

# **SAMOSTUDIU** Základní principy a historie ultrazvukového vyšetřování **SAMOSTUDIU**

Tomáš Jůza

Klinika radiologie a nukleární medicíny FN Brno  
Biofyzikální ústav LF MU

# Ultrazvuk

## SAMOSTUDIUM 2020

Ultrazvuk je šíření mechanického vlnění o vyšší než slyšitelné frekvenci

netopýrů mechanickým vlněním o vyšší než slyšitelné frekvenci

**Mechanické** vlnění,  $f > 20\text{kHz}$   
(v praxi k diagnostice 2-18MHz)

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

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Prostředí	Rychlost [ $\text{m}\cdot\text{s}^{-1}$ ]
Vzduch	330
Destilovaná voda	1480
Sklivec	1532
Játra	<b>1550</b>
Měkké tkáně	1550
Ledviny	1560
Kost	3500

## SAMOSTUDIUM

# Piezoelektrický jev

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Pierre a Jacques Curie, 1880

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

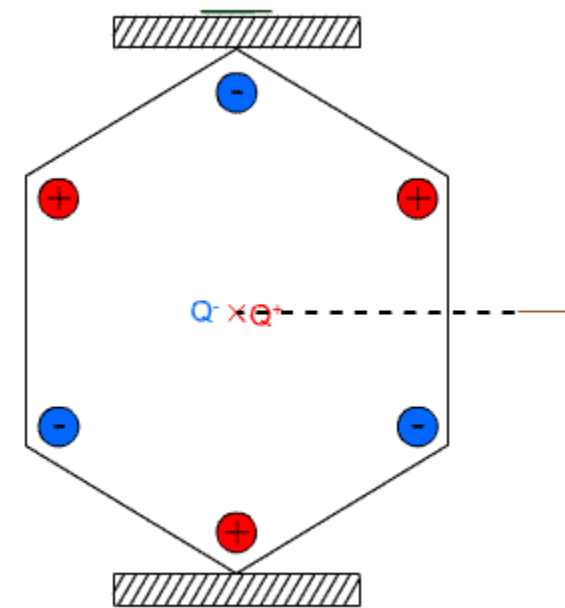
## nepřímý piezoelektrický jev

- 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.

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# Sonar

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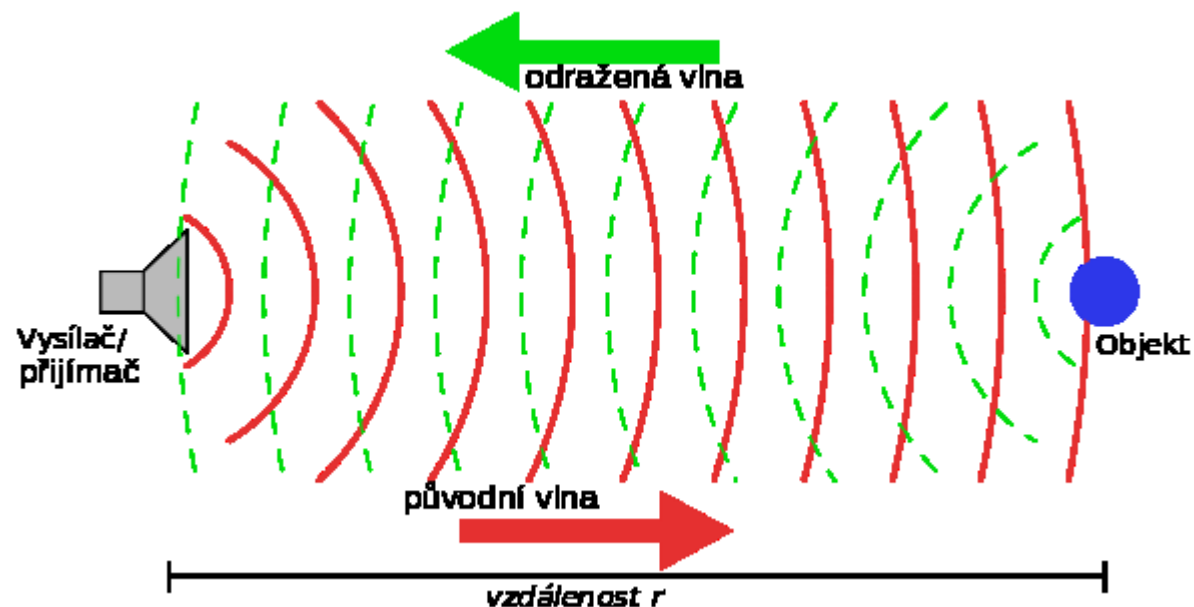
Sound Navigation And Ranging

1914

Aktivní sonar

Pulse-echo princip

„hydrophone“



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# Ultrazvuk v praxi

## SAMOSTUDIUM 2020

První praktické využití - 1941

detekce vad kovových materiálů

„supersonic reflectoscope“

Jan. 11, 1949.

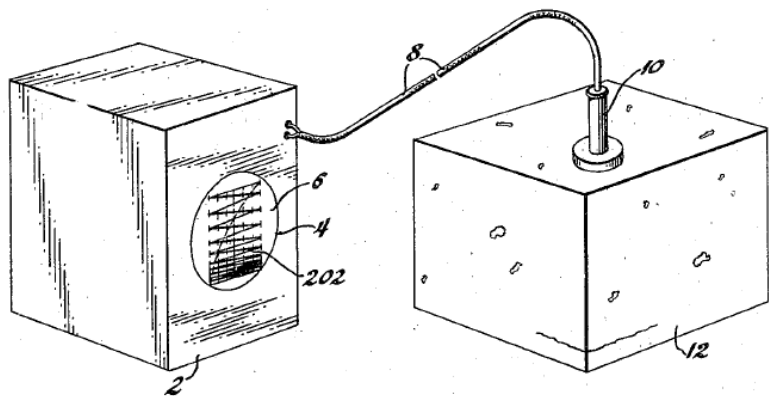
F. A. FIRESTONE

2,458,771

SUPERSONIC REFLECTOSCOPE

Filed March 15, 1943

2 Sheets-Sheet 1



## The 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-

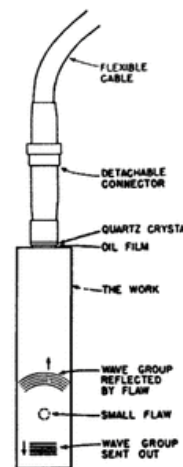


FIG. 1. Principle of the supersonic reflectoscope. A quartz crystal making contact with the work through a thin film of oil sends into the work a wave group consisting of just a few sound waves of short wave-length. This wave group is reflected from the side of the work most distant from the crystal, 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.

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

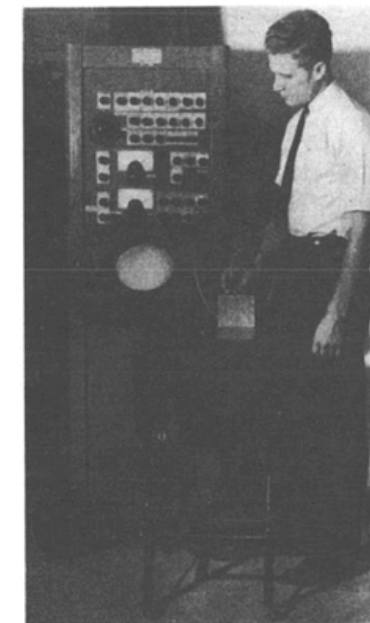


FIG. 2a. Type A supersonic reflectoscope.

# Průkopníci v medicíně

## **SAMOSTUDIUM 2020 SAMOSTUDIUM**

Karl Theodor a Friedrich 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

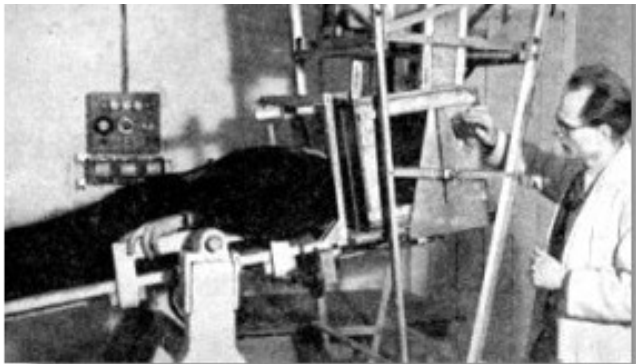
## **SAMOSTUDIUM 2020**

## **SAMOSTUDIUM**

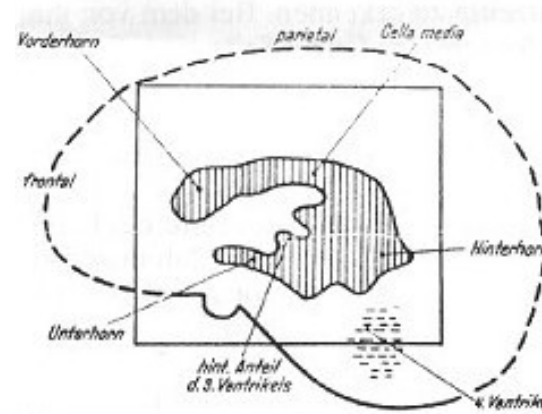
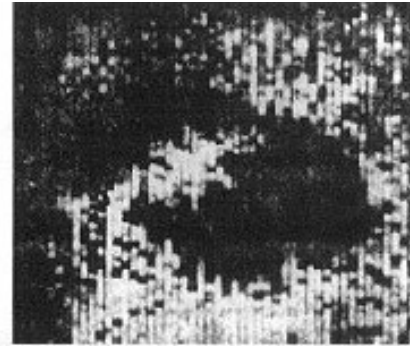
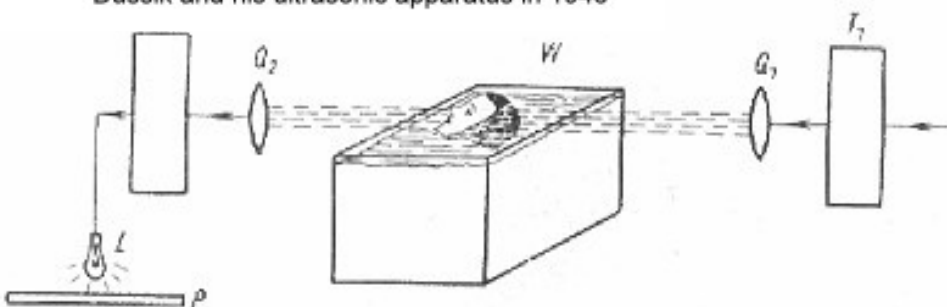
# Karl Theodore Dussik

Weitere Ergebnisse der Ultraschalluntersuchung  
bei Gehirnerkrankungen.

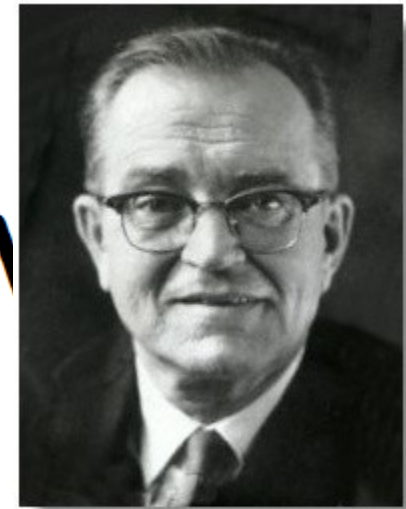
Von  
Karl Theo Dussik, Bad Ischl.  
Mit 13 Textabbildungen.



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 long axis of the muscle bundles do not differ significantly from those found with the energy directed parallel with the muscle fibers.

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

Specific gravities of the tissues are measured. The characteristic acoustic impedances ( $\rho c$  values), calculated from the density and velocity data, vary between  $1.5 \times 10^5$  and  $1.7 \times 10^5$  g/cm<sup>2</sup>/sec. The imaginary component of tissue impedance is calculated and found to be negligible at the frequencies at which the measurements are made.

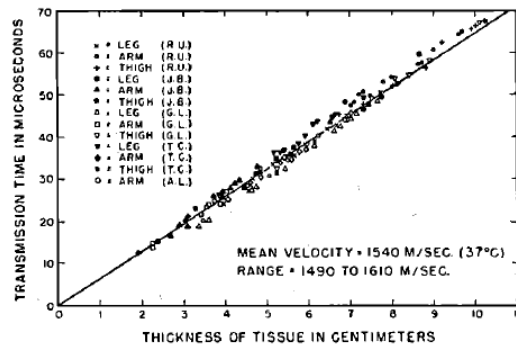


FIG. 4. Transmission time vs. thickness for living human tissue consisting principally of muscle. The line is the best straight-line fit of all data taken on living human tissues.

S. IU



George Ludwig c. 1972

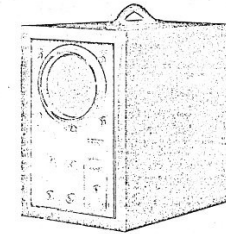
### GPL Ultrasonic Locator

MODEL PM-250

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

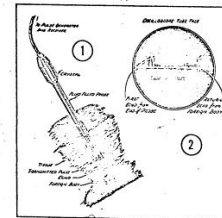
High frequency sound has several interesting properties which suggest its use in clinical research as a diagnostic tool to supplement the X-ray. A sound beam of high frequency is quite directional, traveling through tissue in a narrow beam. Every time this beam encounters an object of different acoustic 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 inhomogeneities 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 ultrasounds 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, as shown in Figure 2. A rough



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# John Julian Wild

## Application of Echo-Ranging Techniques to the Determination of Structure of Biological Tissues<sup>1</sup>

John J. Wild and John M. Reid<sup>2,3</sup>

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

<sup>1</sup>This investigation was supported by a research grant from the National Cancer Institute of the National Institutes of Health, USPHS.

<sup>2</sup>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.

<sup>3</sup>Formerly of the Department of Surgery, University of Minnesota Medical School, Minneapolis.

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

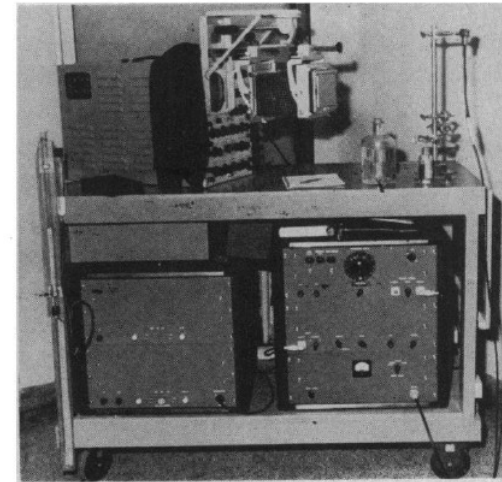


FIG. 3. The complete echographic apparatus as used in hospital. The unidimensional echoscope can be seen clamped to a stand on the right, connected to the transmitter-receiver unit. The cathode-ray screen with the camera in the recording position is to the left on the table.



John J Wild c. 1953

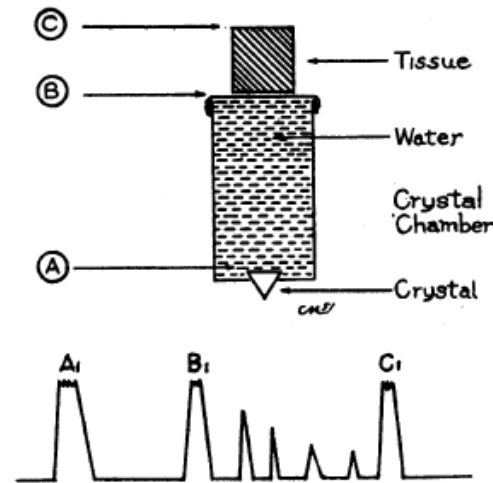


FIG. 2. Cross section of crystal chamber and tissue under examination (top) and a typical unidimensional echogram obtained from the arrangement (bottom).

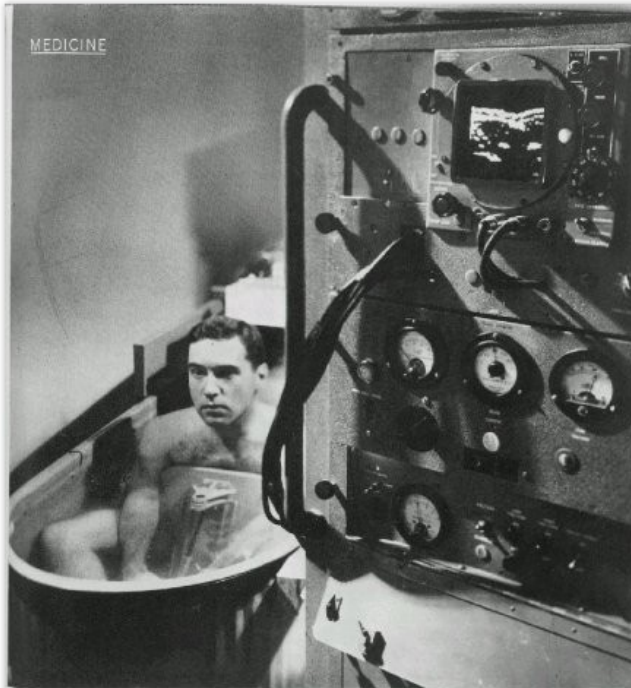
# Douglass Howry

## 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<sup>10, 11</sup> on the development of an original ultrasonic instrument that makes possible the visualization of numerous soft-tissue structures that cannot be demonstrated by roentgenographic methods. Our report is to report on the in vitro application of this instrument for the visualization of malignant tumors, the determination of the extent of tumor involvement of other structures, and the localization of distant sites.

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



**SOUND-WAVE PORTRAIT IN THE FLESH**  
A sonarlike device produces pictures of the human body's soft tissues which are invisible to X-rays

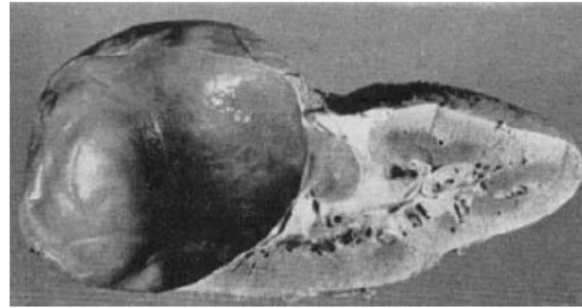


FIG. 2. Kidney with cyst; longitudinal section.

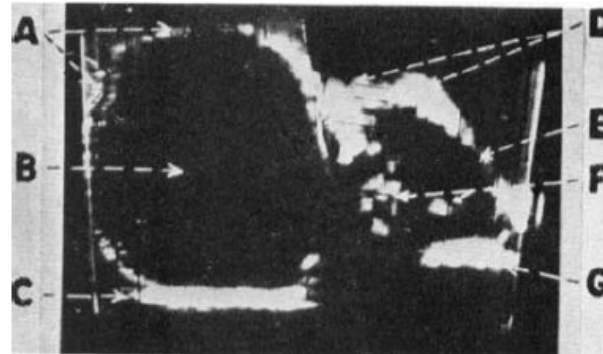
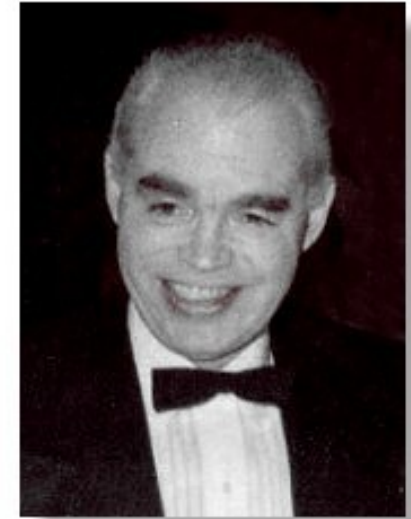


FIG. 3. Somagram of kidney specimen. A, Wall of cyst; B, homogeneous fluid; C, sonic reflector behind cyst; D, attached perirenal fat; E, kidney surface; F, calyxes and blood vessels; G, deep surface of kidney and perirenal fat.



Douglass Howry, late 1960s

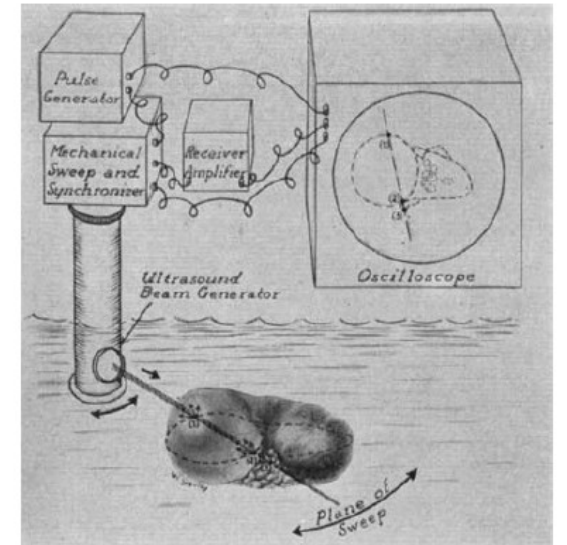


FIG. 1. Diagram of somascope scanning tissue specimen.



www.siemens.com/pre  
SS

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](#) ]

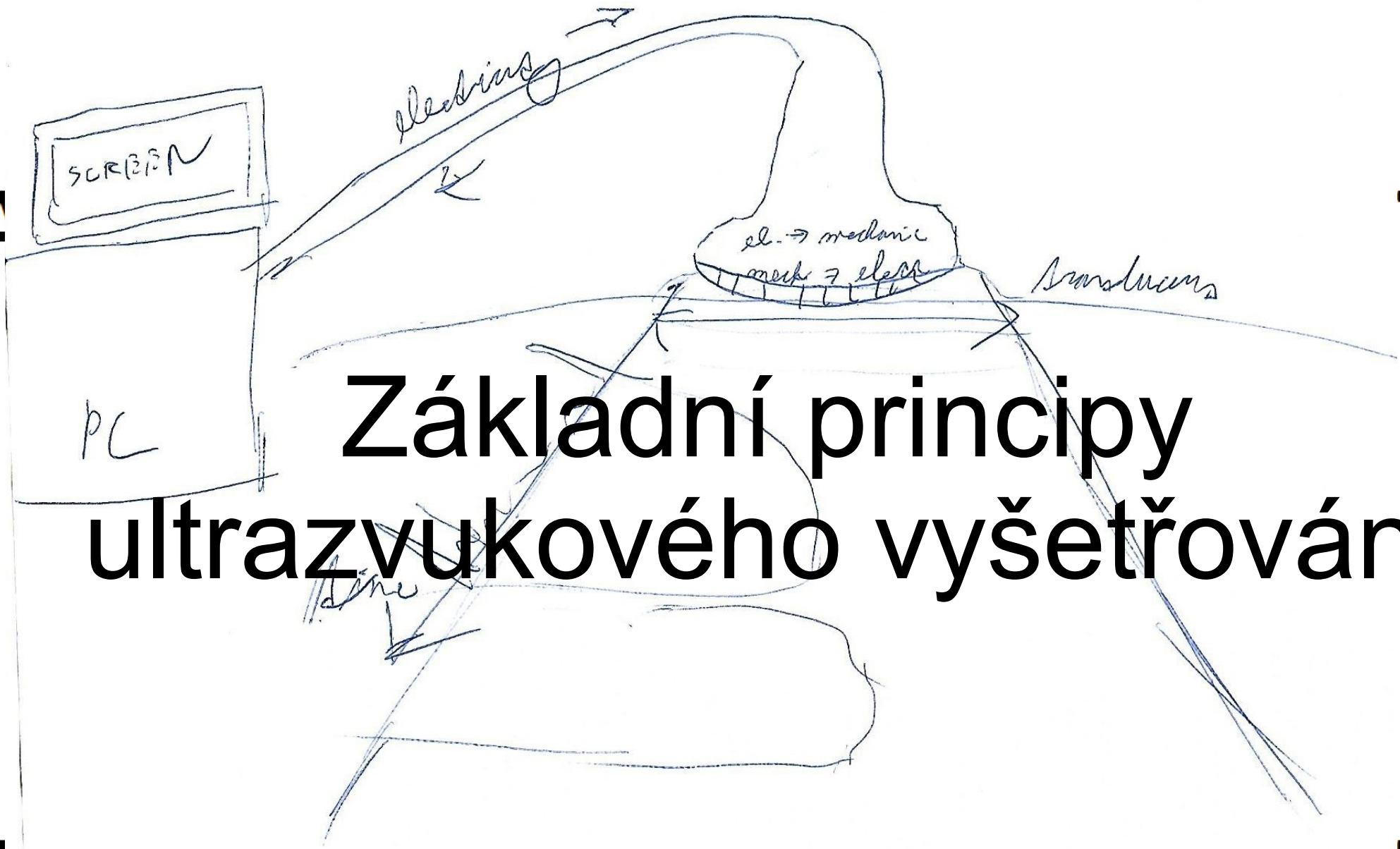
[read this first](#)

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 **S**ound **N**avigation and **R**anging. Ultrasound scanners can be regarded as a form of 'medical' Sonar.



SA

TUDIU



# Základní principy ultrazvukového vyšetřování

SA

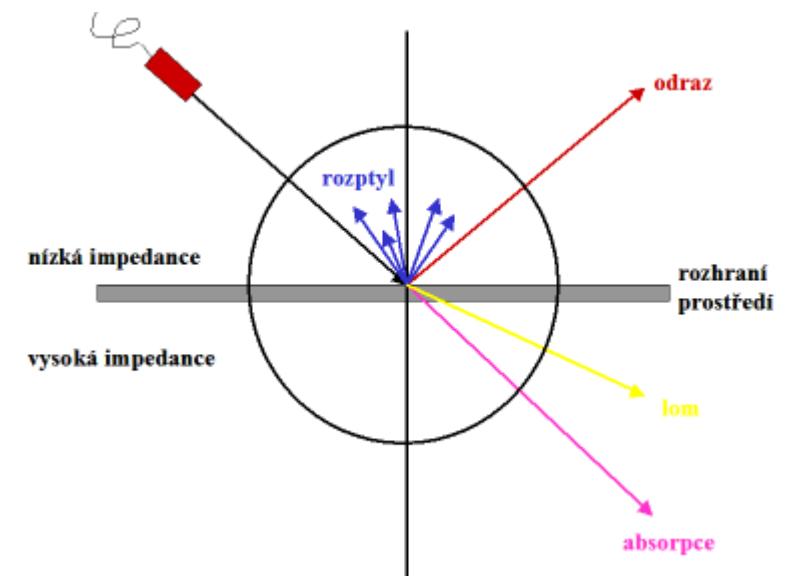
TUDIU

# Šíření ultrazvuku prostředním

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



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# Principy ultrazvukového zobrazování

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Důležitá akustická veličina rozhraní prostředí 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

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# Možnosti rekonstrukce obrazu

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- 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

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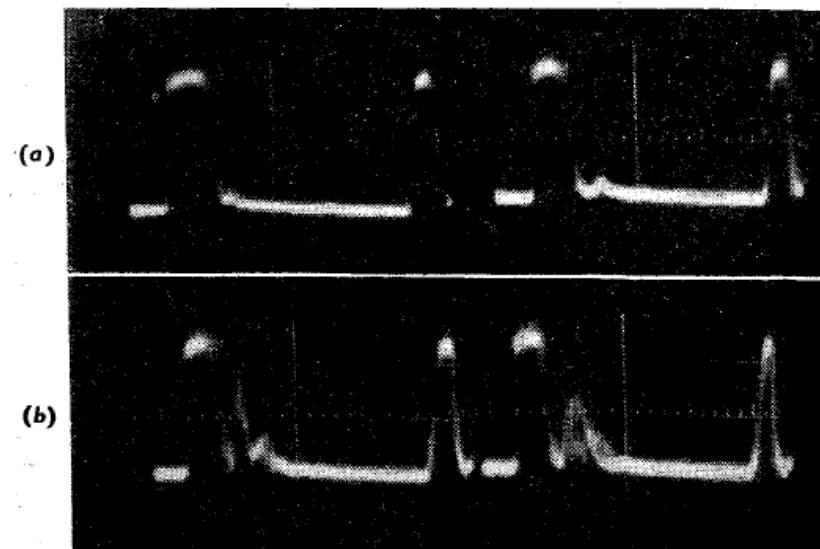


Fig. 5(a)—Two typical ultrasonograms of normal human breast in case I. The saturated peak to the left is given by the rubber membrane on the ultrasonograph. The peak to the right is an artefact inherent in the machine and is considered to be due to “ringing” of the pulses within the apparatus. Note that 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

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FR 26Hz  
RS

2D  
75%  
C 48  
P Low  
HGen

Right

P

41  
57  
69  
75  
82  
83  
83  
82

SAN

DIU

SAN

DIU

B-mód



16



3D

**SAMO**

**MOSTUDIU**



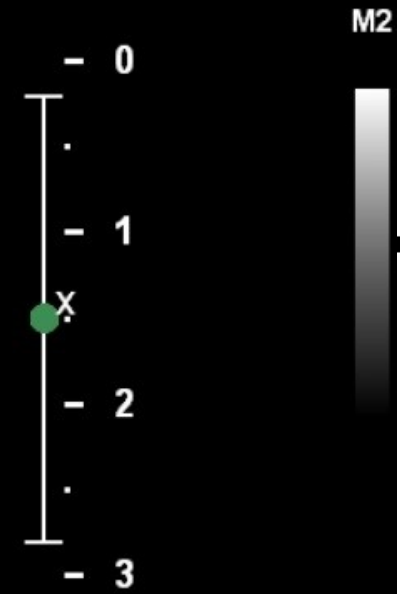
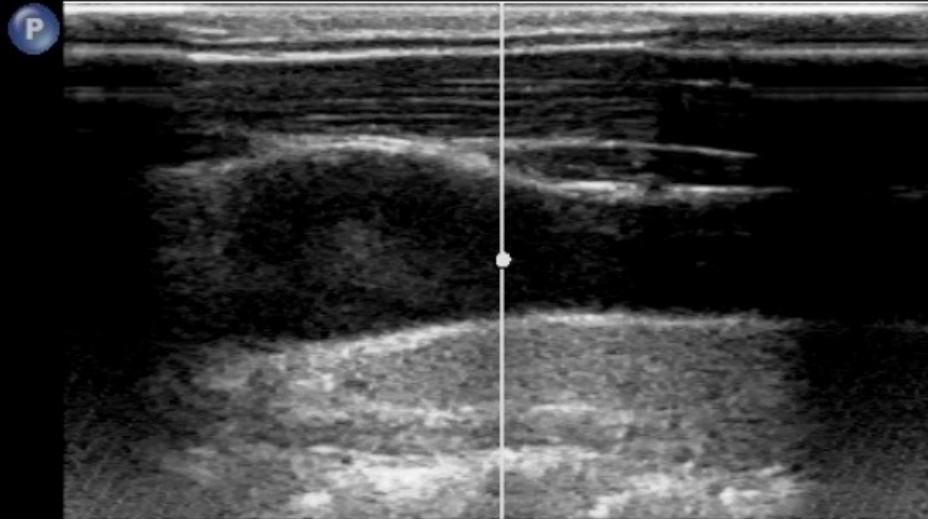
**SAMO**

**MOSTUDIU**

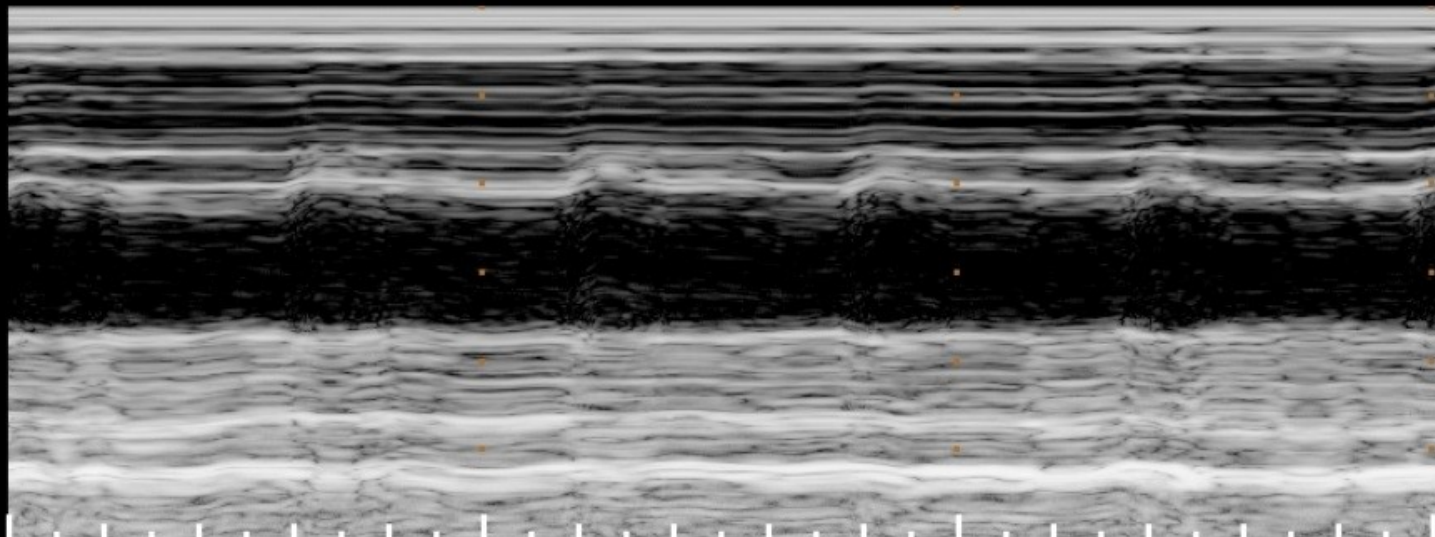
MSK Gen  
L12-5  
52Hz  
RS

TIS0.1 MI 0.9

2D / MM  
59% 62%  
C 52  
P Med  
Res



M-mód



-0  
-1  
-2

66mm/s

FR 28Hz  
RS

M2

2D  
55%  
C 55  
P Low  
HGen

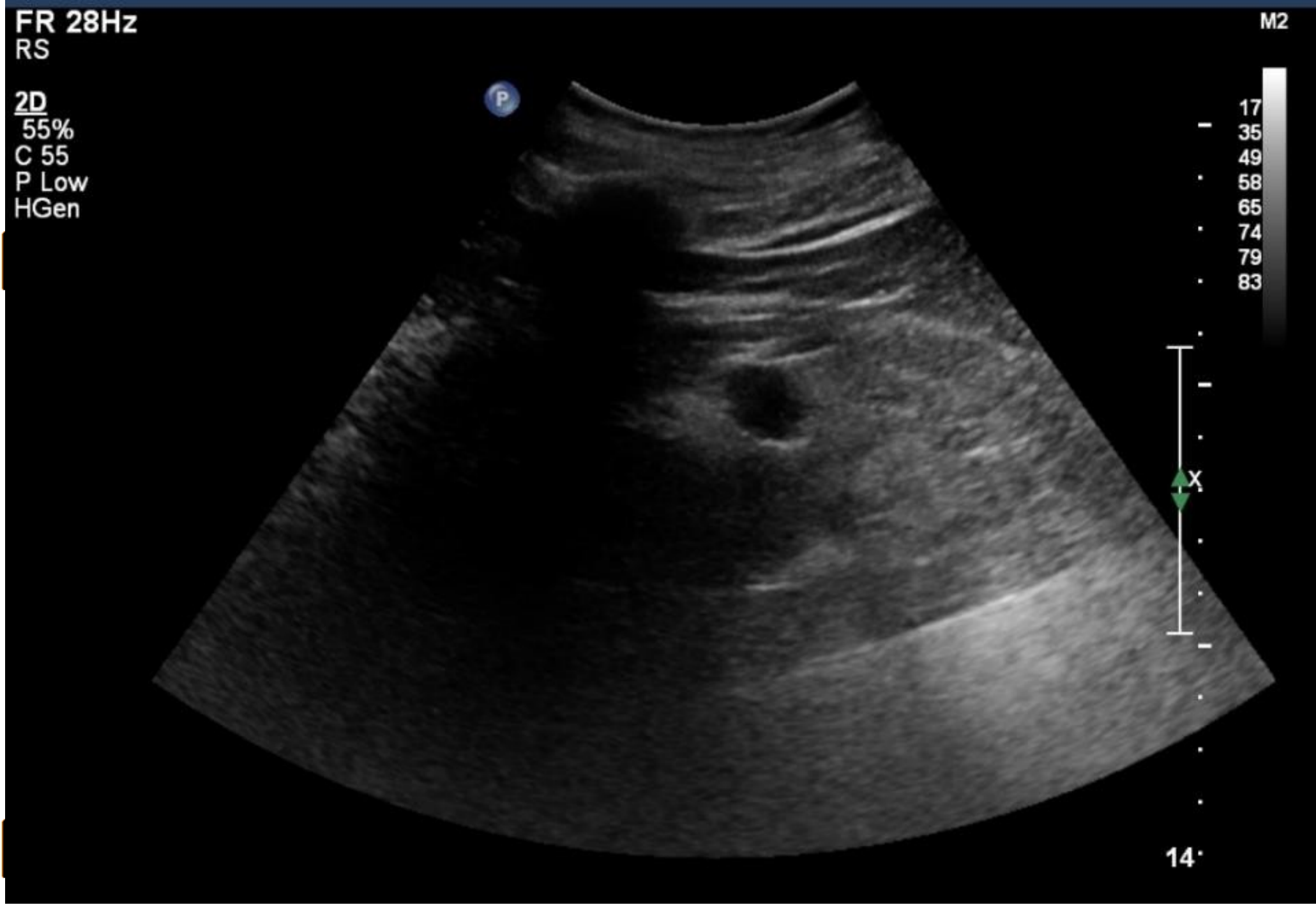
17  
35  
49  
58  
65  
74  
79  
83

SAR

DIU

SAR

DIU



14

FR 24Hz  
RS

2D  
77%  
C 48  
P Low  
HGen

M3

34  
53  
68  
78  
85  
87  
89  
91

X

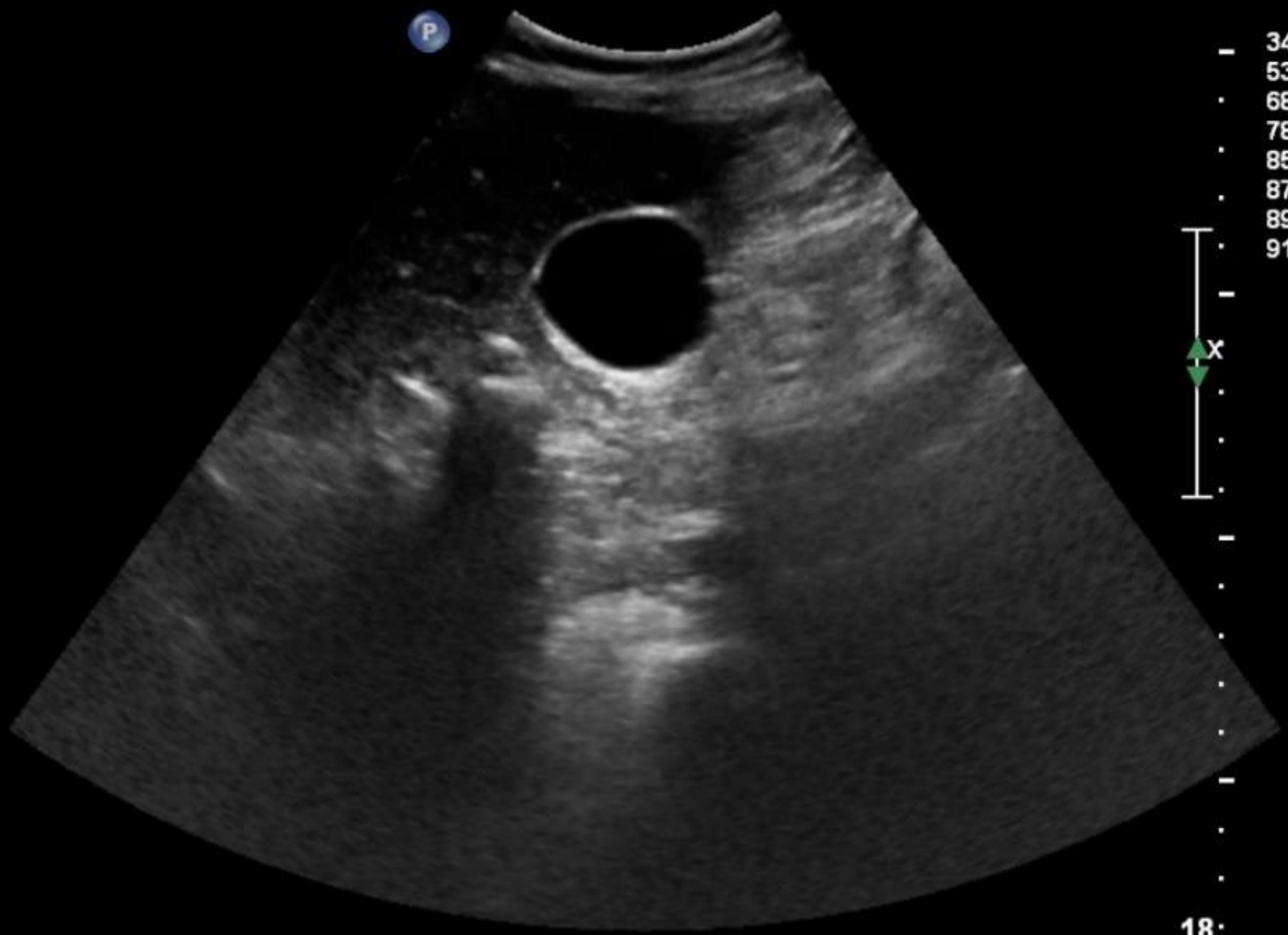
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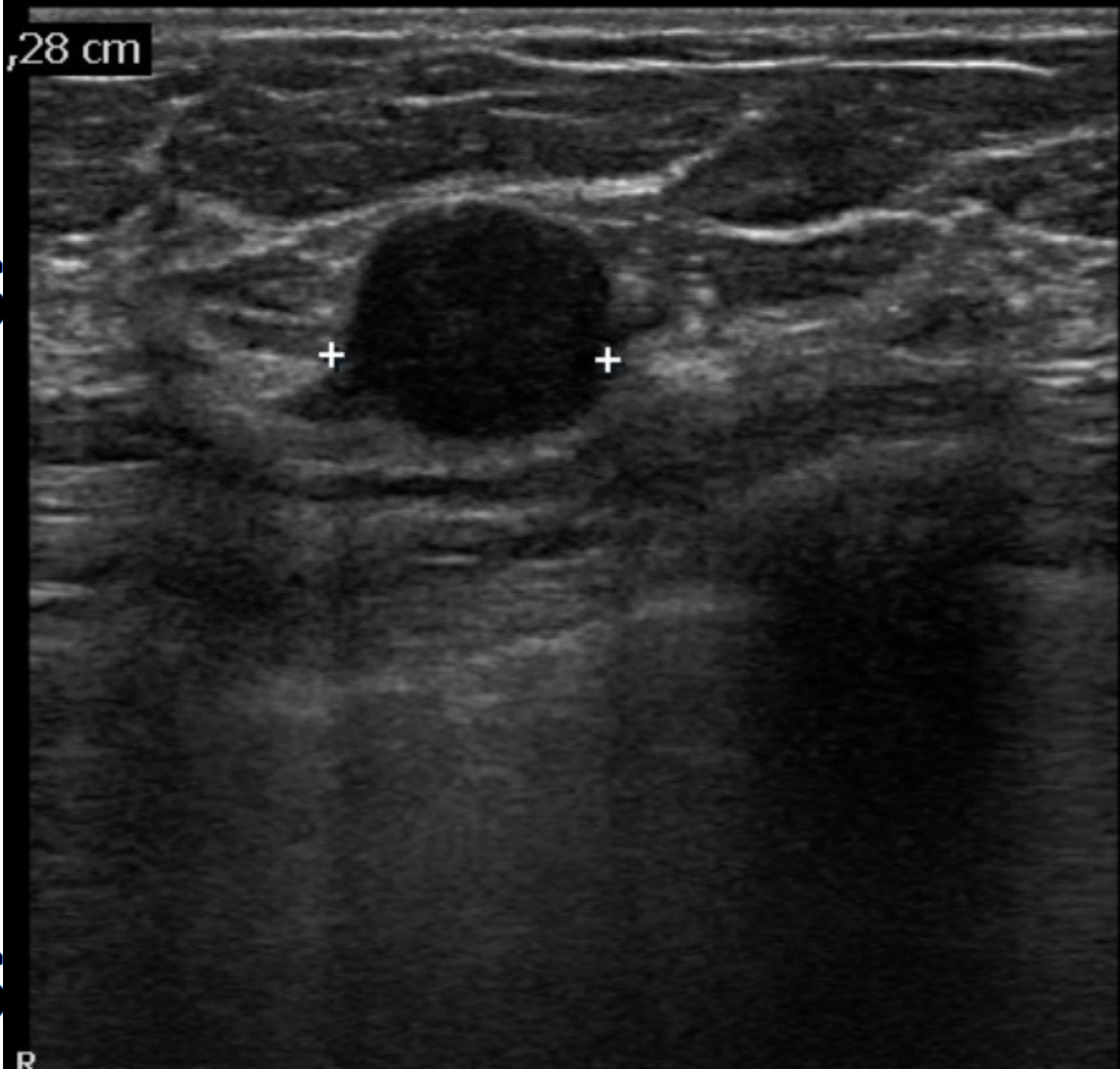
DIU

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DIU



28 cm



SAMOS

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R

# Dopplerův jev



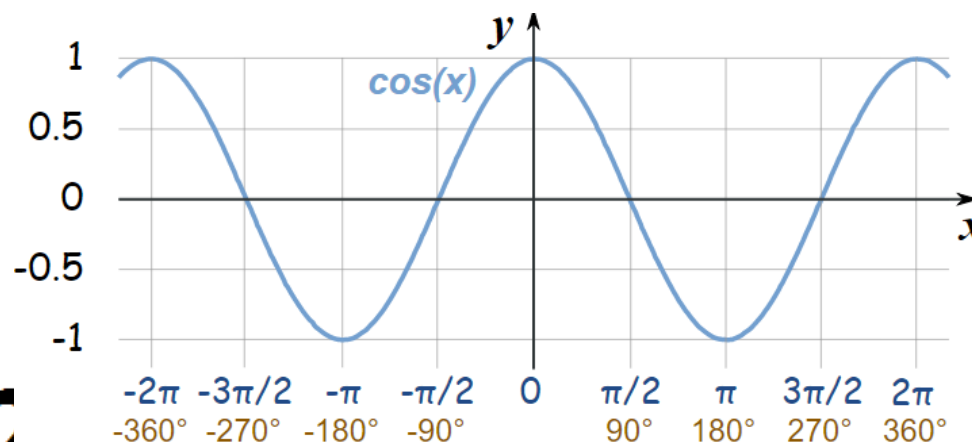
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Přibližuje-li se zdroj zvuku o konstantní výšce (frekvenci) tónu směrem k pozorovateli, vnímá pozorovatel výšku tónu vyšší, rozdíl mezi frekvencemi záleží na rychlosti pohybu.

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

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



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# Dopplerovské techniky

## SAMOSTUDIUM 2020

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



## SAMOSTUDIUM 2020

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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

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(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

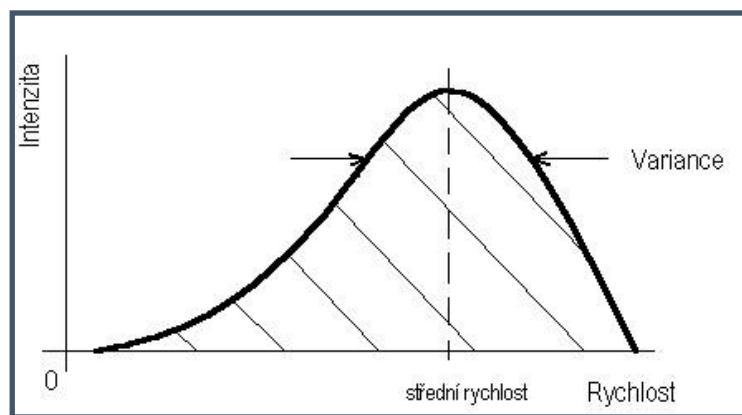
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Energetický doppler

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



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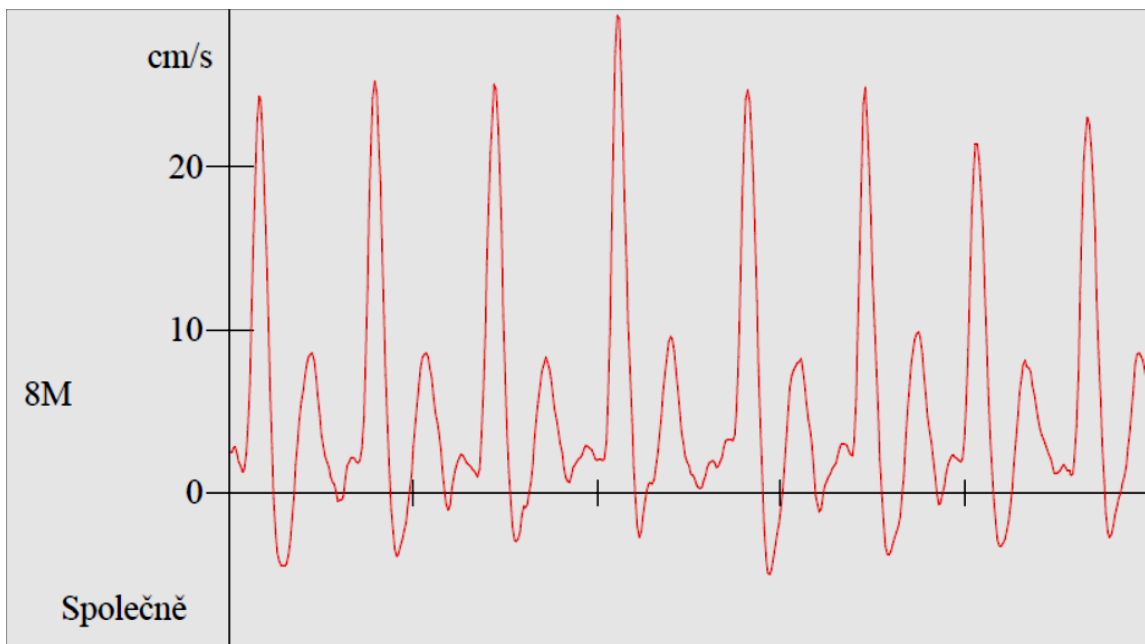
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Spektrální záznam z

kontrastní „dopler“

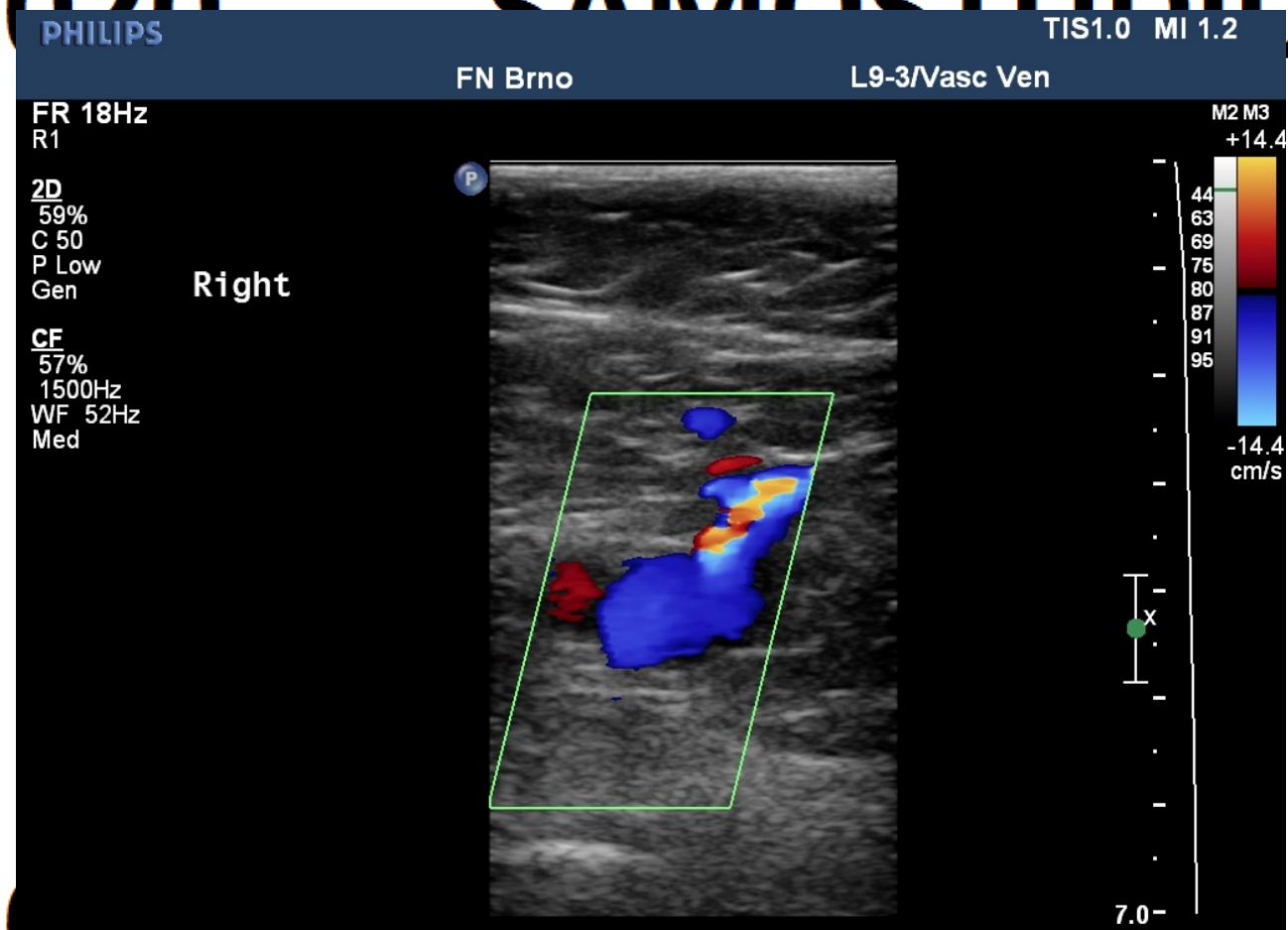
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Barevný mód

2020

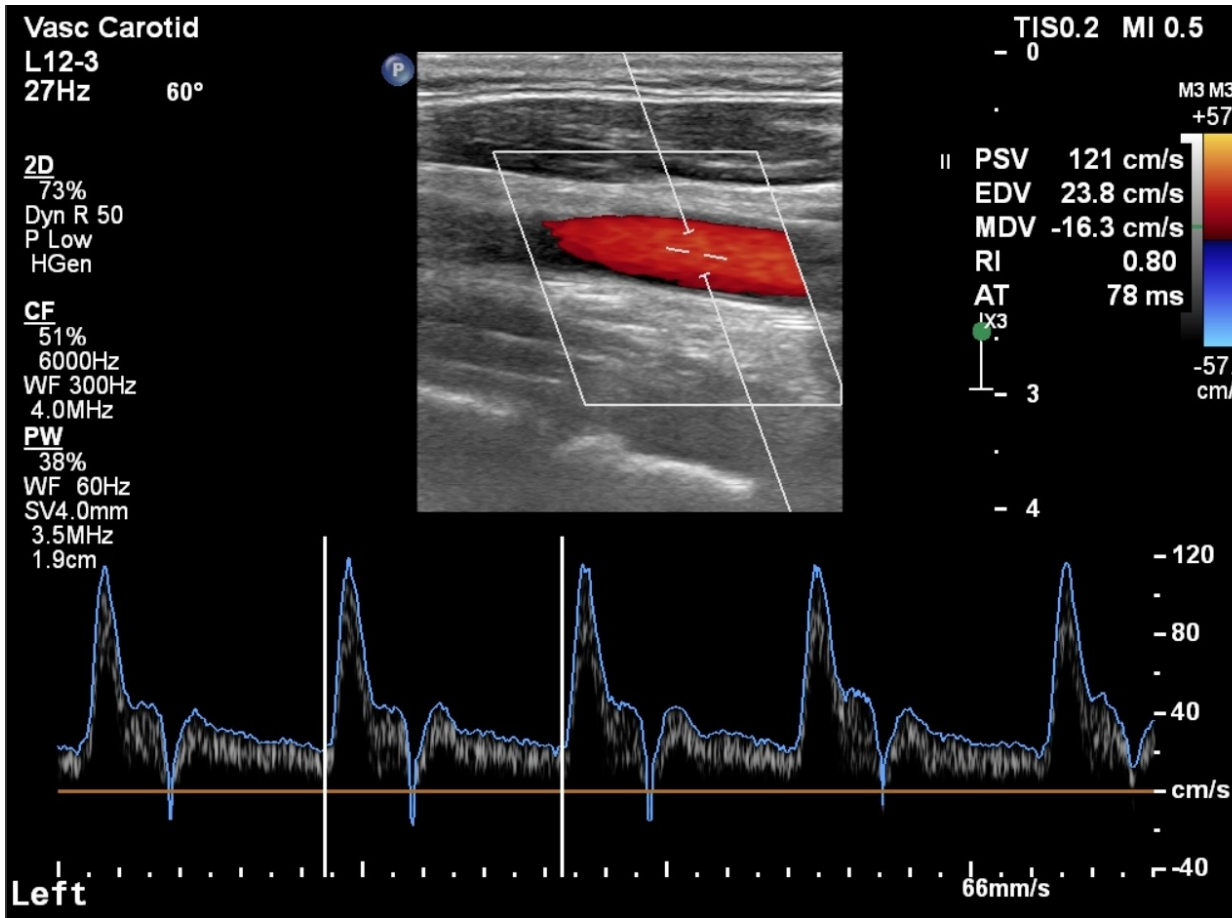


2020

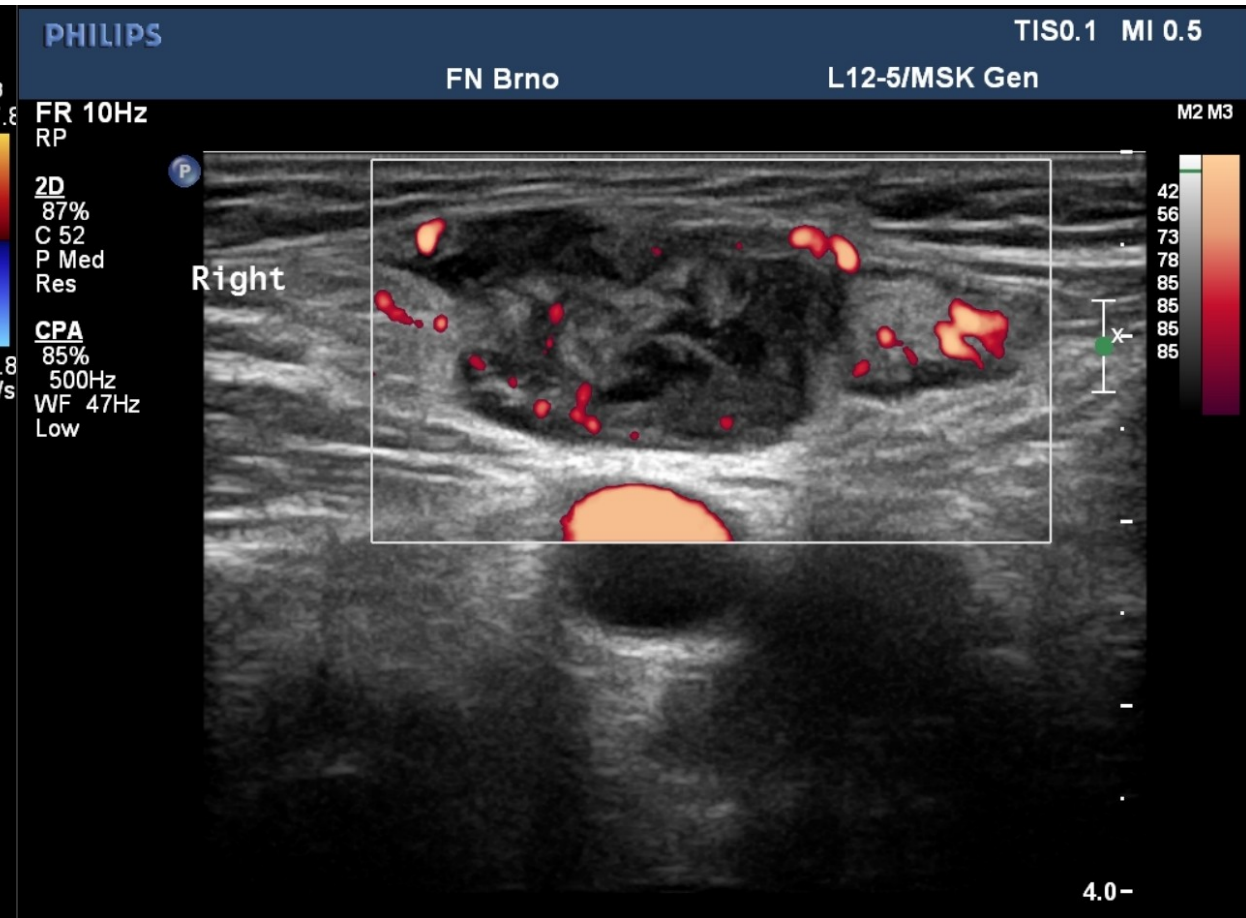
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# Triplexní zobrazení



# Power doppler



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# Bezpečnost ultrazvukového vyšetřování

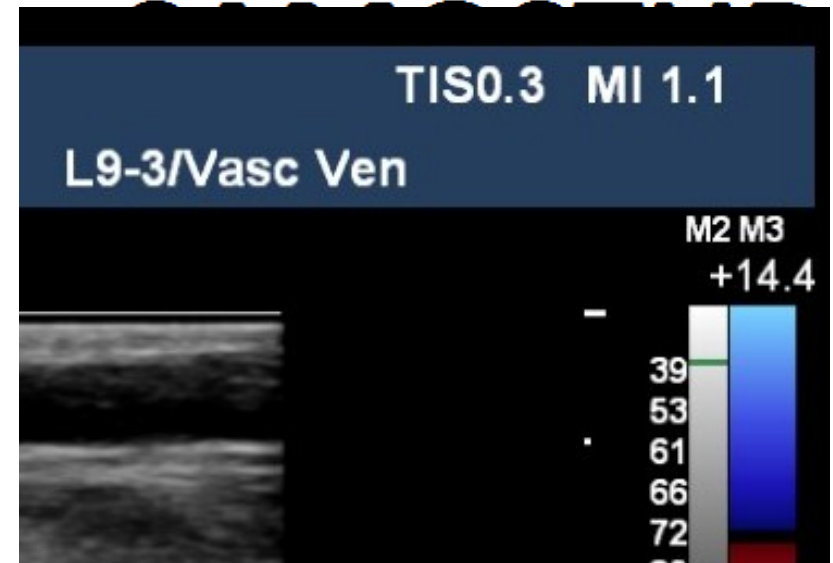
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Mechanický index (MI)

- 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  $1^{\circ}\text{C}$
- TIS – „soft tissue“, TIB – „bone“, TIC – „cranial bone“



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# SAMOSTUDIUM 2020

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Dopplerův jev

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# Zdroj dopplerovského posunu

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# Matematický základ

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

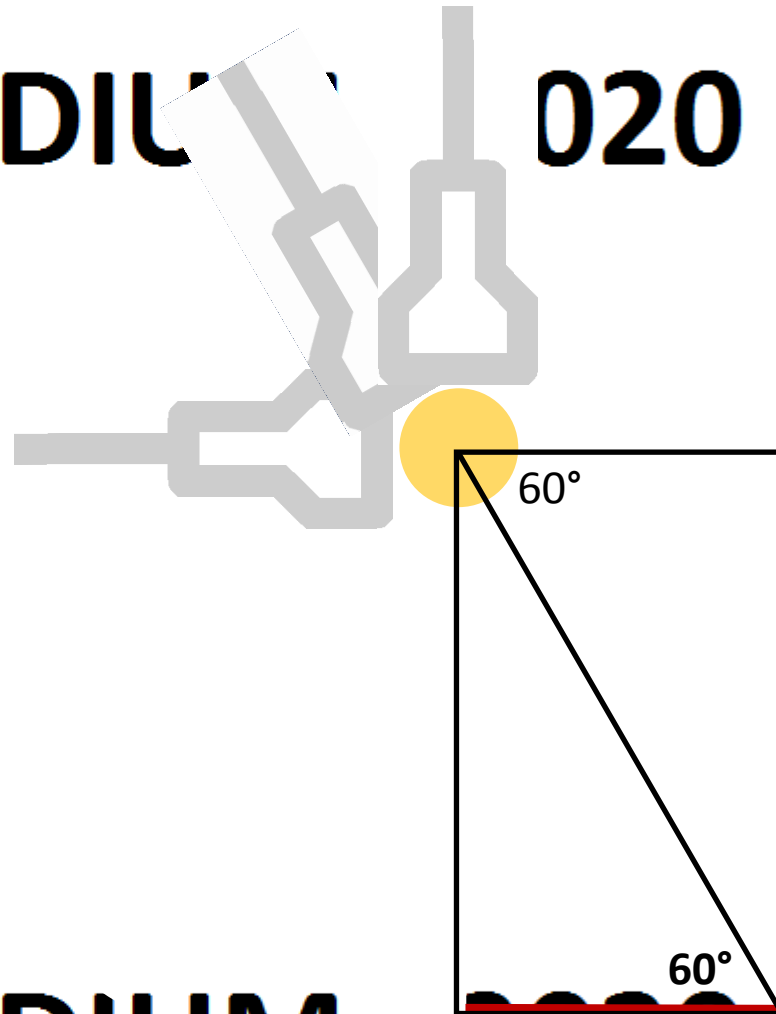
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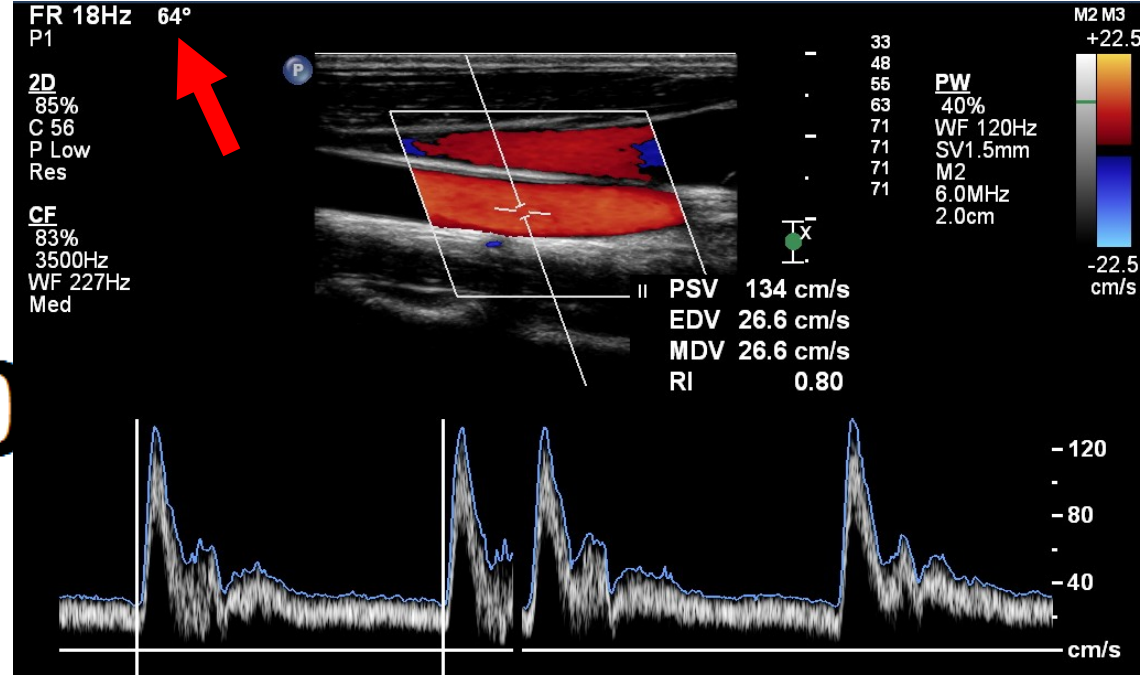
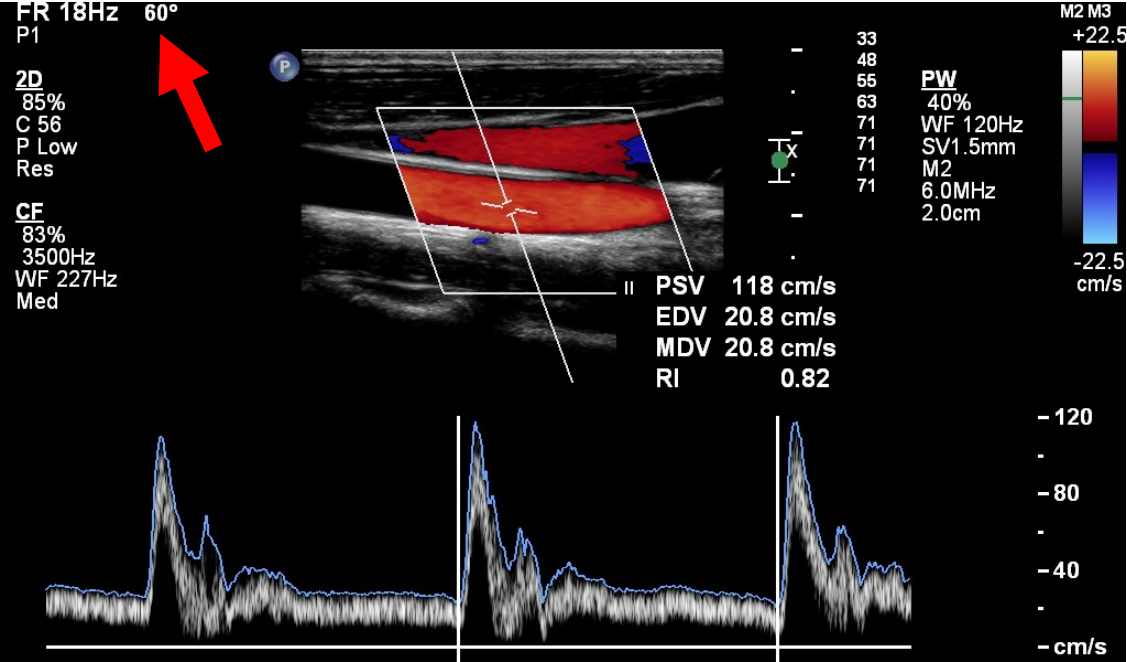
$$\Delta f = \frac{2f_0 v \cos \alpha}{c}$$

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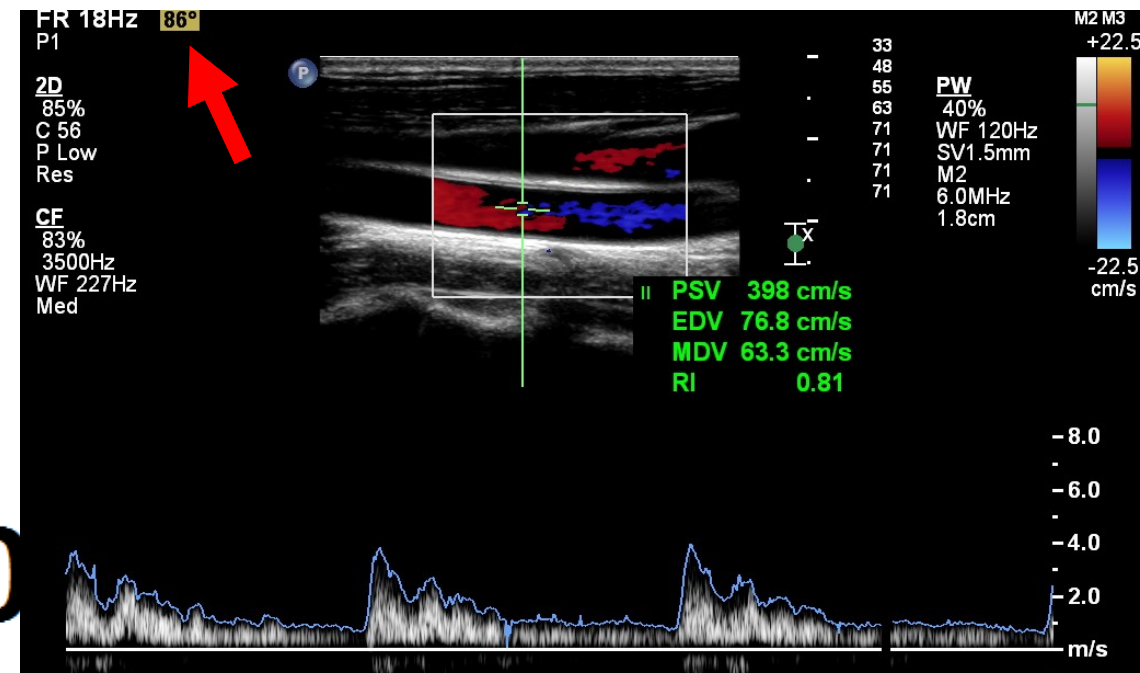
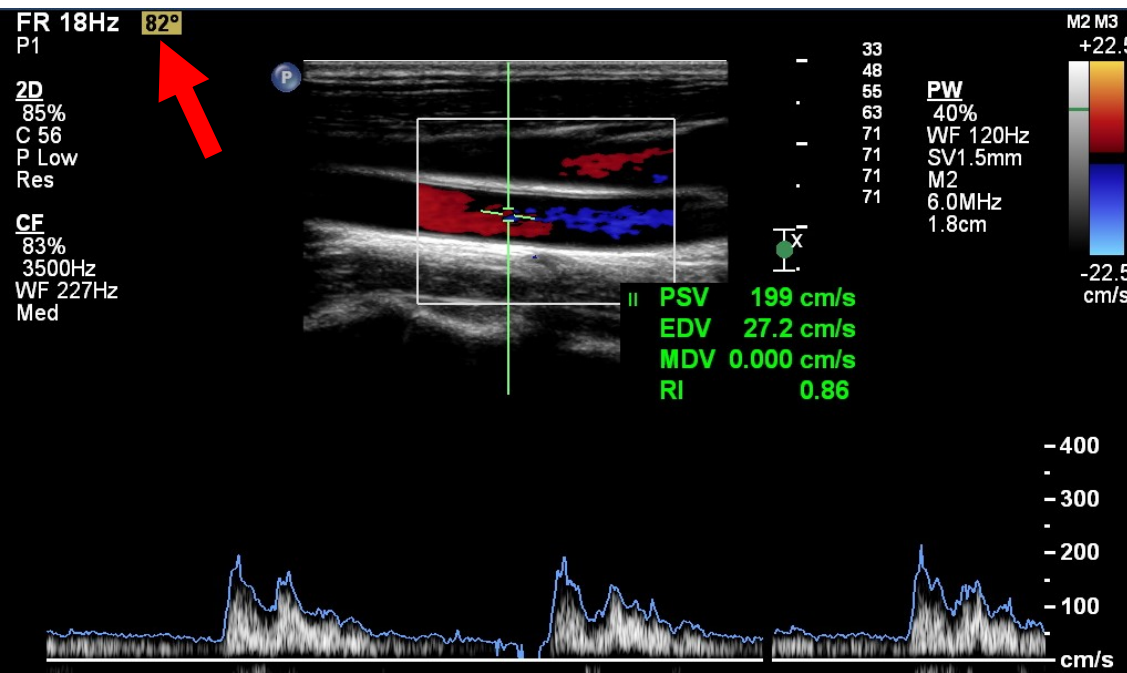


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2020



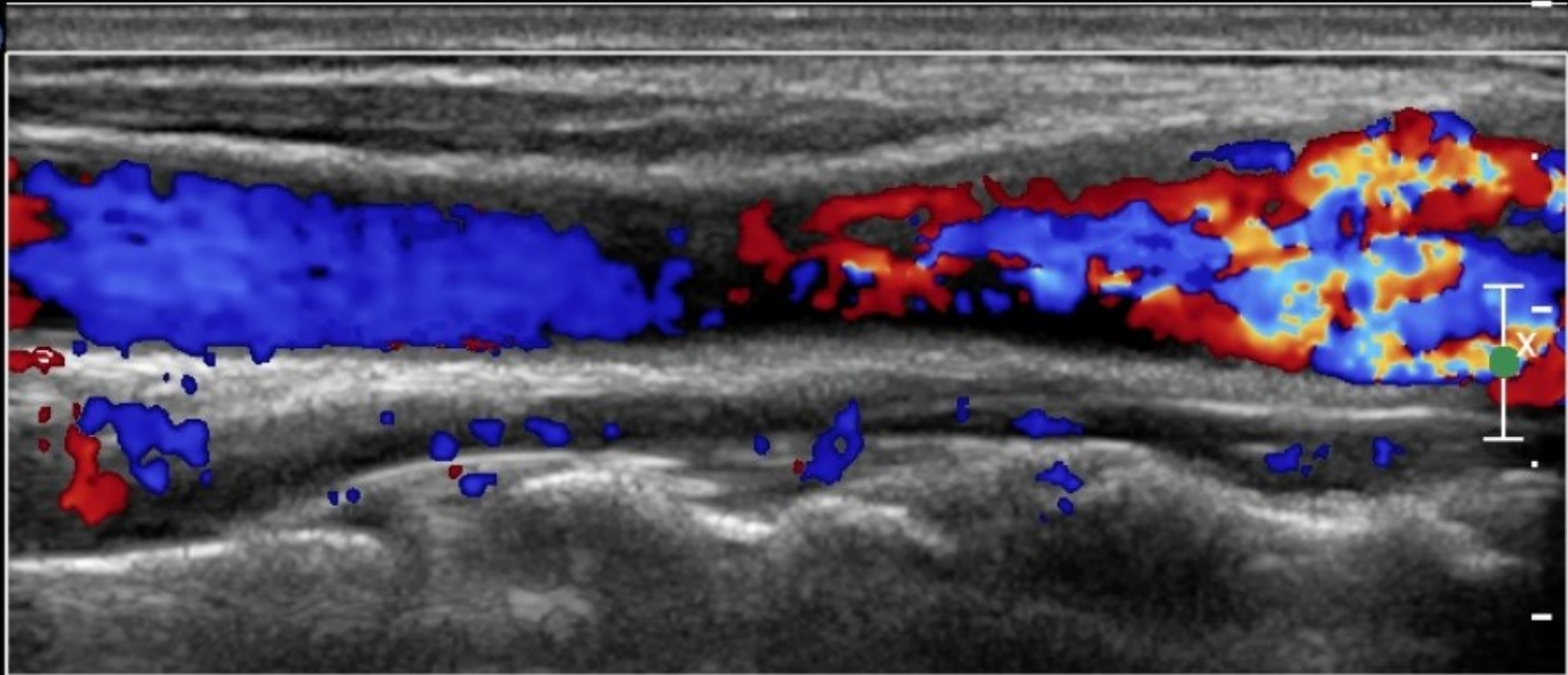
2020

FR 6Hz  
RP

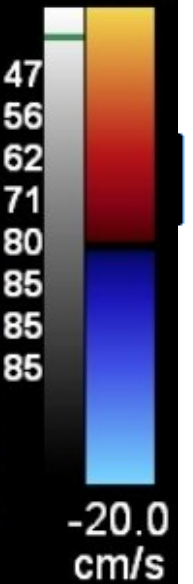
2D  
84%  
C 64  
P Med  
Res

CF  
77%  
3247Hz  
WF 162Hz  
Low

P



M3 M3  
+20.0



S/

U

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**Dopplerovské  
techniky**

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# Kontinuální doppler

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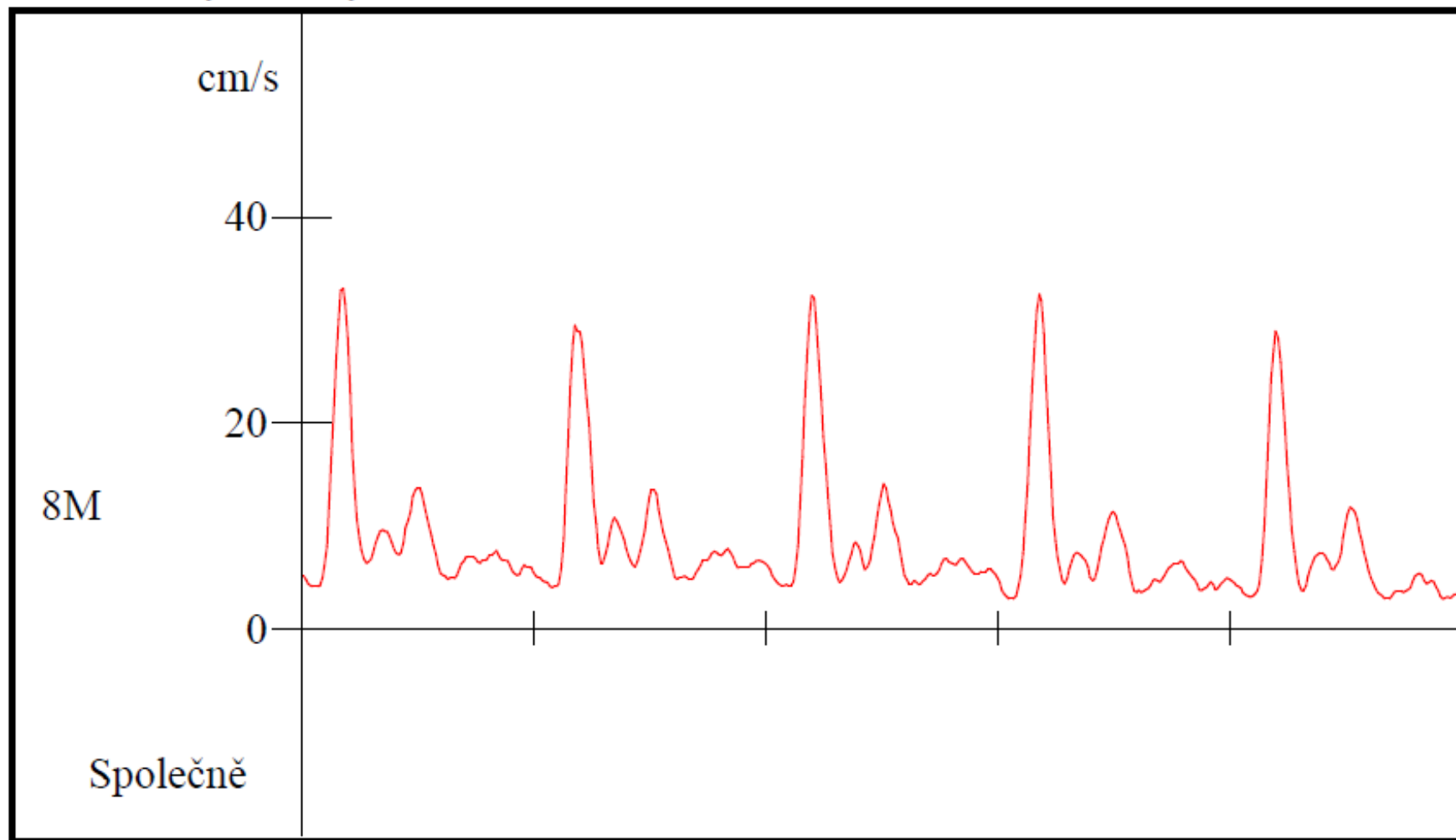
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Hor.končetiny --- Pravý Radial

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TUDIU



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

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TUDIU

# Pulzní doppler

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# Barevný doppler

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BART

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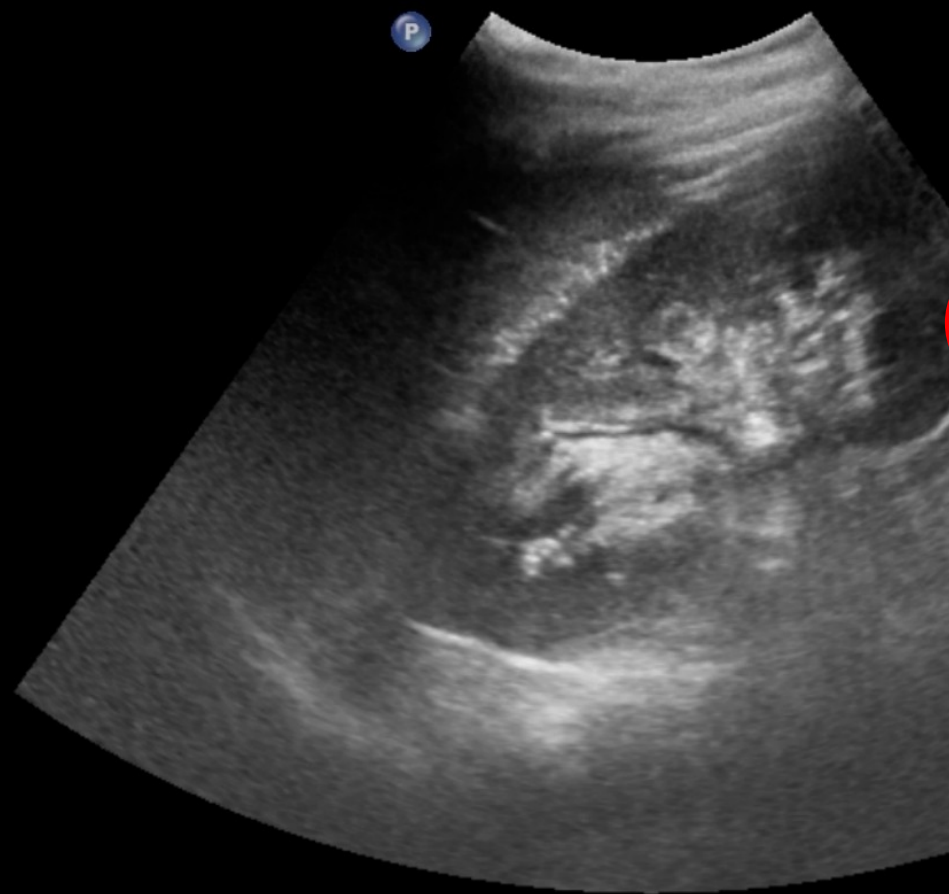


FR 28Hz  
RS

2D  
84%  
C 48  
P Low  
HGen

M3

46  
62  
76  
83  
89  
95



FR 5Hz  
RP

2D  
86%  
C 48  
P Med  
HGen

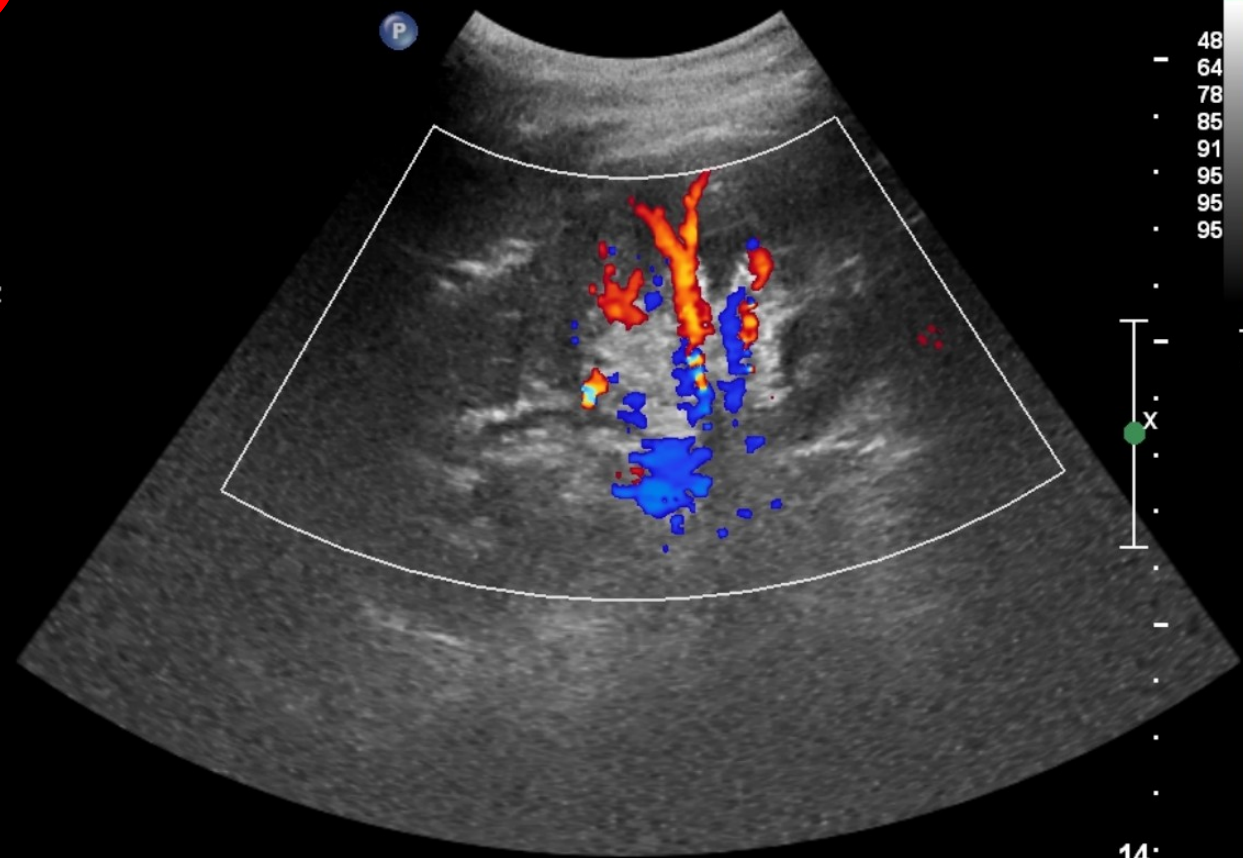
CF  
61%  
2200Hz  
WF 109Hz  
Med

M3 M6

+30.8

48  
64  
78  
85  
91  
95  
95

-30.8  
cm/s



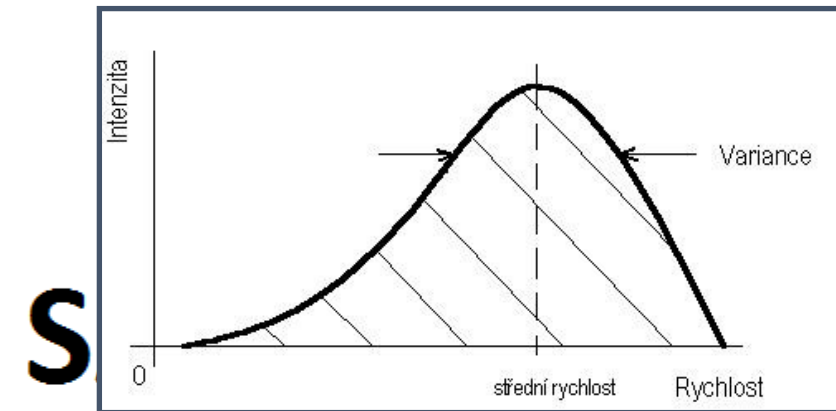
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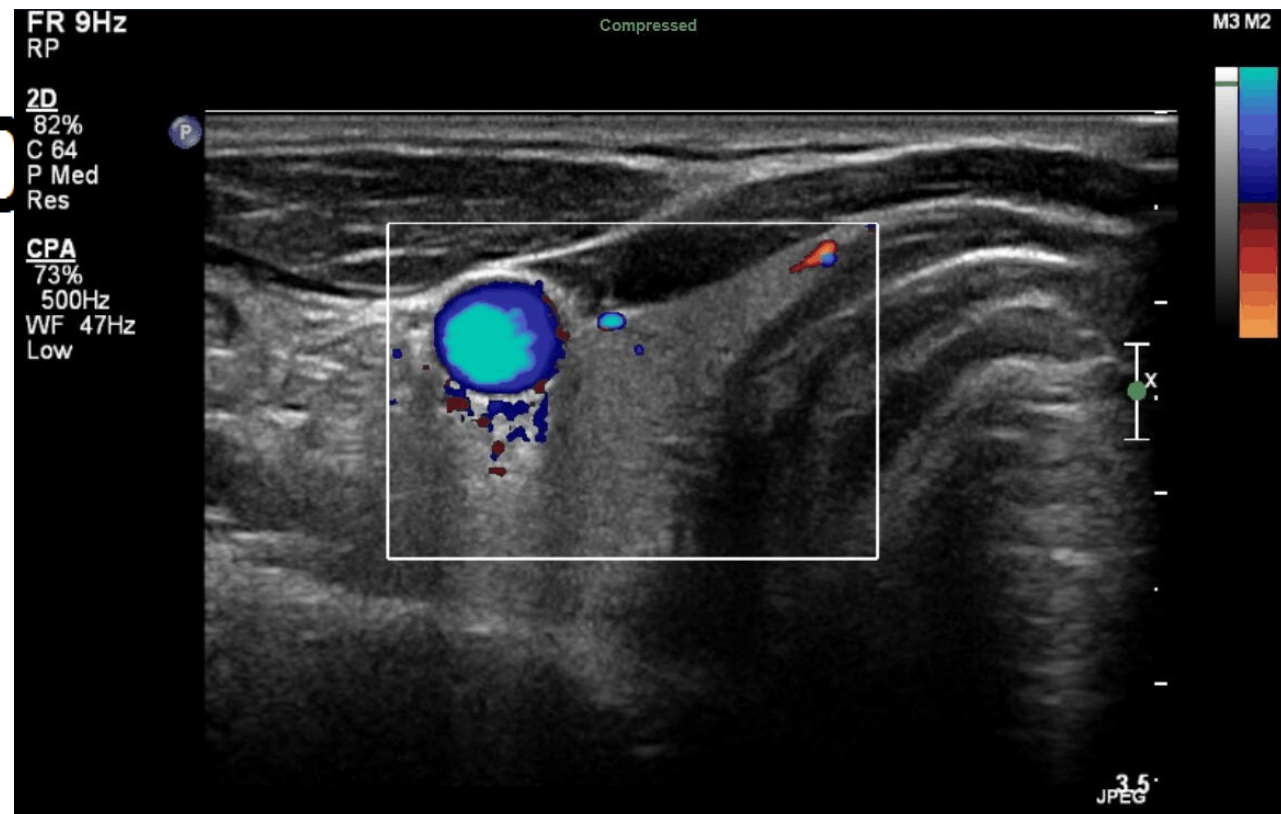
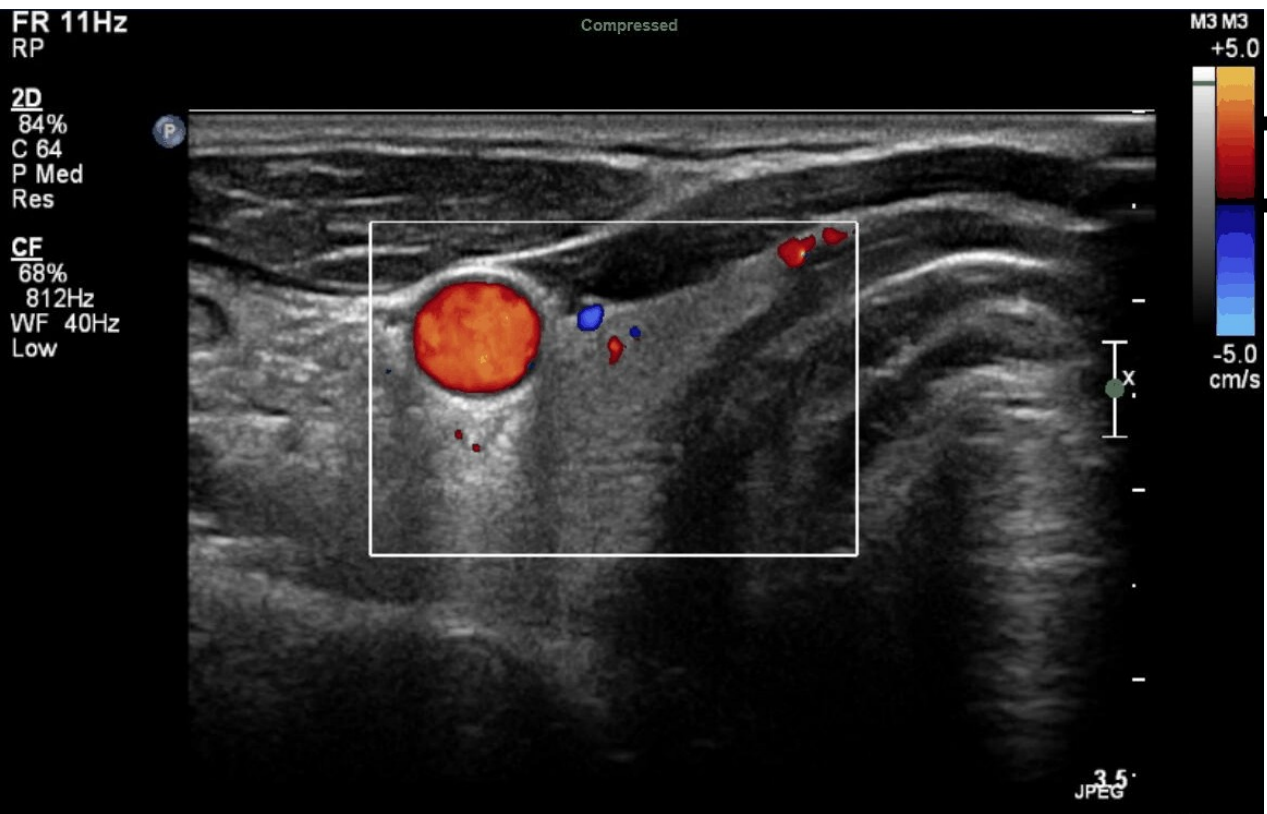
# Energetický doppler

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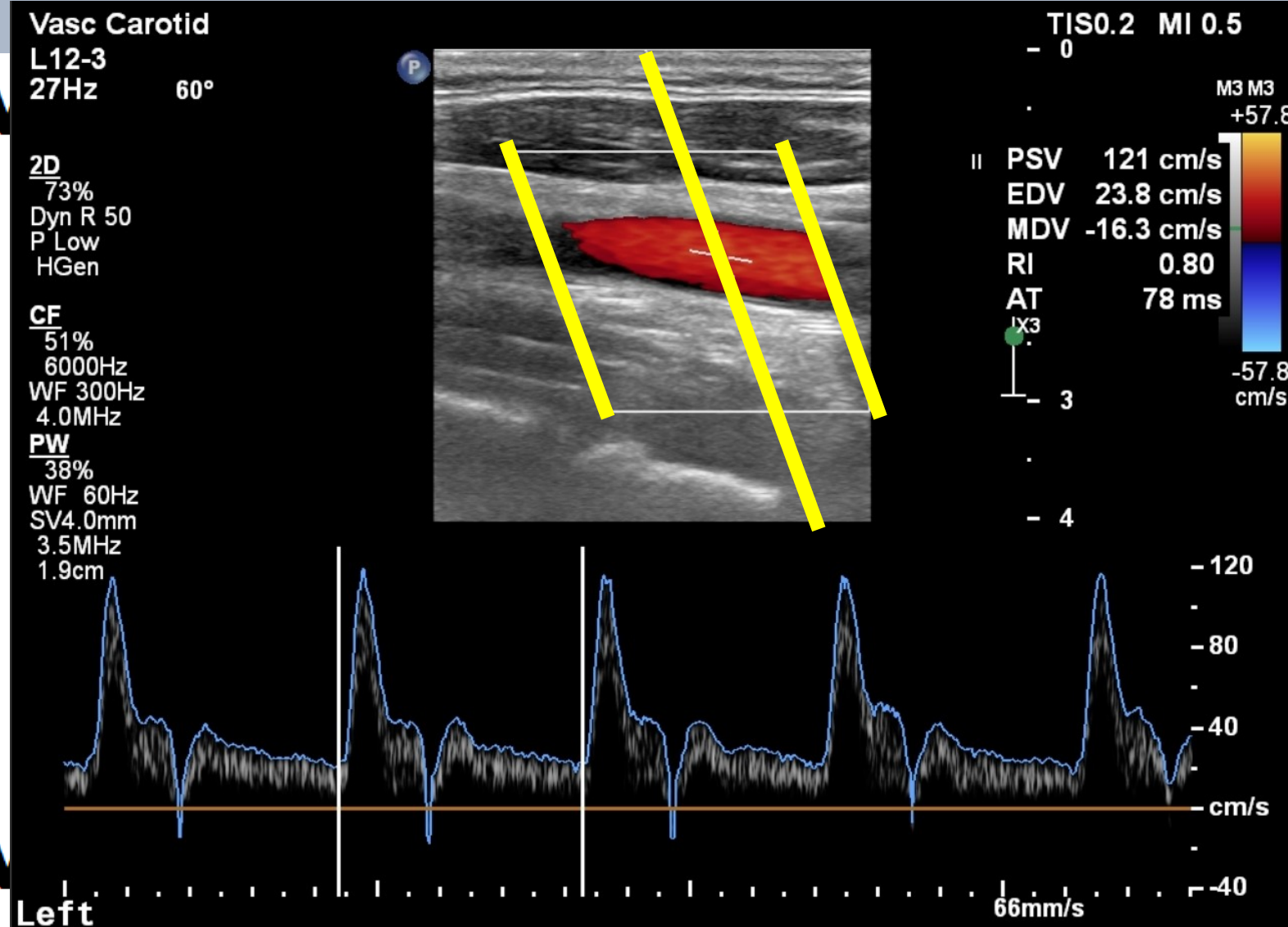


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# Praktická nastavení dopplerovského ultrazvuku

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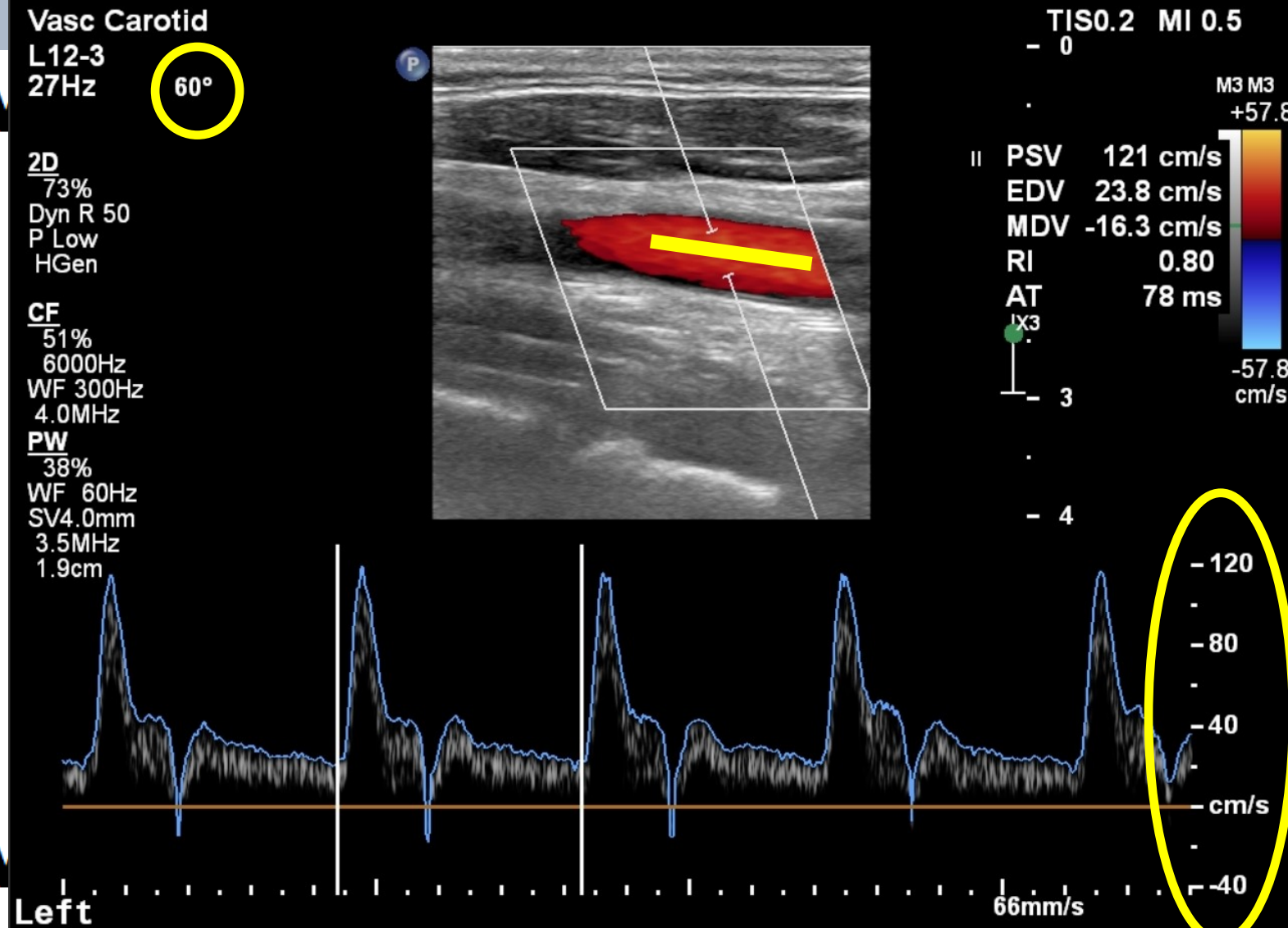


SAMOSTUDIUM

# Praktická nastavení dopplerovského ultrazvuku

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Angle correction - uloženo

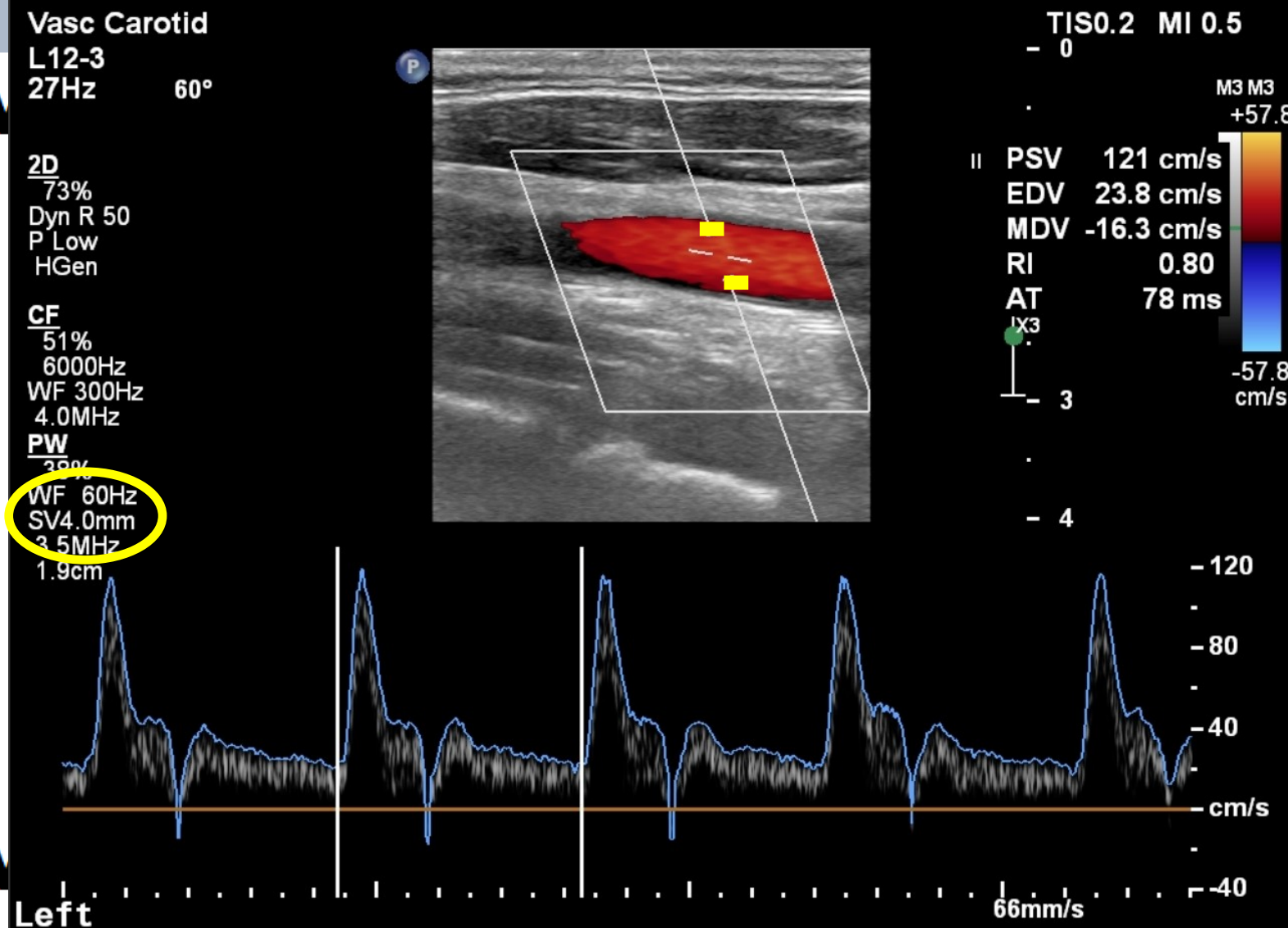


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# Praktická nastavení dopplerovského ultrazvuku

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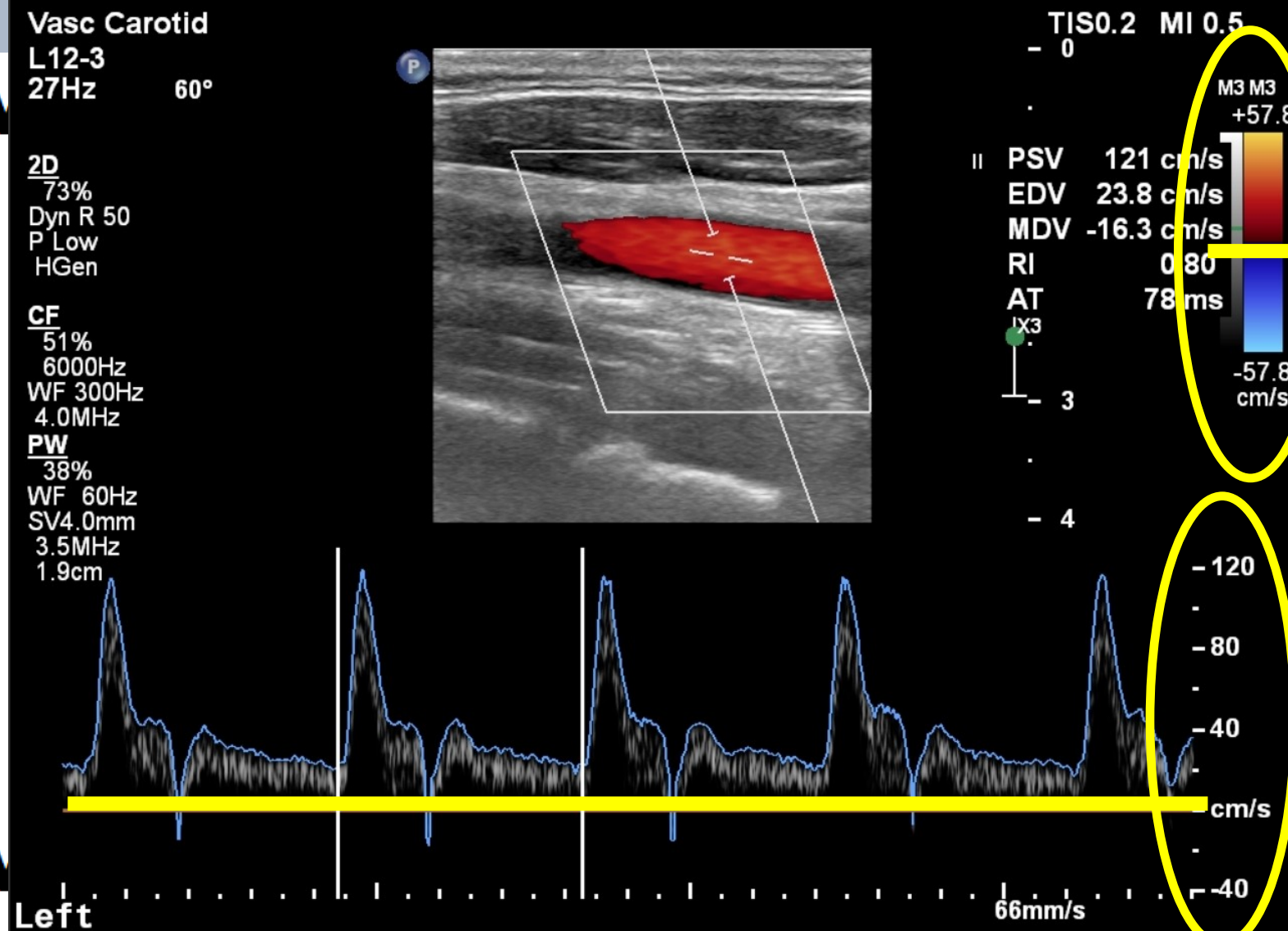
Sample Volume



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# Praktická nastavení dopplerovského ultrazvuku

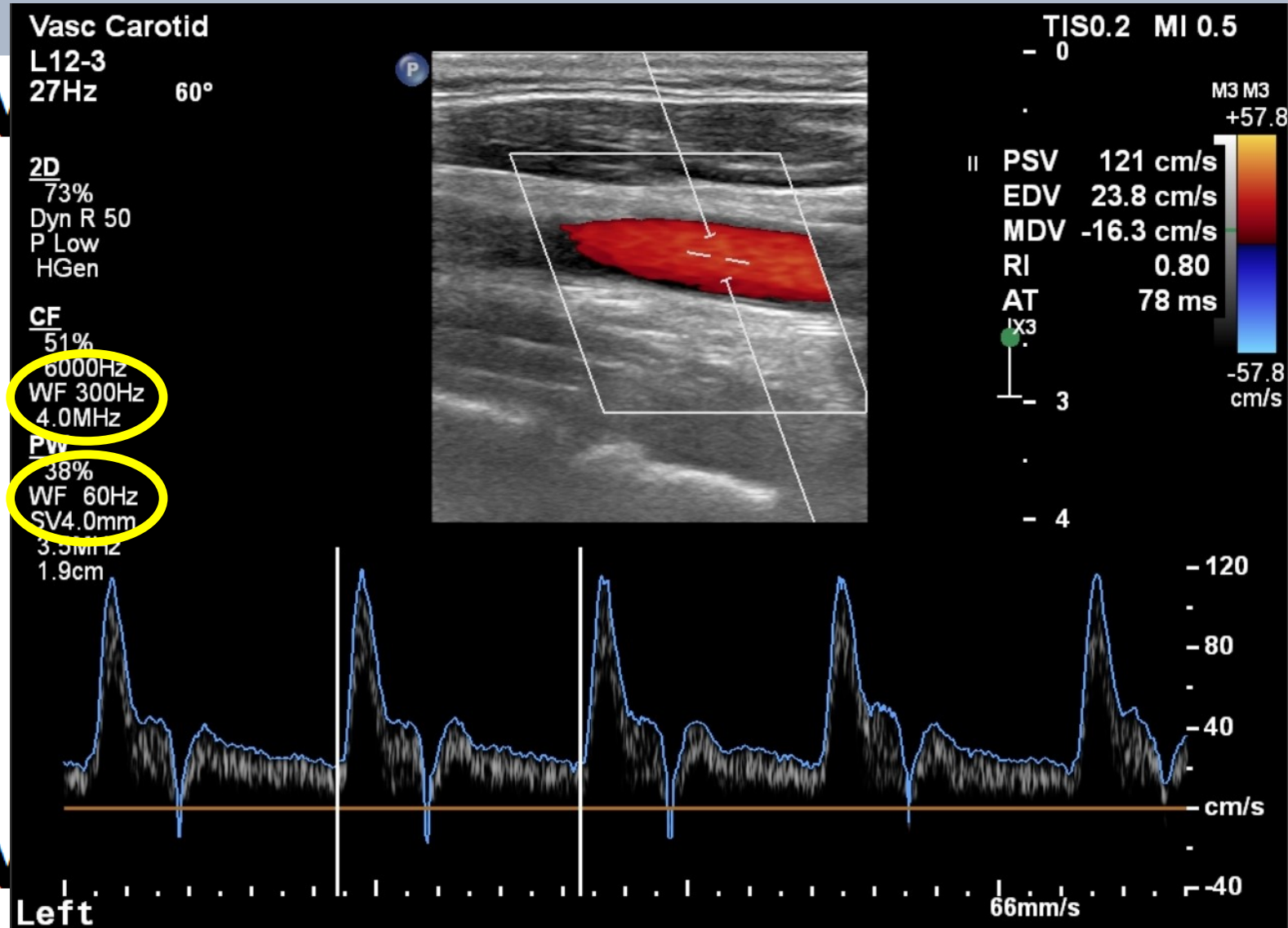
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# Praktická nastavení dopplerovského ultrazvuku

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# Hodnocení dopplerovského záznamu

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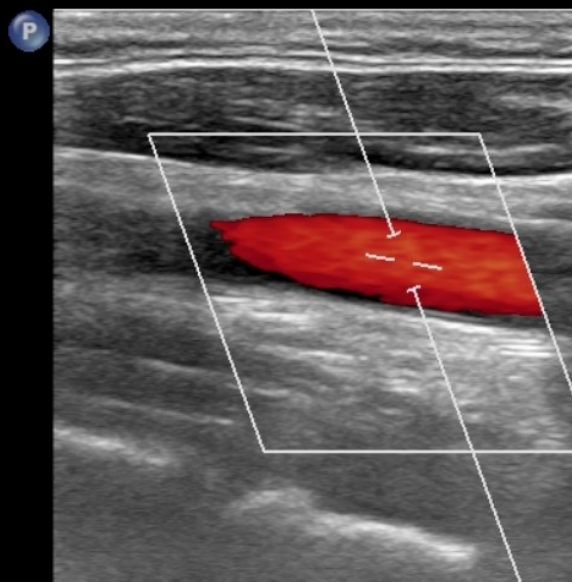
Vasc Carotid

L12-3  
27Hz 60°

2D  
73%  
Dyn R 50  
P Low  
HGen

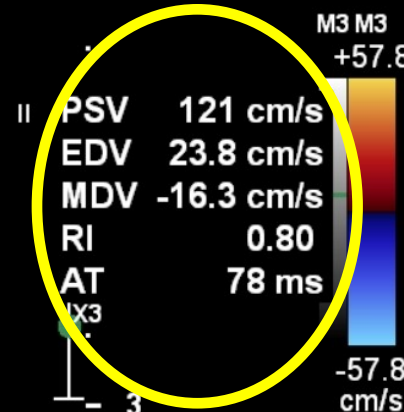
CF  
51%  
6000Hz  
WF 300Hz  
4.0MHz

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

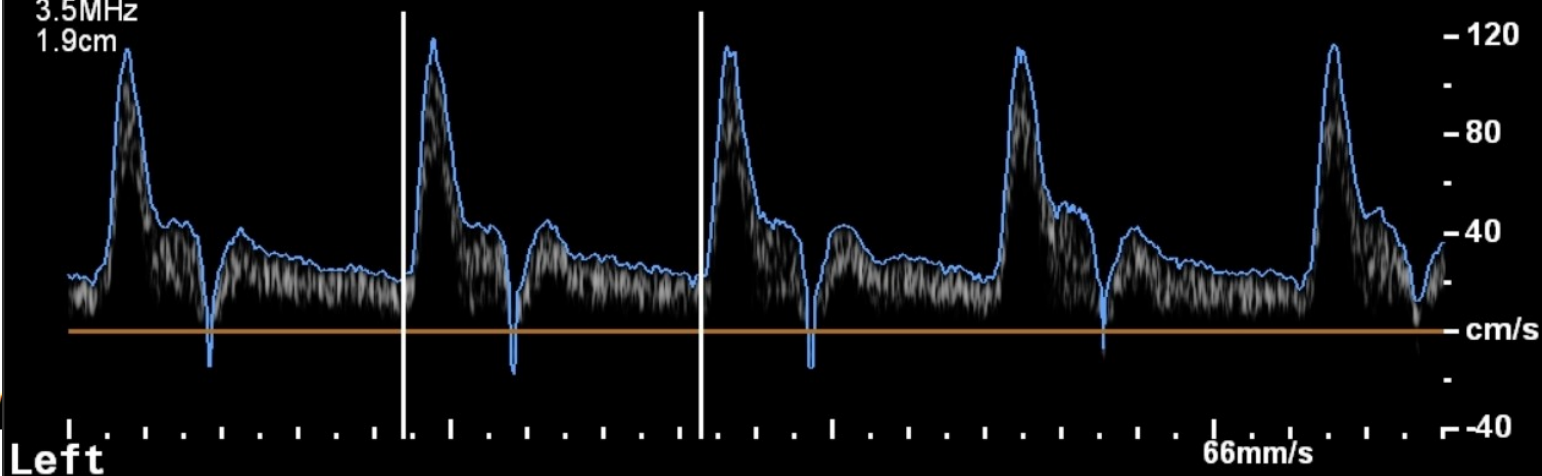


TISO.2 MI 0.5

- 0



- 4



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# Závěr

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- Dodržovat správné nastavení

- Co nejmenší úhel (do  $60^\circ$ ) – steering!

- Úhlová korekce dle skutečného průběhu cévy

- Přizpůsobení baseline a scale – odstranění artefaktů

- Vhodný přednastavený program

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# 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."*