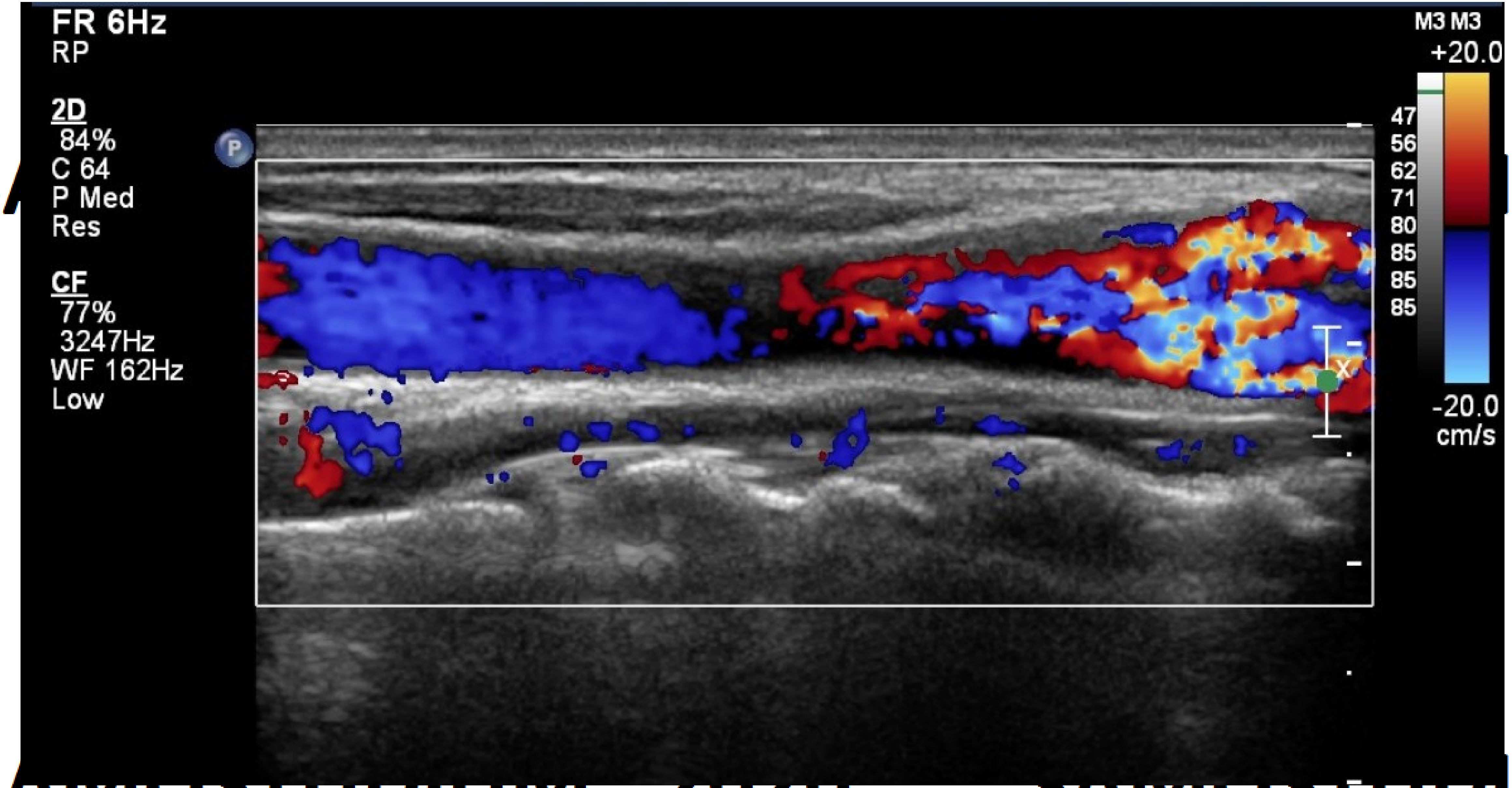


PSV 199 cm/s
EDV 27.2 cm/s
MDV 0.000 cm/s
RI 0.86

2020



PSV 398 cm/s
EDV 76.8 cm/s
MDV 63.3 cm/s
RI 0.81

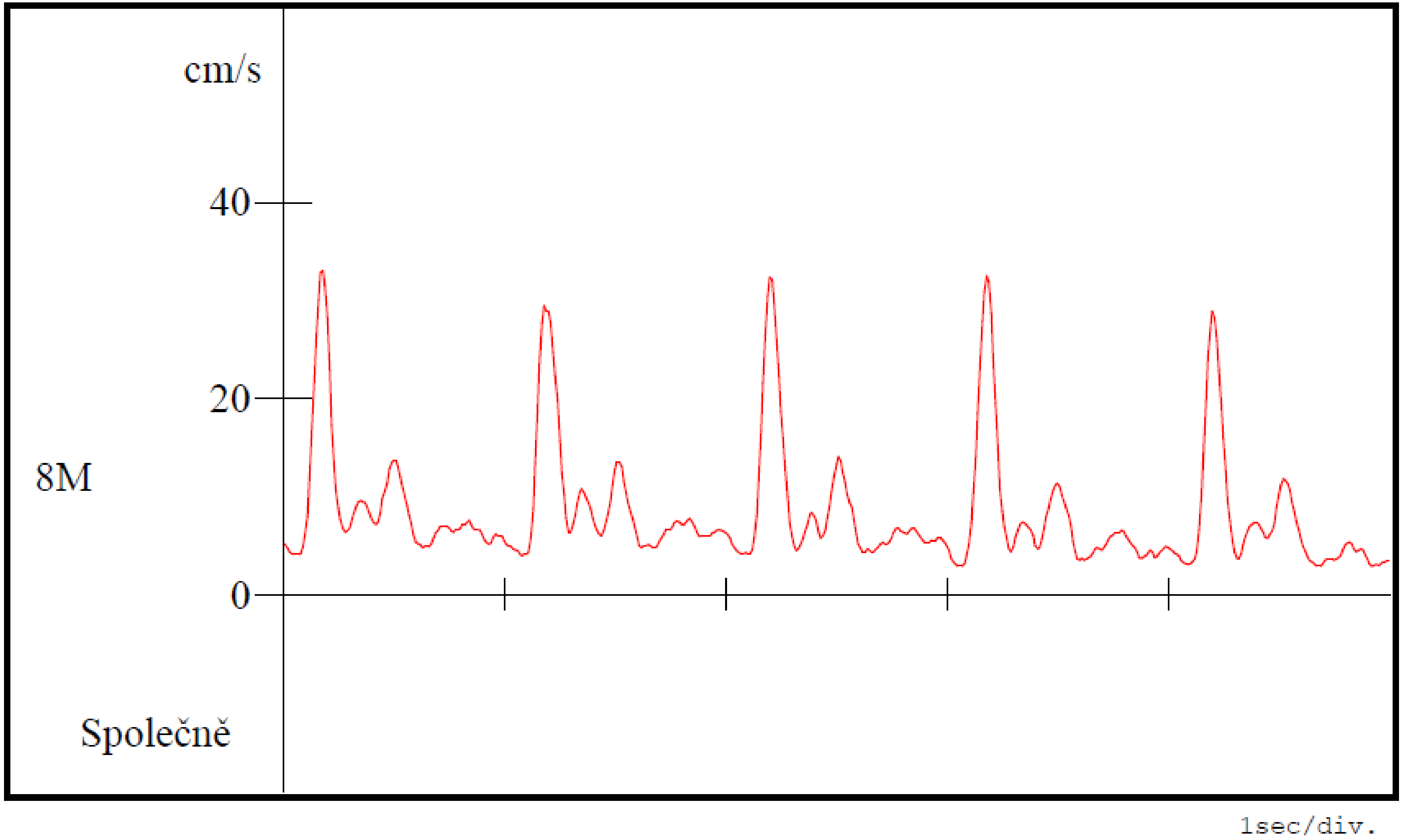

FR 6Hz
RP
2D
84%
C 64
P Med
Res
CF
77%
3247Hz
WF 162Hz
Low
P
M3 M3
+20.0
47
56
62
71
80
85
85
85
-20.0
cm/s
X

Dopplerovské techniky

Kontinuální doppler

S kontinuální nosnou vlnou (continuous wave

Hor.končetiny --- Pravý Radial



Numerická data

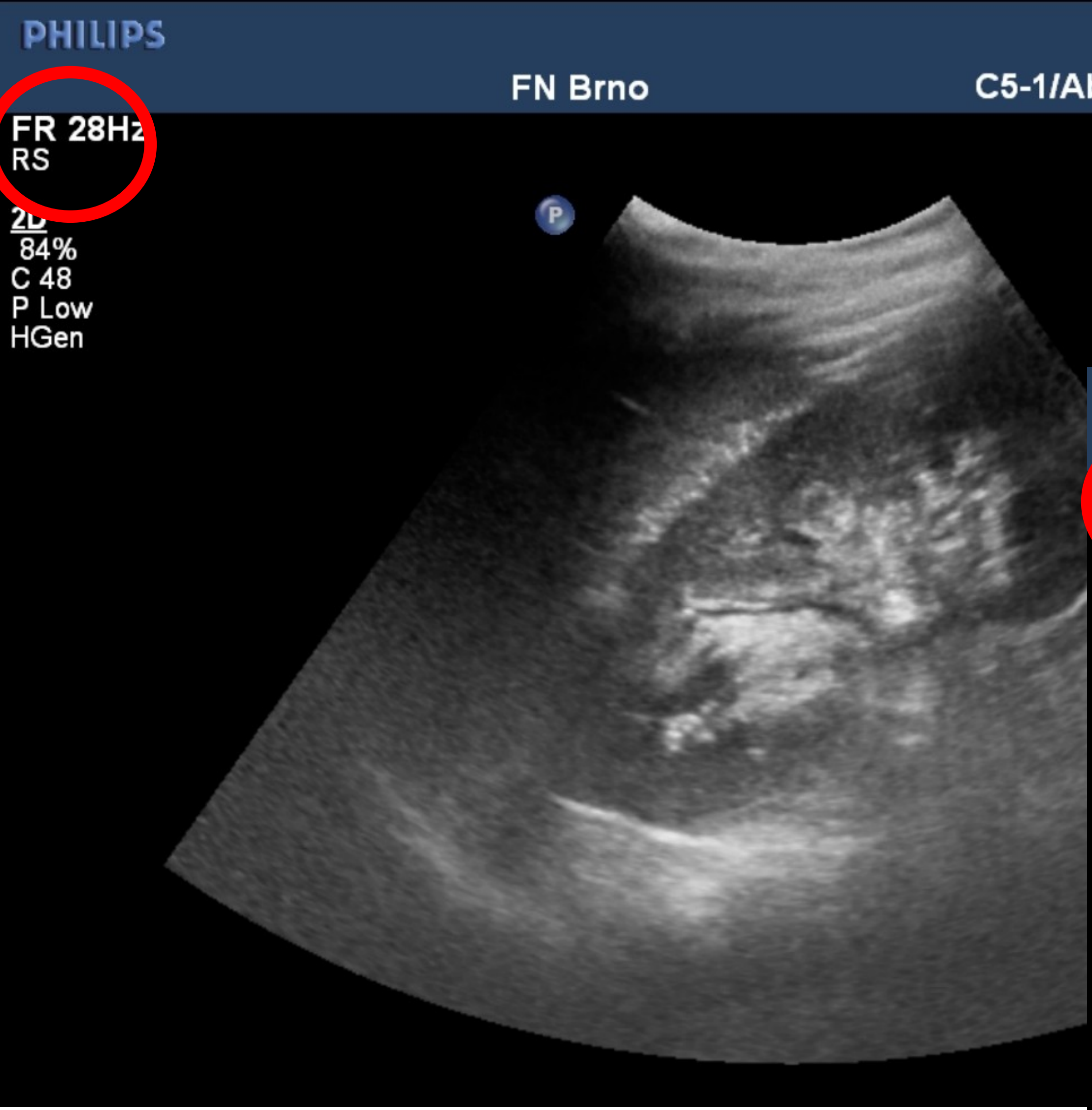
Max	31,6 cm/s	SD	7,71
Prům.	8,9 cm/s	RP	0,87
D	4,1 cm/s	PI	3,09
Min	4,1 cm/s	Puls	60 BMP

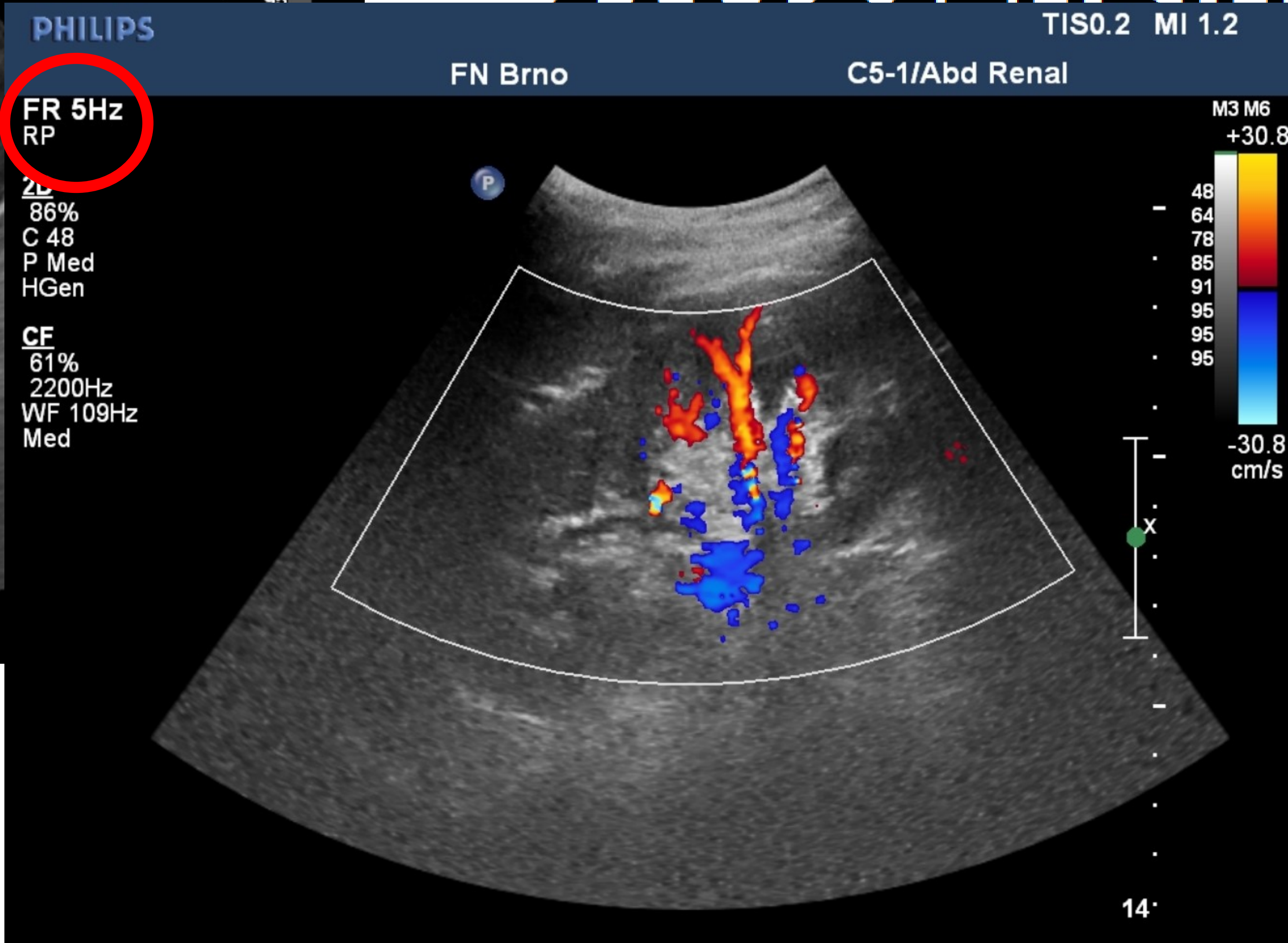
Pulzní doppler

Barevný doppler

Barevné mapování, color doppler

BART

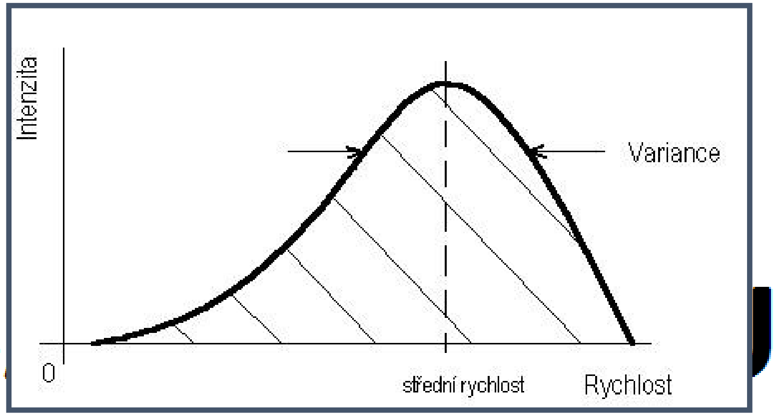


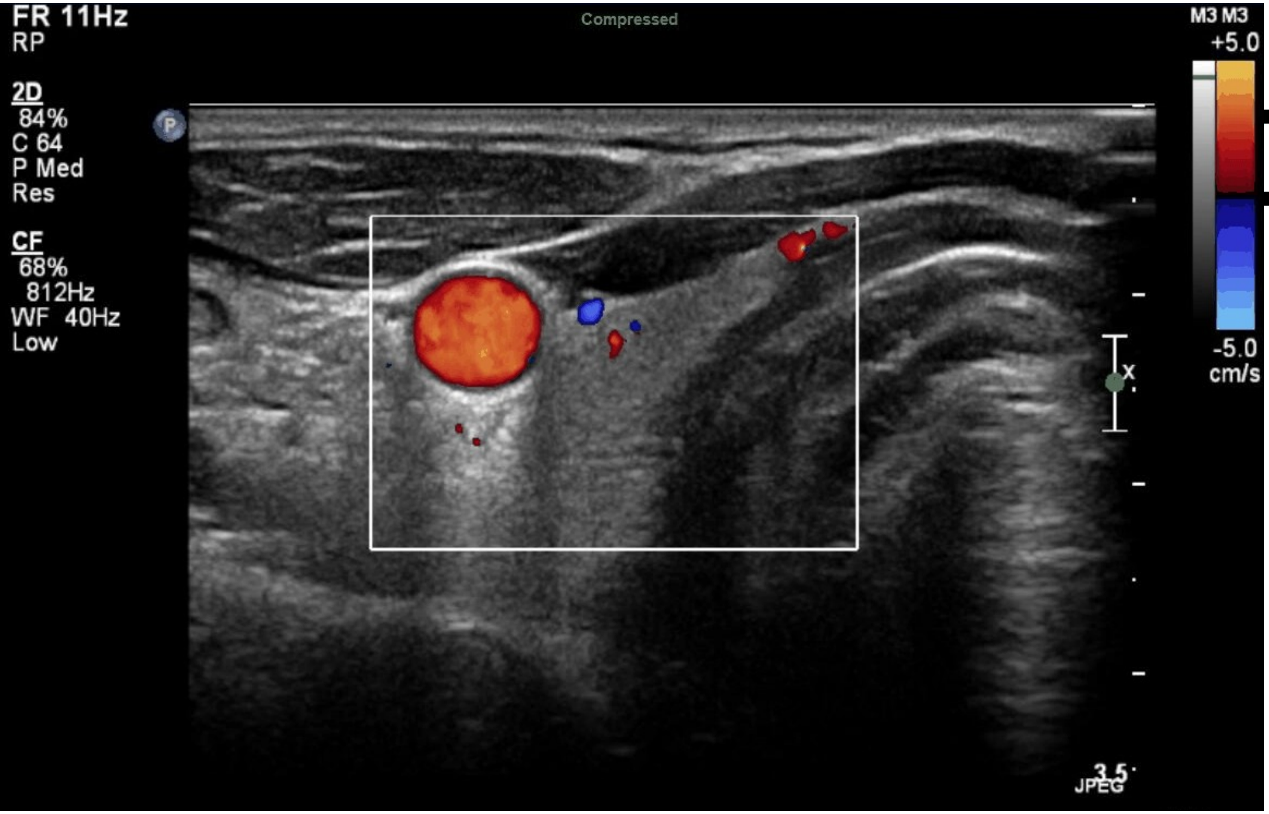


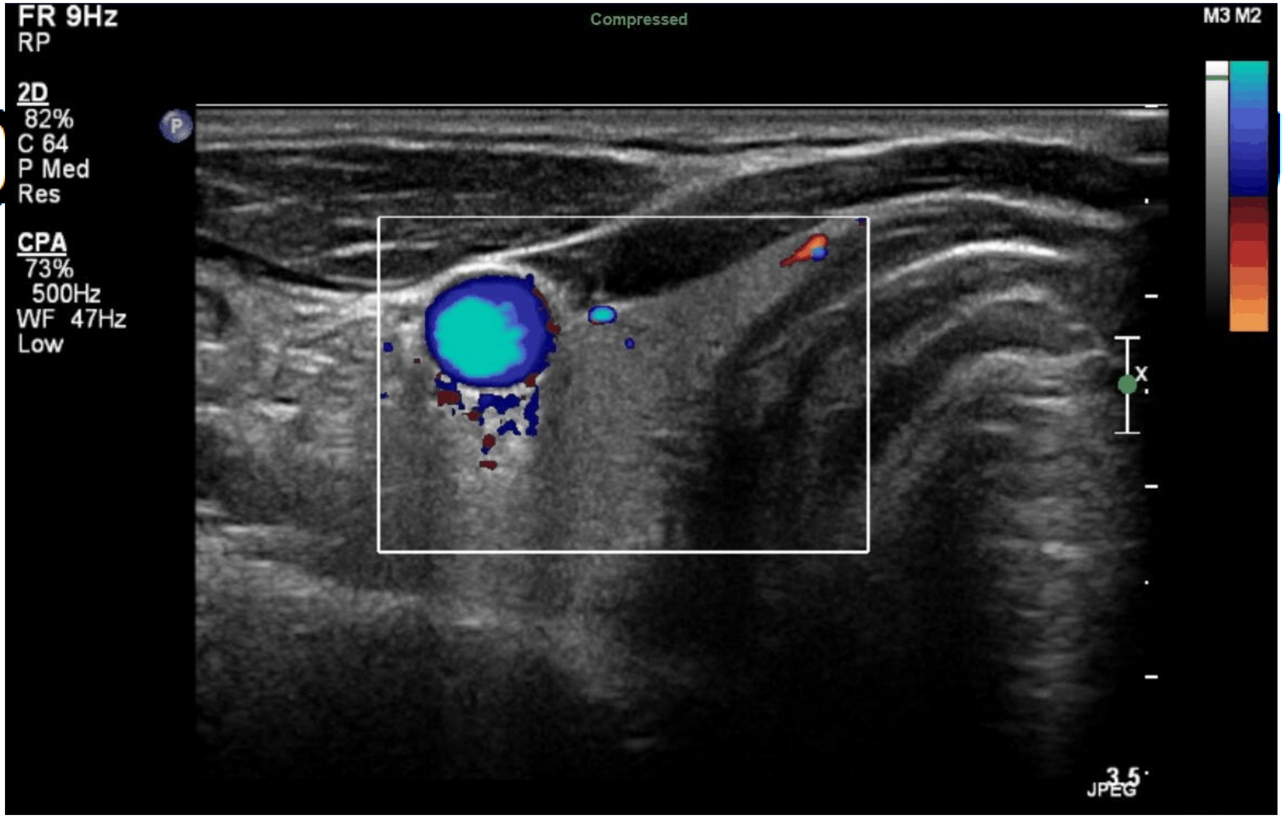
SAMOSTUDIUM

Energetický doppler

Power doppler (CPA color power angio)



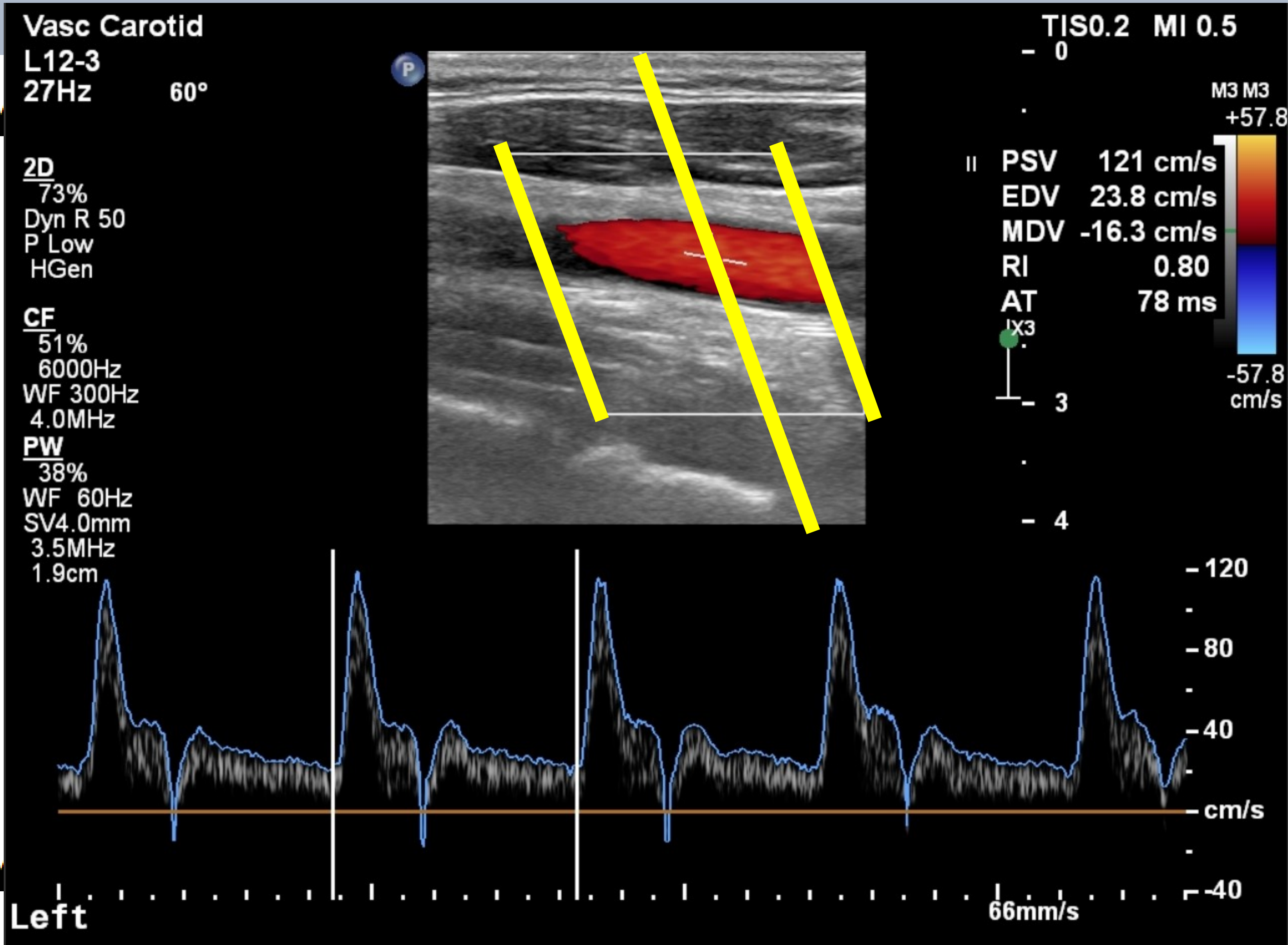

FR 11Hz
RP
Compressed
M3 M3
+5.0
2D
84%
C 64
P Med
Res
CF
68%
812Hz
WF 40Hz
Low
-5.0
cm/s
P
X
3.5
JPEG


FR 9Hz
RP
Compressed
M3 M2
2D
82%
C 64
P Med
Res
CPA
73%
500Hz
WF 47Hz
Low
P
X
3.5
JPEG

Praktická nastavení dopplerovského ultrazvuku

SAMOSTUDIUM

Steer – [illegible] UZ


Vasc Carotid
L12-3
27Hz 60°

2D
73%
Dyn R 50
P Low
HGen

CF
51%
6000Hz
WF 300Hz
4.0MHz

PW
38%
WF 60Hz
SV4.0mm
3.5MHz
1.9cm

TIS0.2 MI 0.5

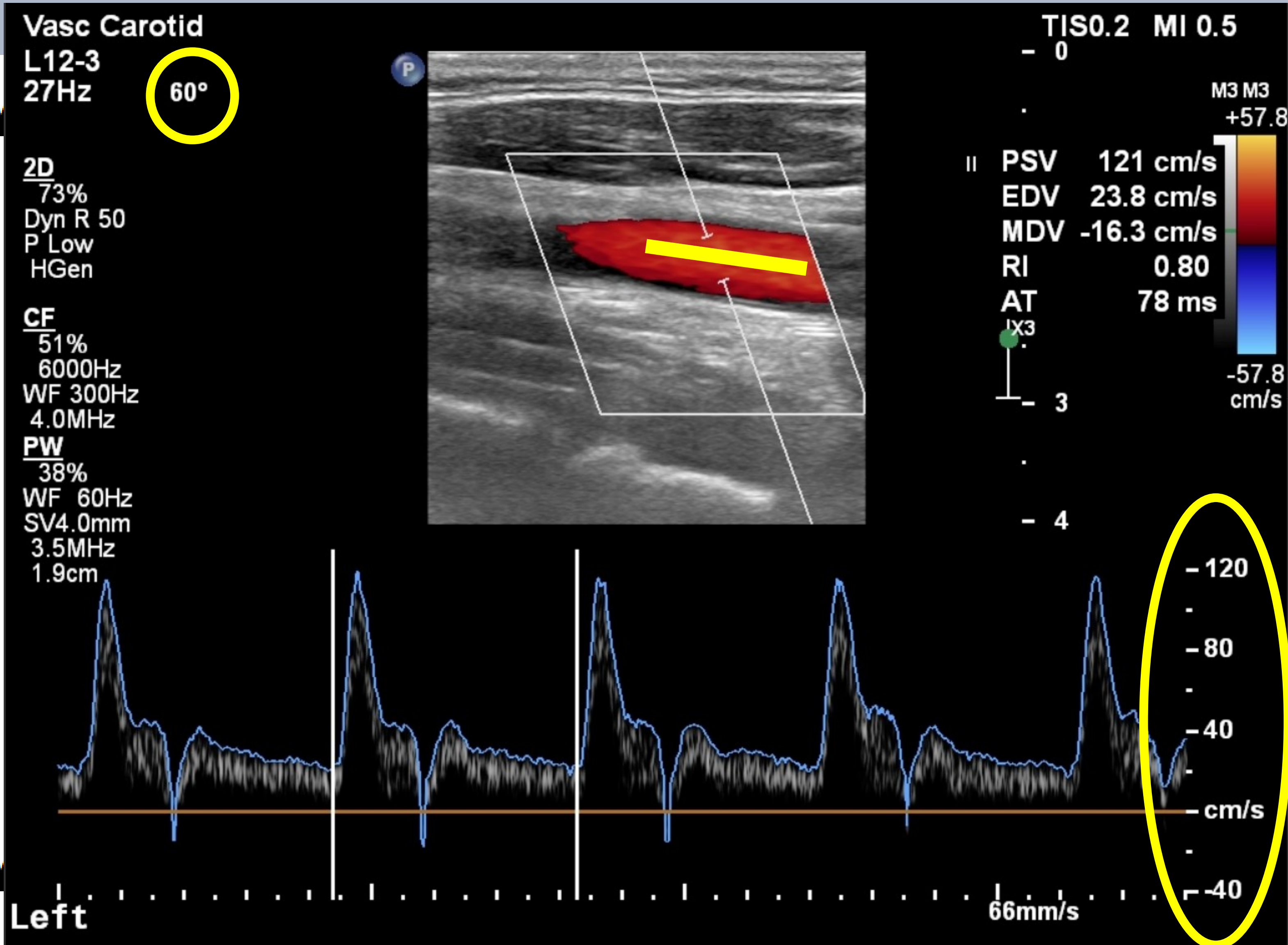
PSV 121 cm/s
EDV 23.8 cm/s
MDV -16.3 cm/s
RI 0.80
AT 78 ms

SAMOSTUDIUM

Praktická nastavení dopplerovského ultrazvuku

SAMOSTUDIUM

Angle correct – úhlová


Vasc Carotid
L12-3
27Hz
60°

2D
73%
Dyn R 50
P Low
HGen

CF
51%
6000Hz
WF 300Hz
4.0MHz

PW
38%
WF 60Hz
SV4.0mm
3.5MHz
1.9cm

TIS0.2 MI 0.5

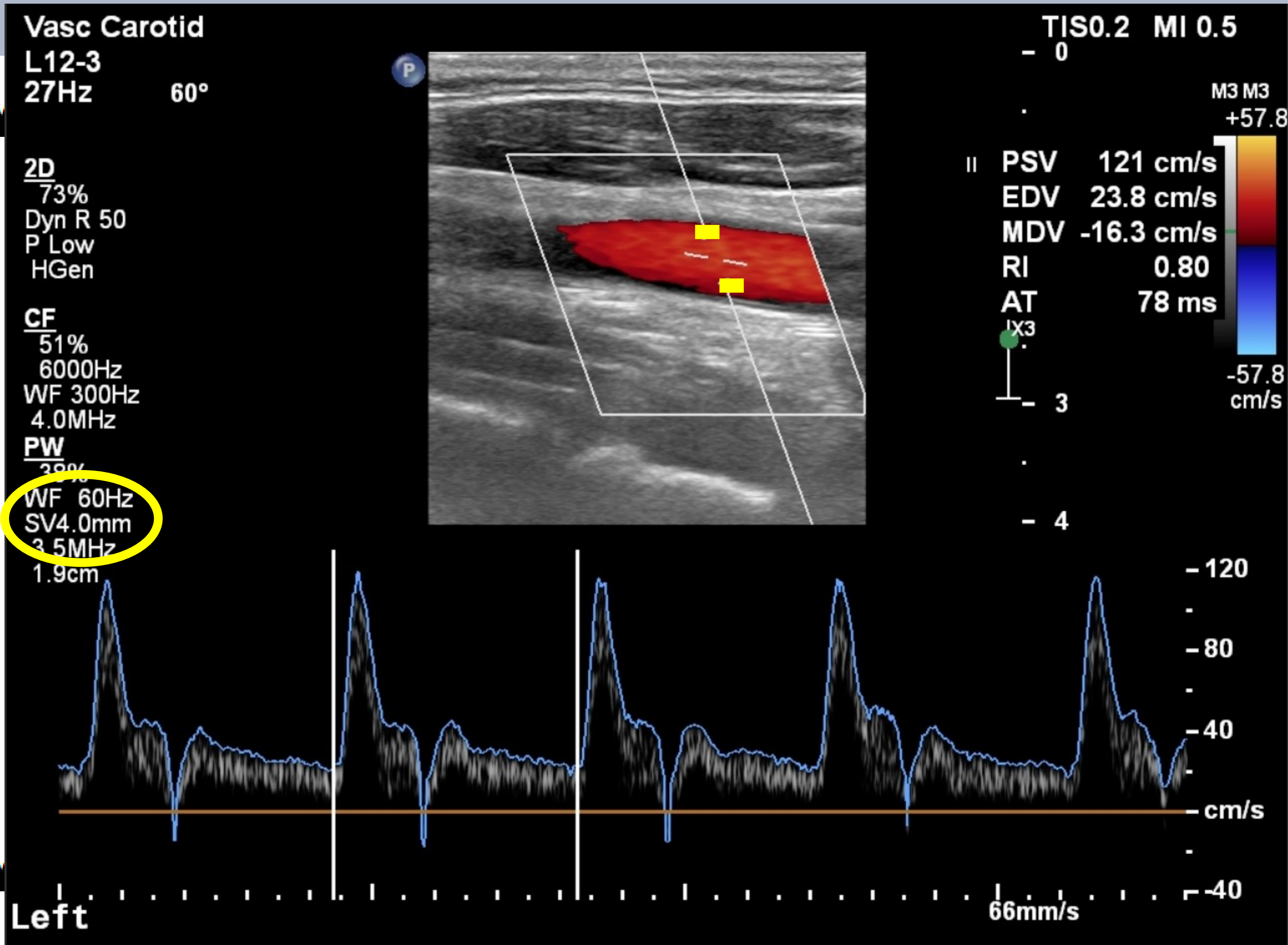
PSV	121 cm/s
EDV	23.8 cm/s
MDV	-16.3 cm/s
RI	0.80
AT	78 ms

SAMOSTUDIUM

Praktická nastavení dopplerovského ultrazvuku

SAMOSTUDIUM

Sample volume –


Vasc Carotid
L12-3
27Hz 60°

2D
73%
Dyn R 50
P Low
HGen

CF
51%
6000Hz
WF 300Hz
4.0MHz

PW
38%
WF 60Hz
SV4.0mm
3.5MHz
1.9cm

TIS0.2 MI 0.5

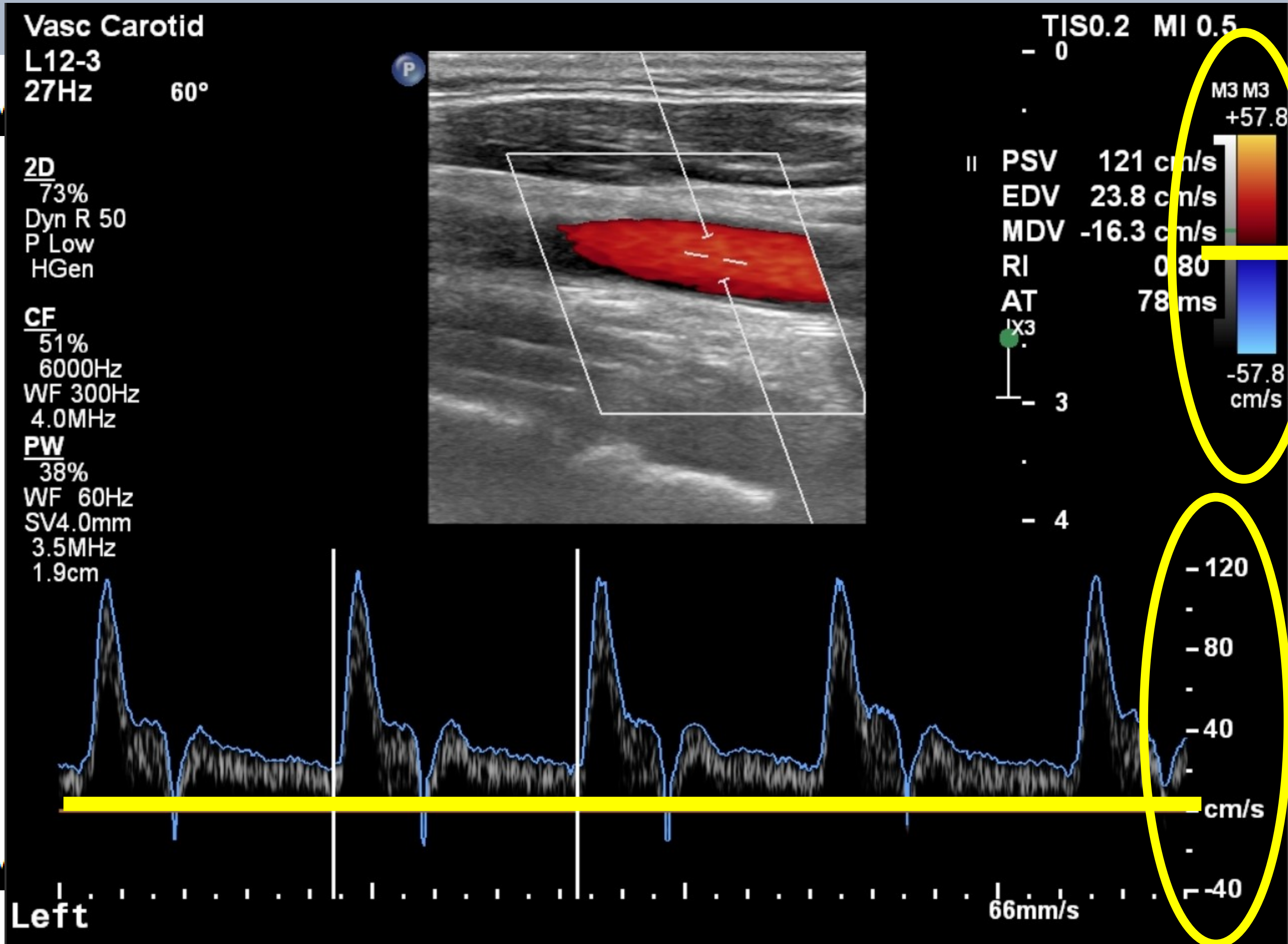
PSV 121 cm/s
EDV 23.8 cm/s
MDV -16.3 cm/s
RI 0.80
AT 78 ms

SAMOSTUDIUM

Praktická nastavení dopplerovského ultrazvuku

SAMOSTUDIUM

Scale – škála a definice



Vasc Carotid
L12-3
27Hz
60°

2D
73%
Dyn R 50
P Low
HGen

CF
51%
6000Hz
WF 300Hz
4.0MHz

PW
38%
WF 60Hz
SV4.0mm
3.5MHz
1.9cm

TIS0.2 MI 0.5

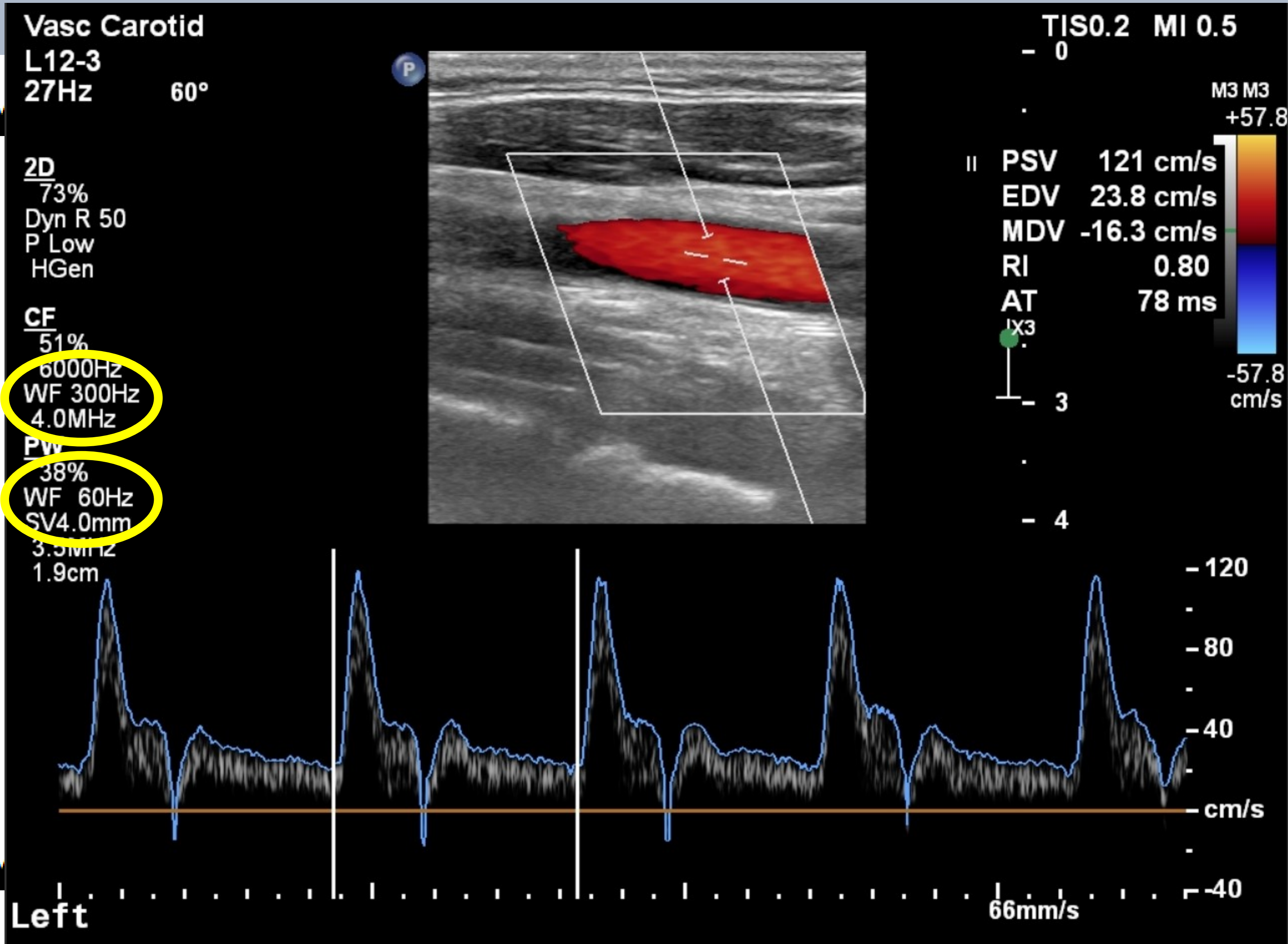
PSV 121 cm/s
EDV 23.8 cm/s
MDV -16.3 cm/s
RI 0.80
AT 78 ms

SAMOSTUDIUM

Praktická nastavení dopplerovského ultrazvuku

SAMOSTUDIUM

WF - wall filter

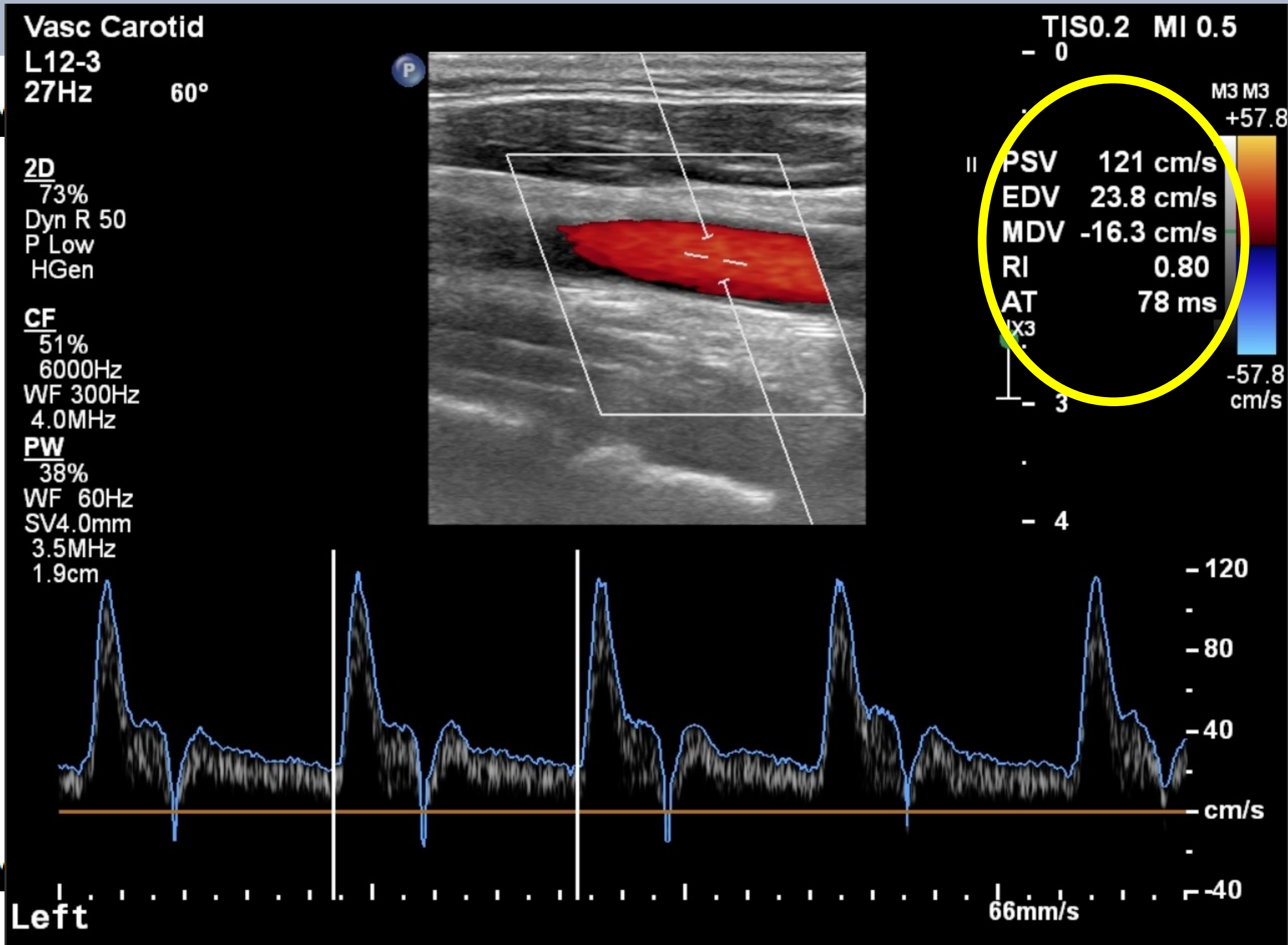


SAMOSTUDIUM

Hodnocení dopplerovského záznamu

SAMOSTUDIUM

Velocities – rychlosti



SAMOSTUDIUM

Závěr

Dodržovat správné nastavení

- Co nejmenší úhel (do 60°) – steering!
- Úhlová korekce dle skutečného průběhu cévy
- Přizpůsobení baseline a scale – odstranění artefaktů

- Vhodný přednastavený program

Děkuji za pozornost

"I love hearing that lonesome wail of the train whistle as the magnitude of the frequency of the wave changes due to the Doppler effect."

J

J