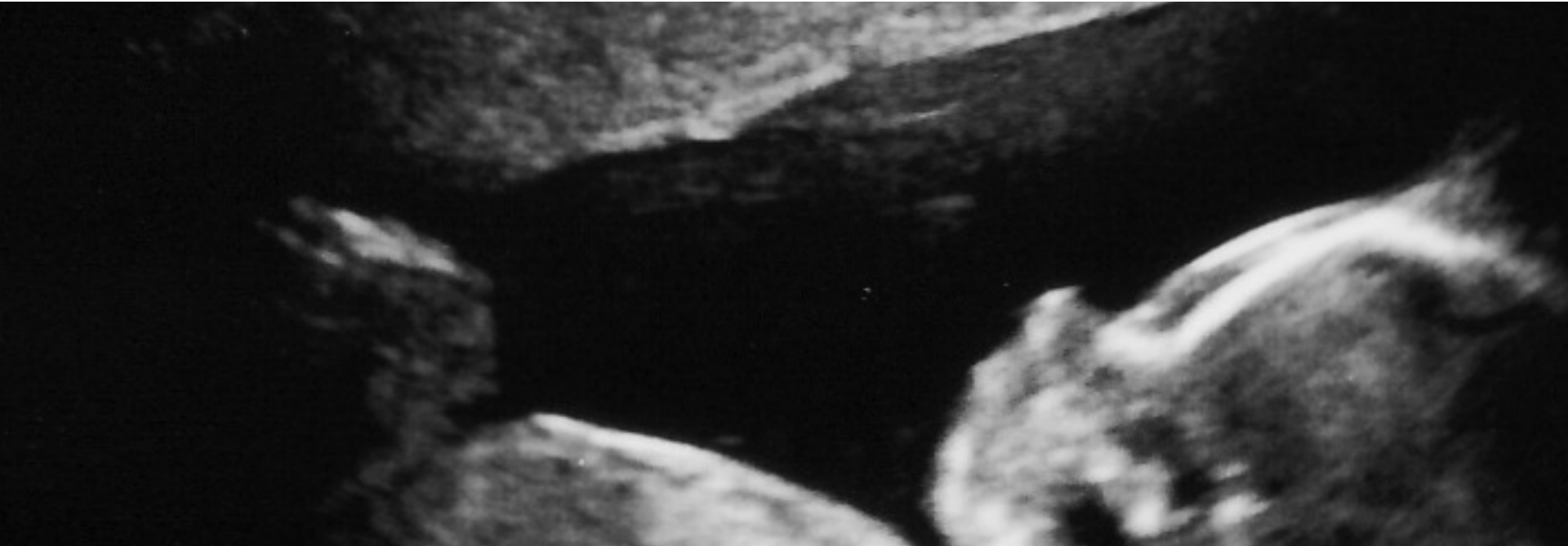


Ultrasound Physics (BWHRR.US)

4. Advanced Imaging Methods



Phillip Jason White, Ph.D.

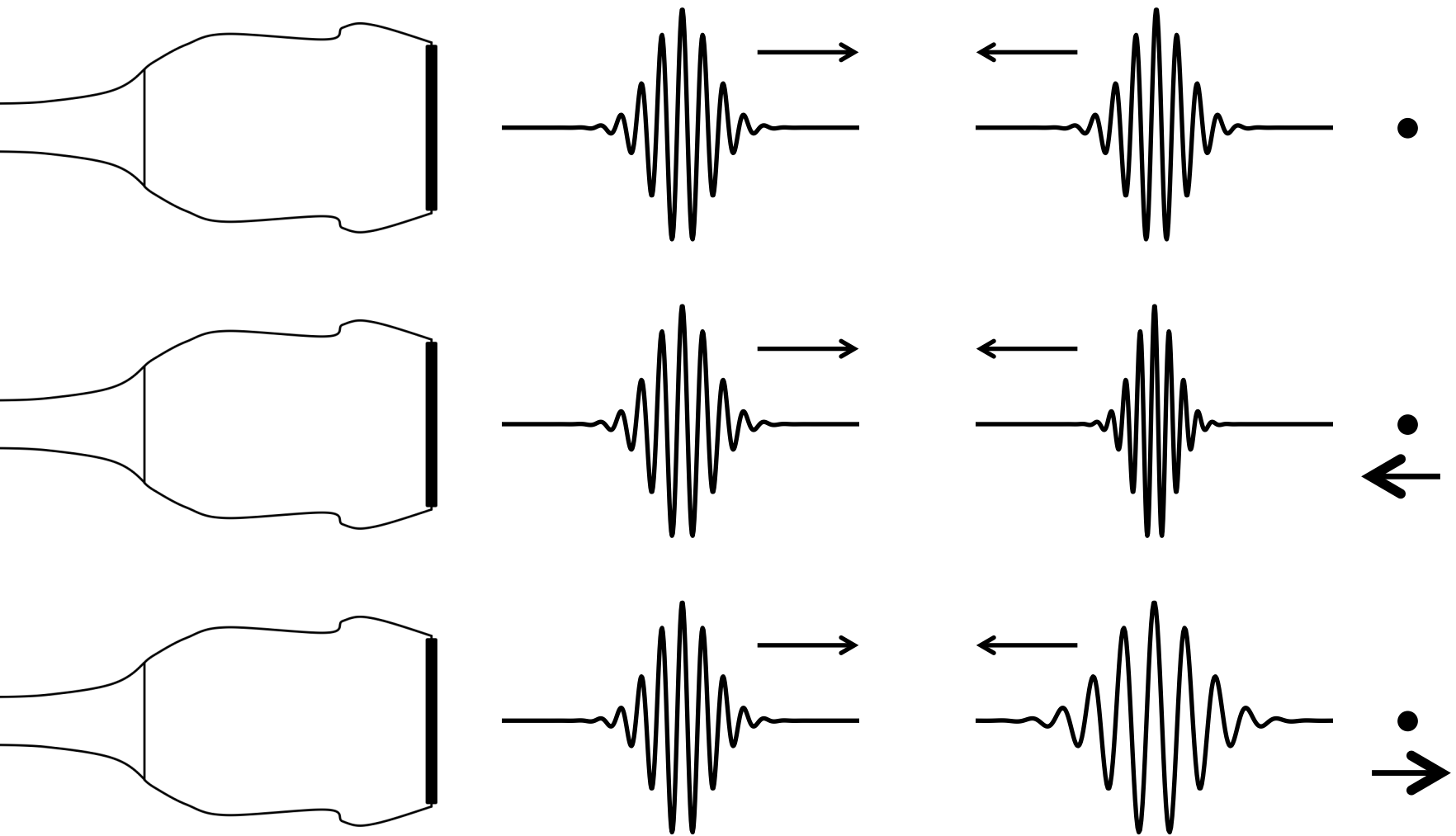
Department of Radiology

Brigham and Women's Hospital | Harvard Medical School

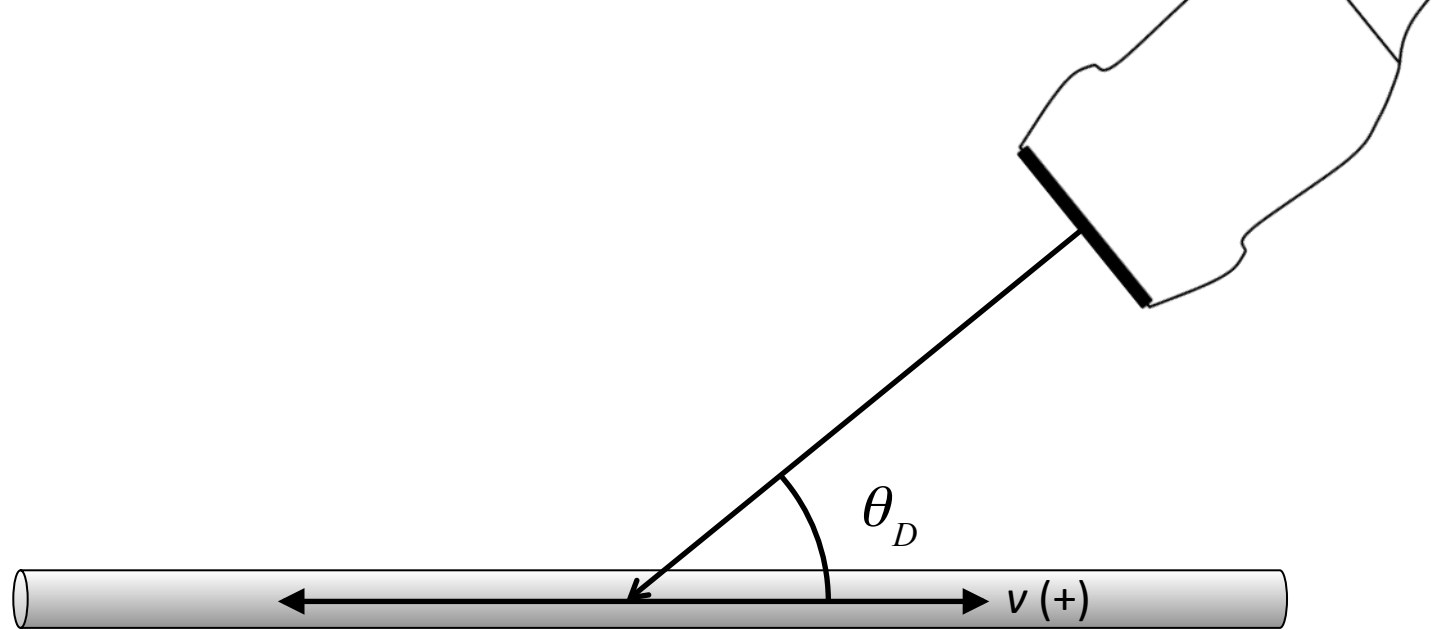
221 Longwood Avenue | EBRC 521

Boston, MA 02115

Contact: (617) 525-7465, white@bwh.harvard.edu

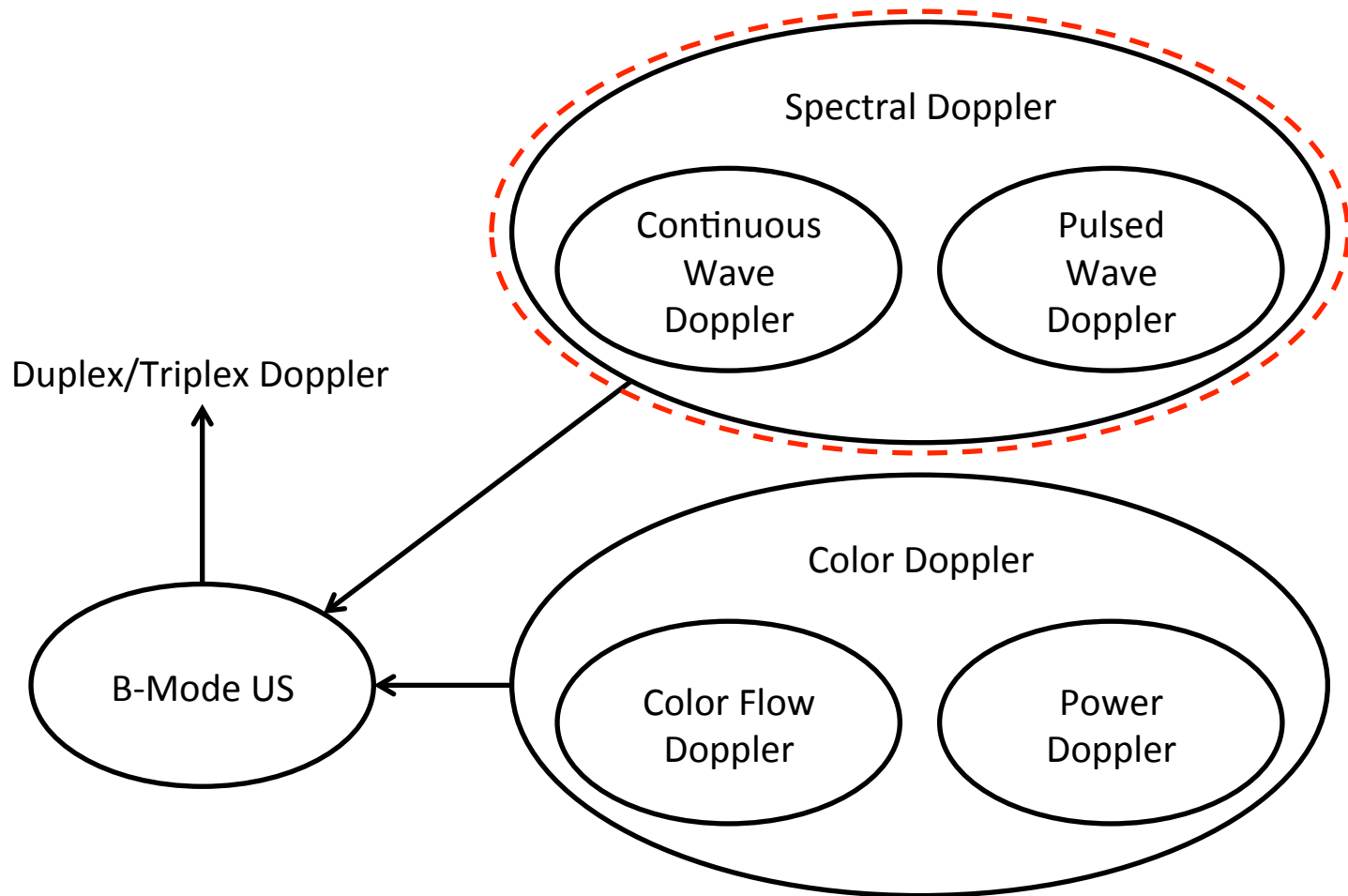


Doppler Ultrasound

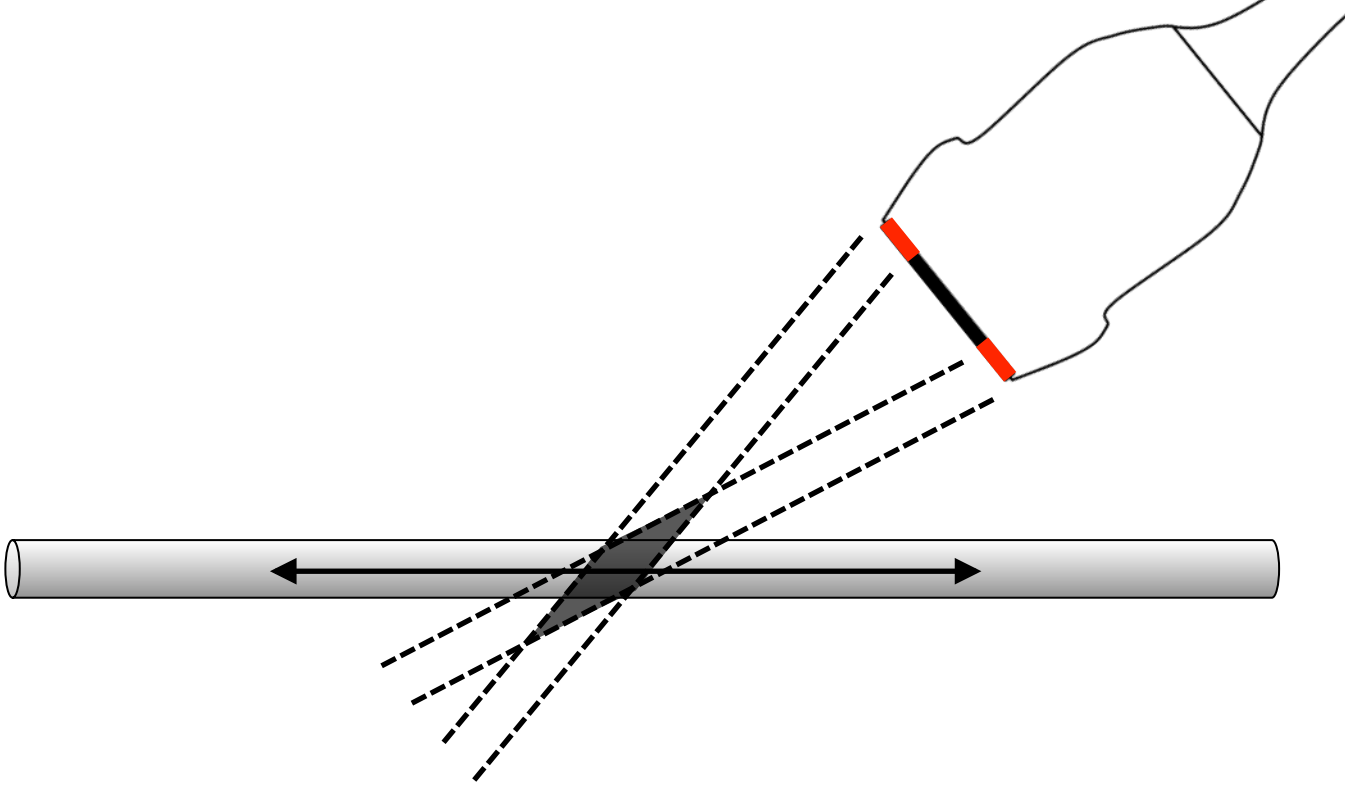


$$f_D = f_R - f_T = \frac{2v}{c} f_T \cos(\theta_D) \quad \Rightarrow \quad v = \frac{f_D c}{2 f_T \cos(\theta_D)}$$

Doppler Ultrasound

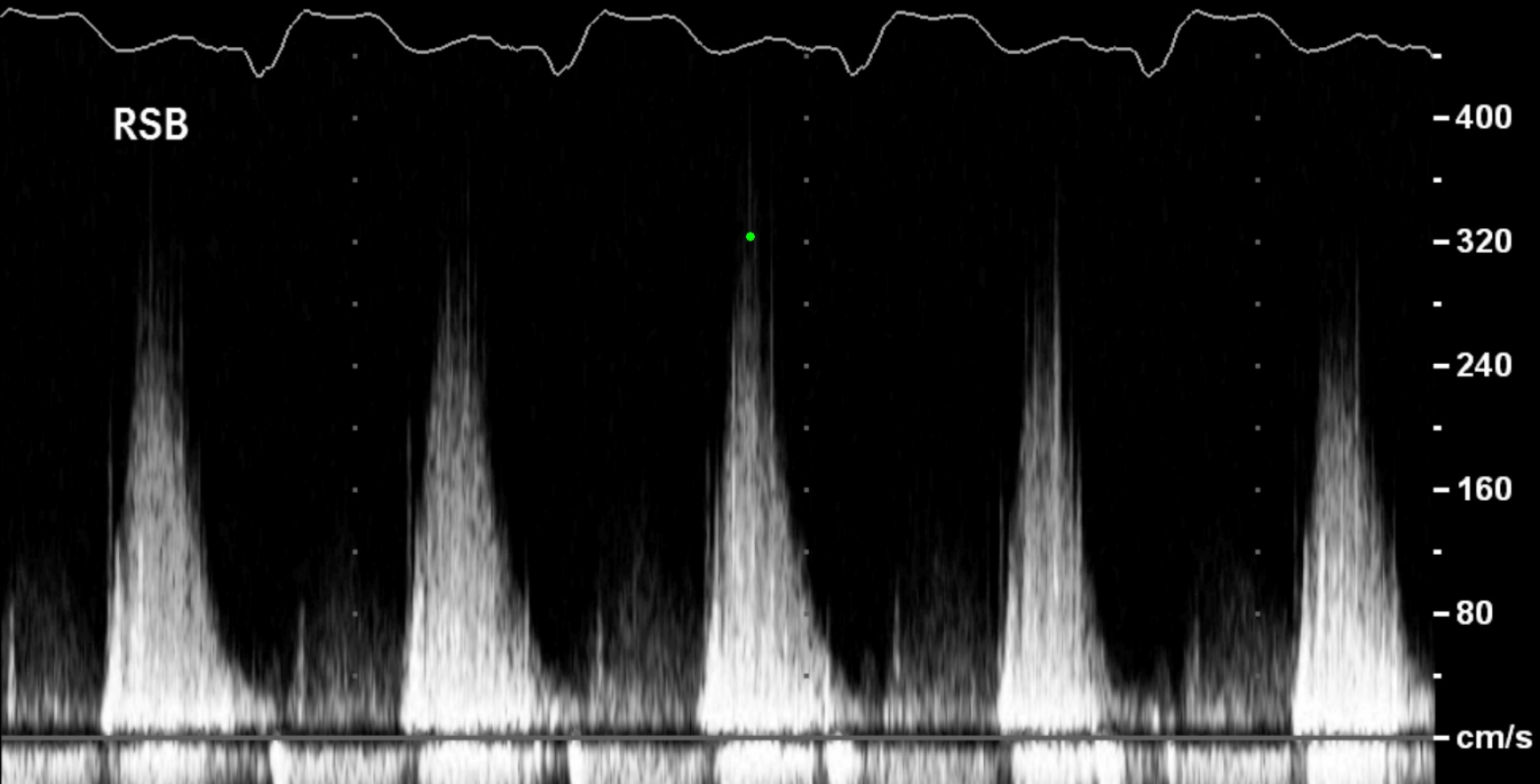


Doppler Ultrasound

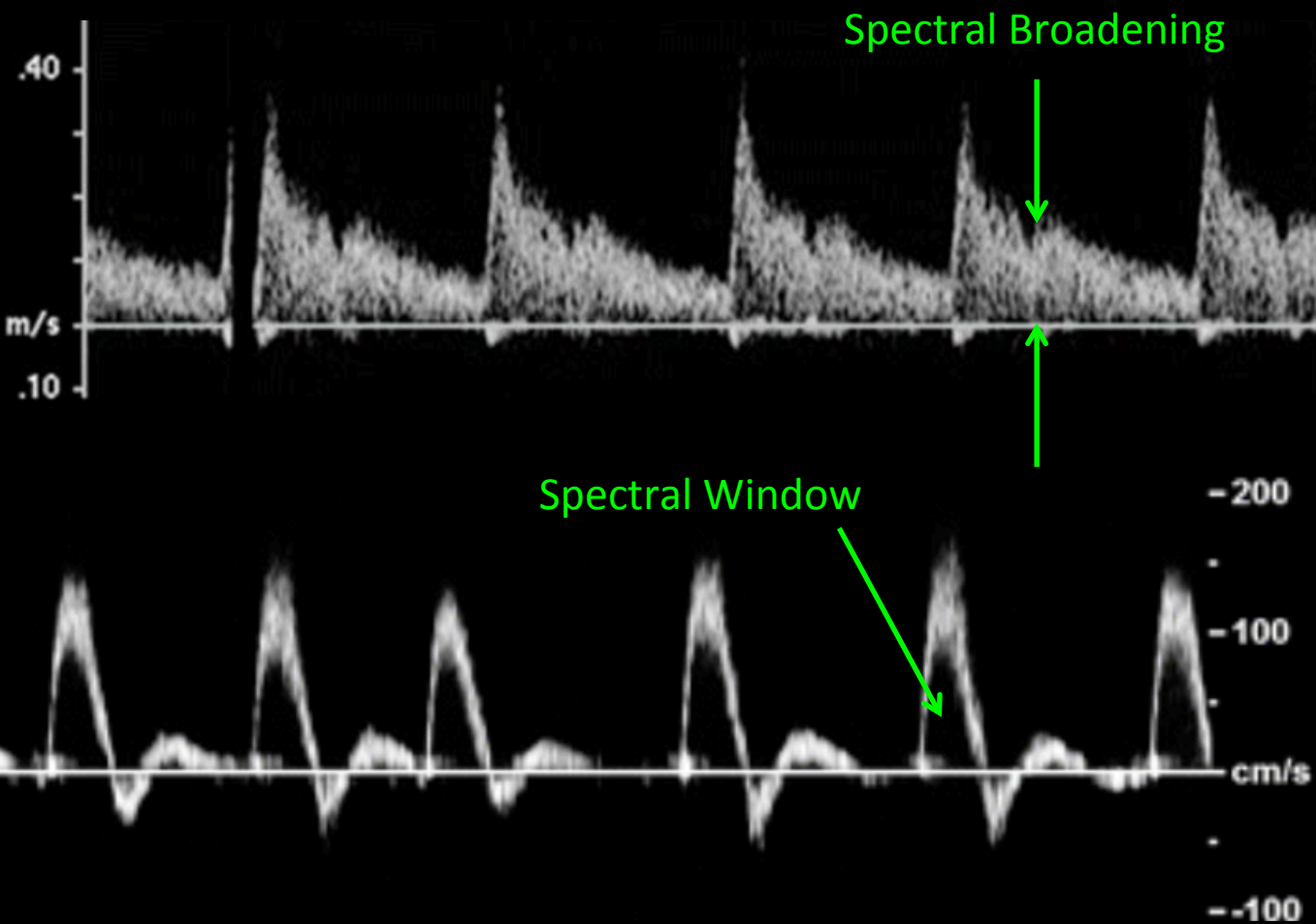


Continuous Wave Doppler (CWD)

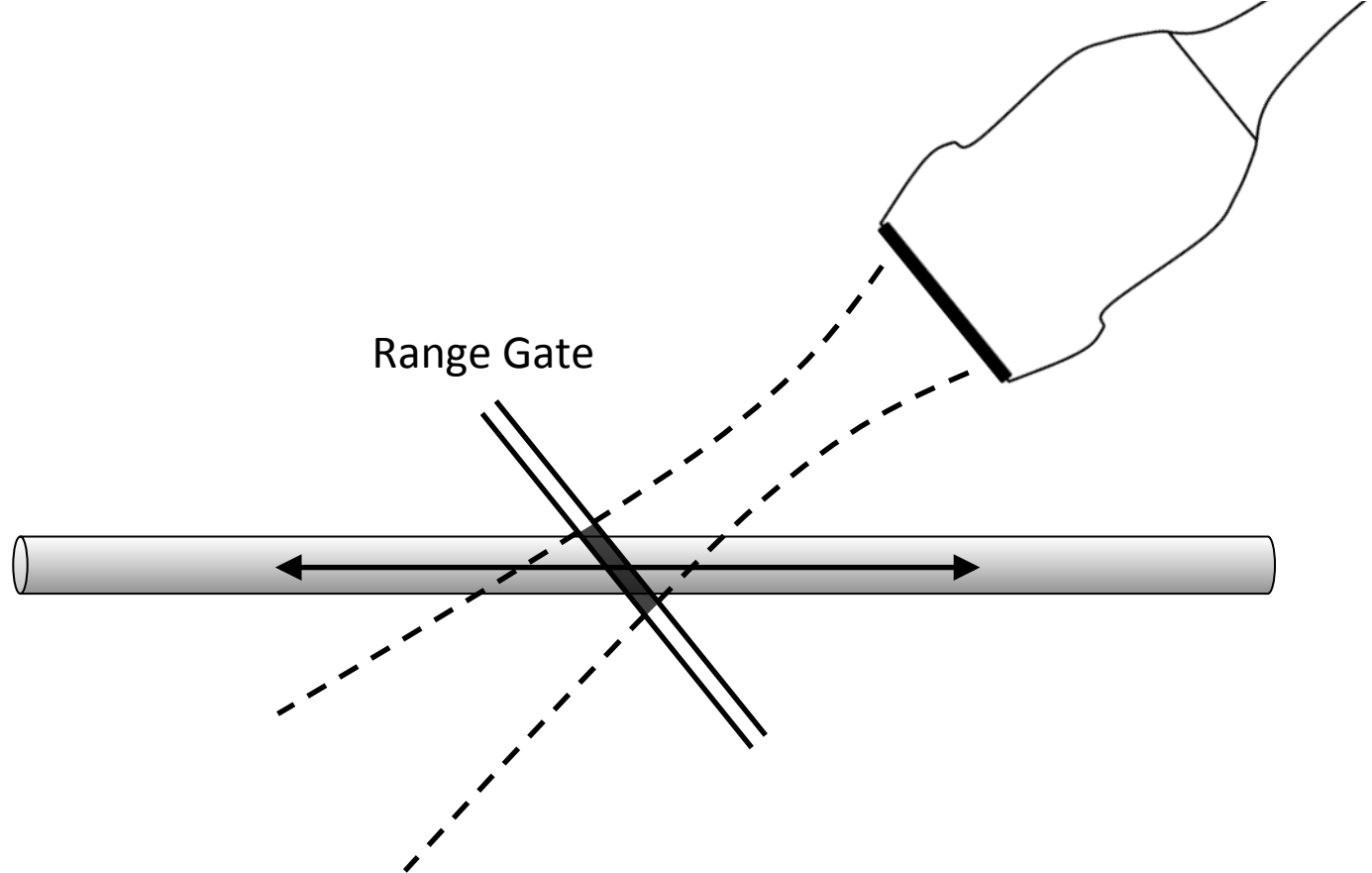
CW
50%
2.0MHz
WF 225Hz



Continuous Wave Doppler (CWD)

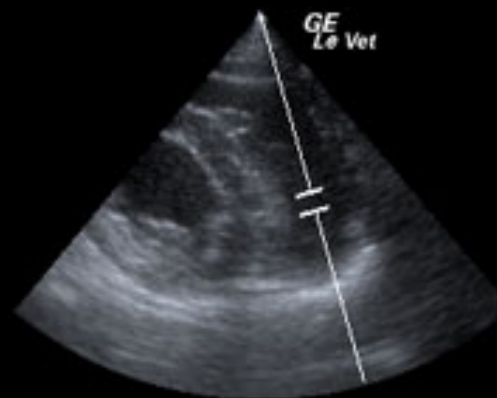


Continuous Wave Doppler (CWD)

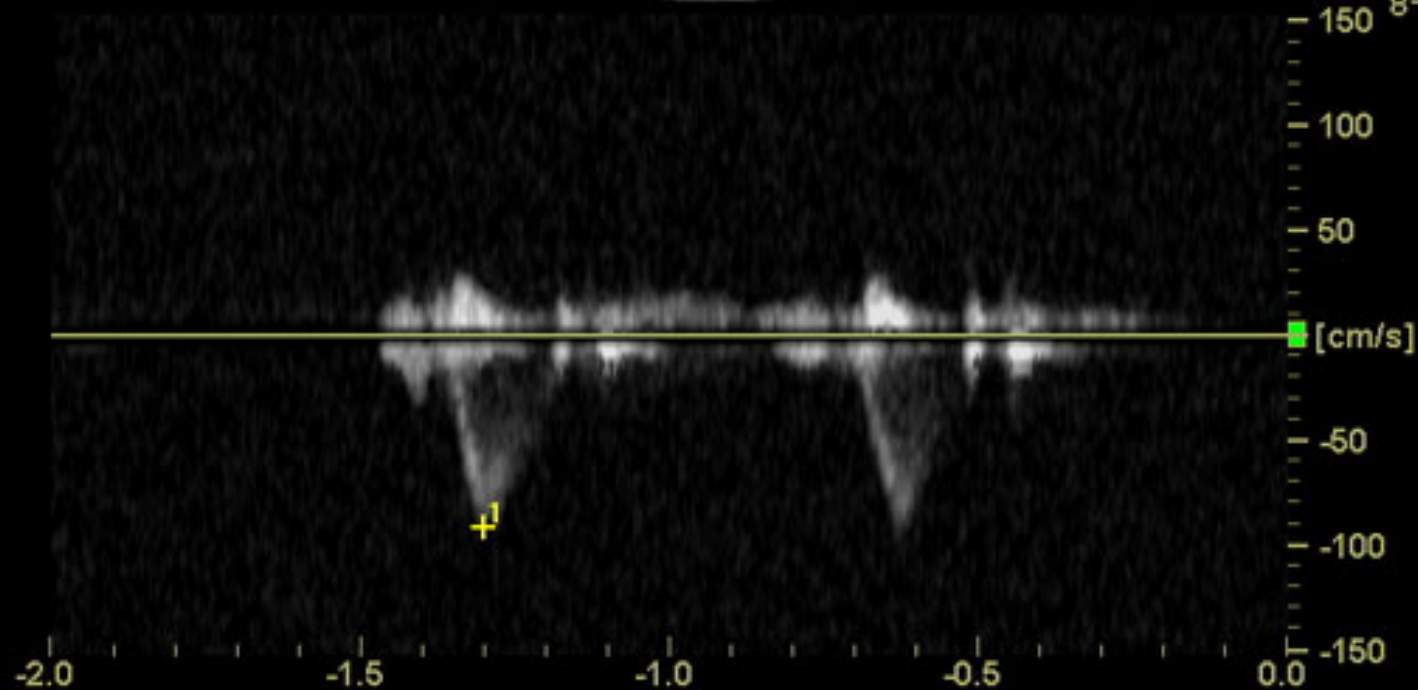


Pulsed Wave Doppler (PWD)

1 v 0.93 m/s
p 3.45 mmHg
Frq 3.01 kHz



B CHI
Frq 6.0 MHz
2- Gn 58
E/A 2/1
Map D/0/0
4- D 8.0 cm
DR 72
FR 62 Hz
6- AO 100 %
XBeam Off



PW
Frq 2.5 MHz
Gn 9
AO 100 %
PRF 9.9 kHz
WF 198 Hz
SV 4
DR 52
SVD 4.1 cm

Pulsed Wave Doppler (PWD)

FR 45Hz

18cm

0:50:20

M3

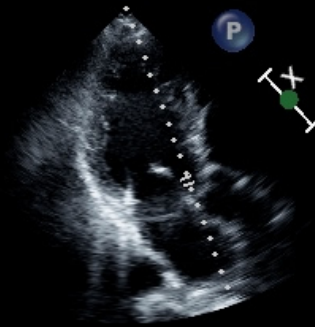
2D

68%

C 50

P Low

HGen



LVOT
(Apical LA)

PW

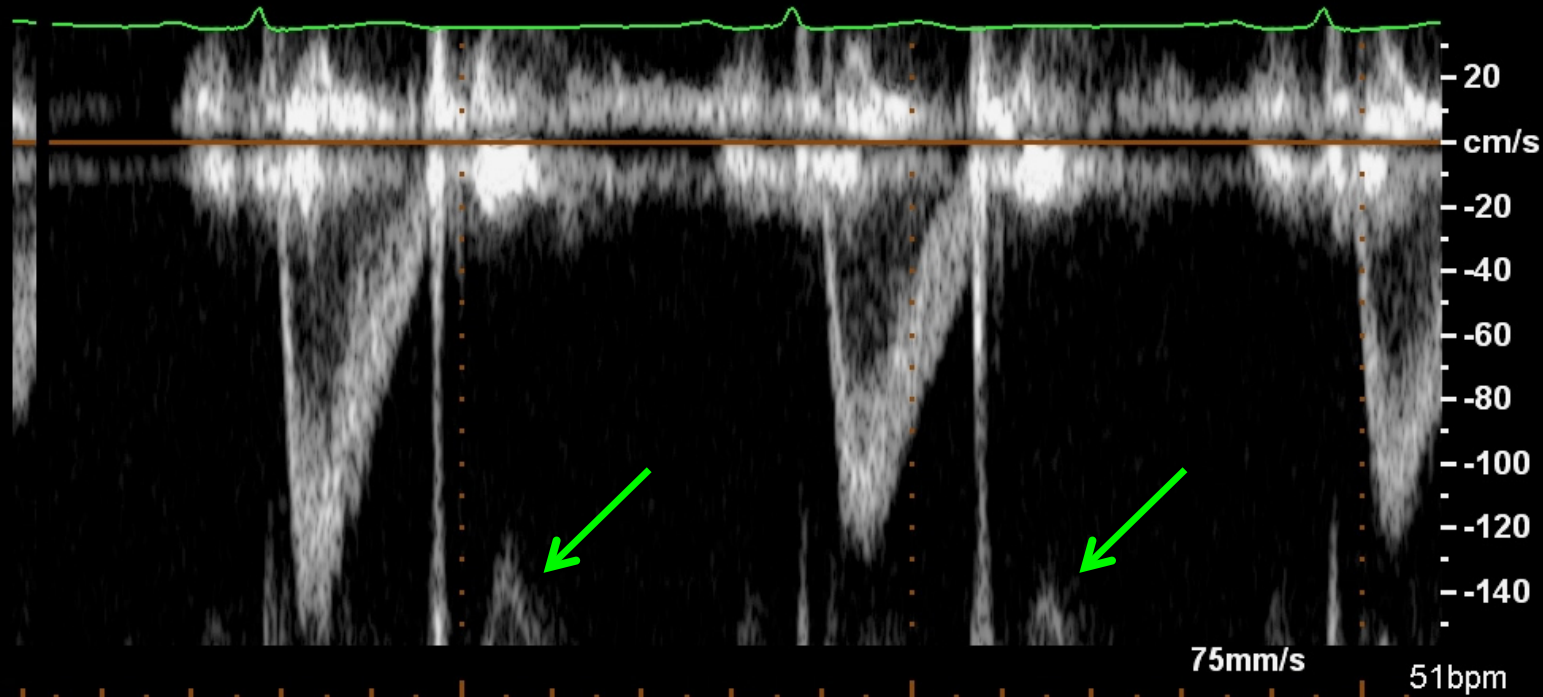
75%

1.6MHz

WF 125Hz

SV4.0mm

10.5cm



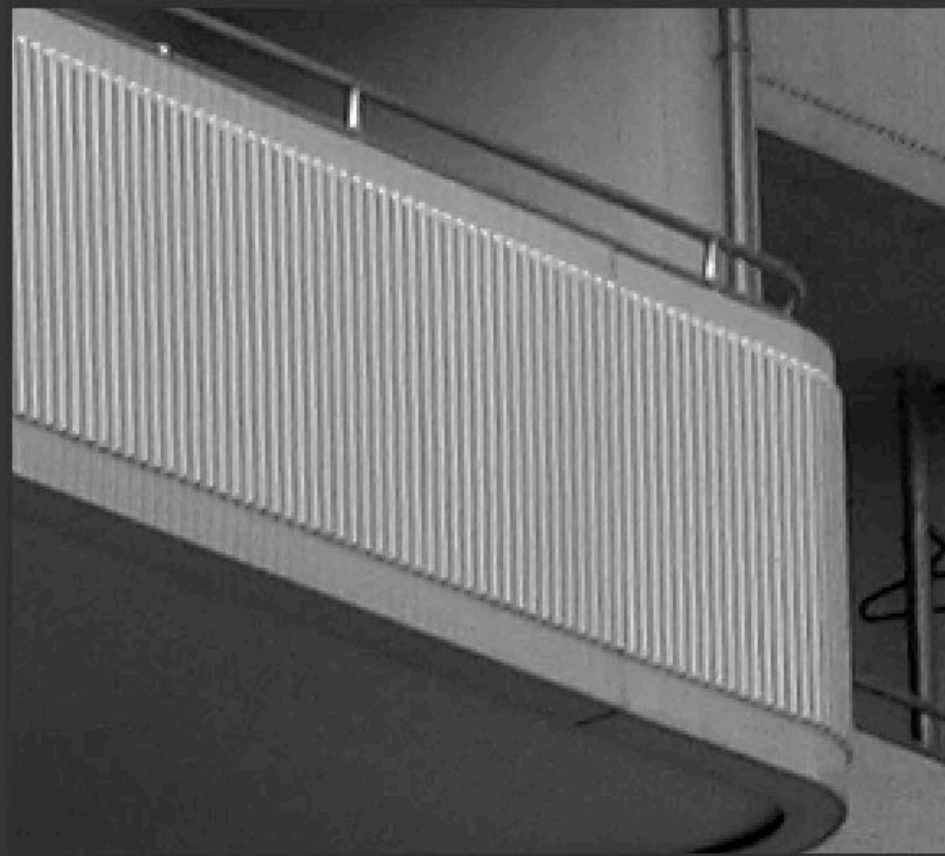
Pulsed Wave Doppler (PWD)



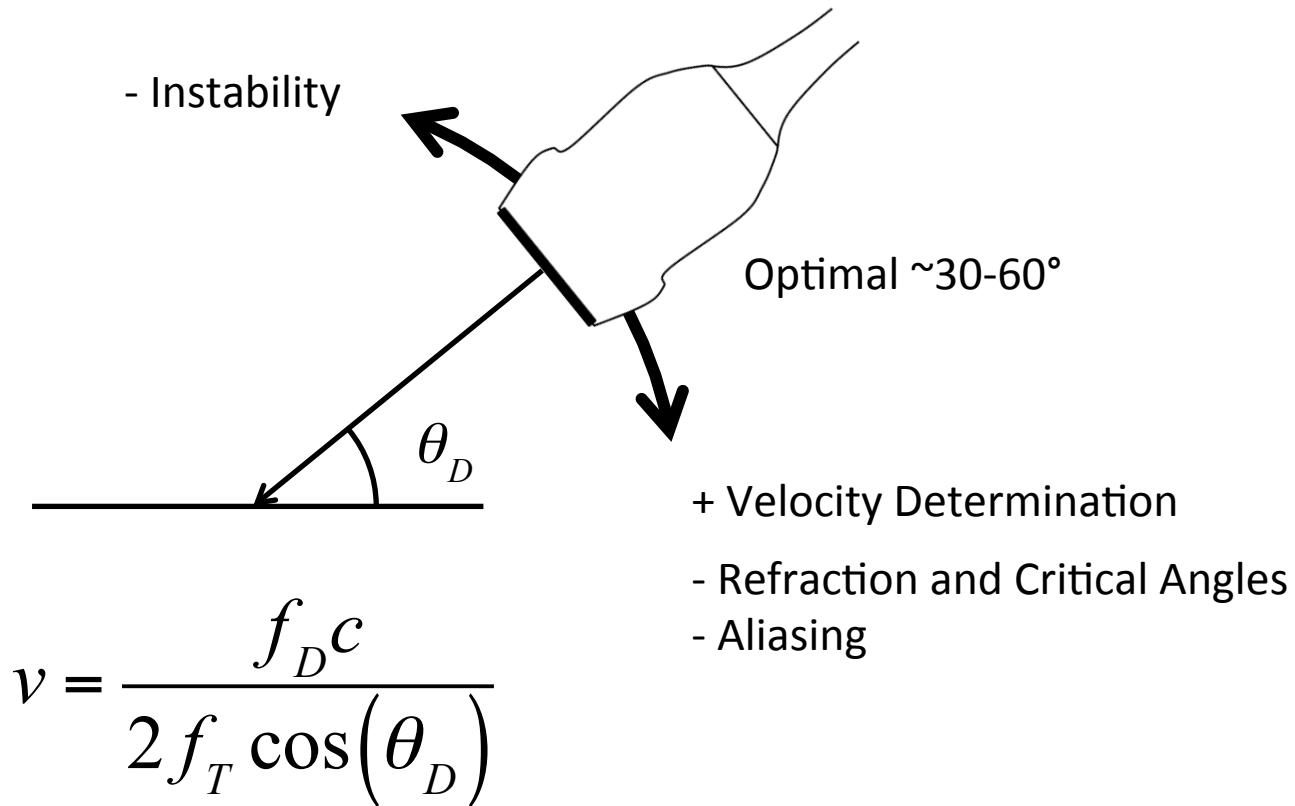
Aliasing



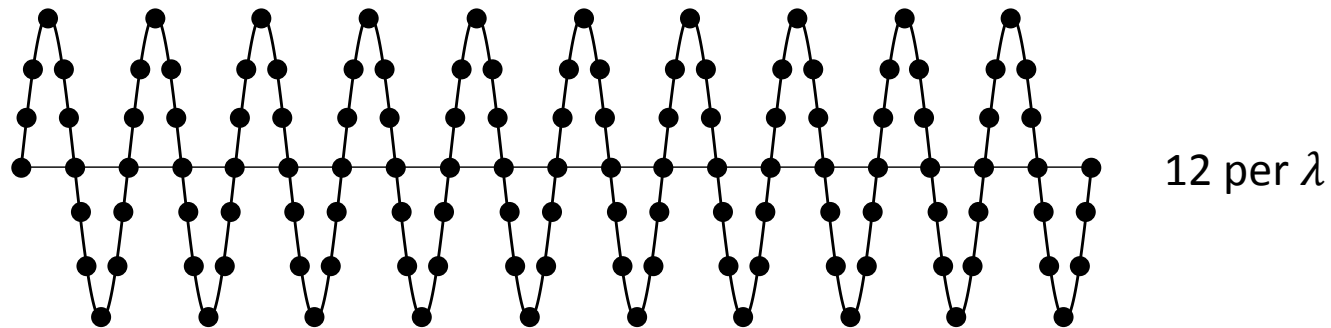
Aliasing



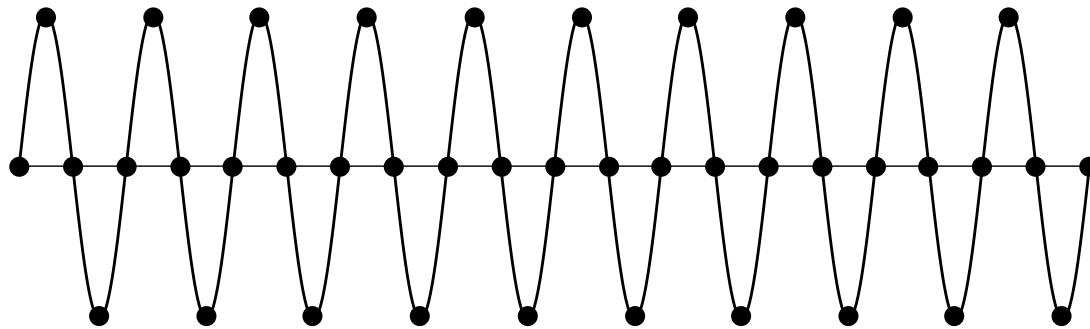
Aliasing



Aliasing

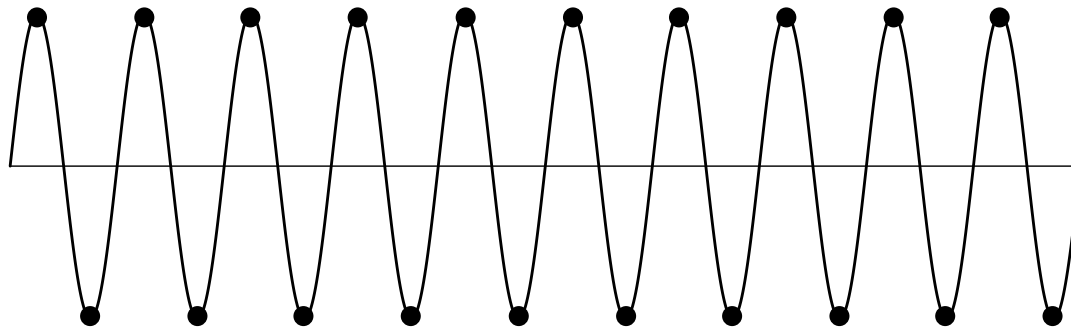


Aliasing



4 per λ

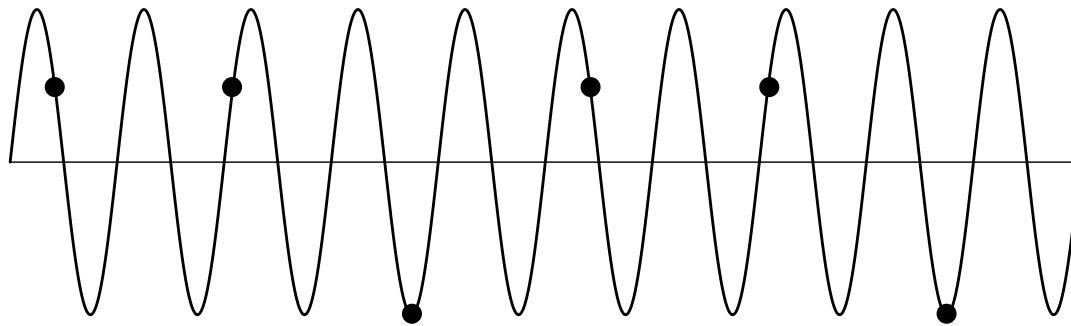
Aliasing



2 per λ (Nyquist Limit)

Critically Sampled

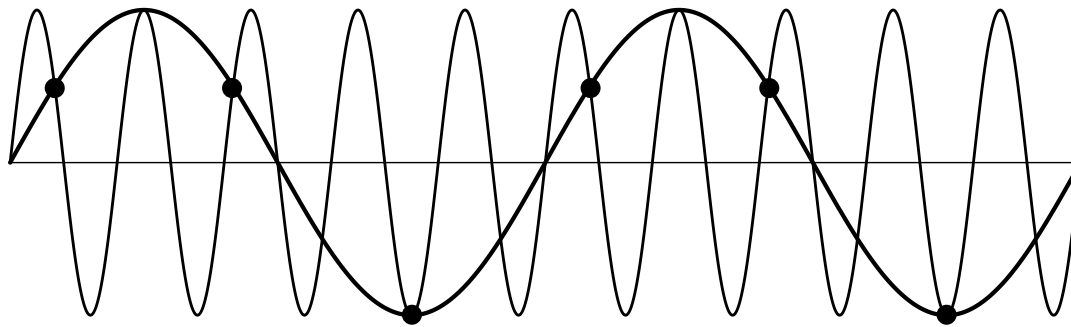
Aliasing



0.6 per λ

Undersampled

Aliasing



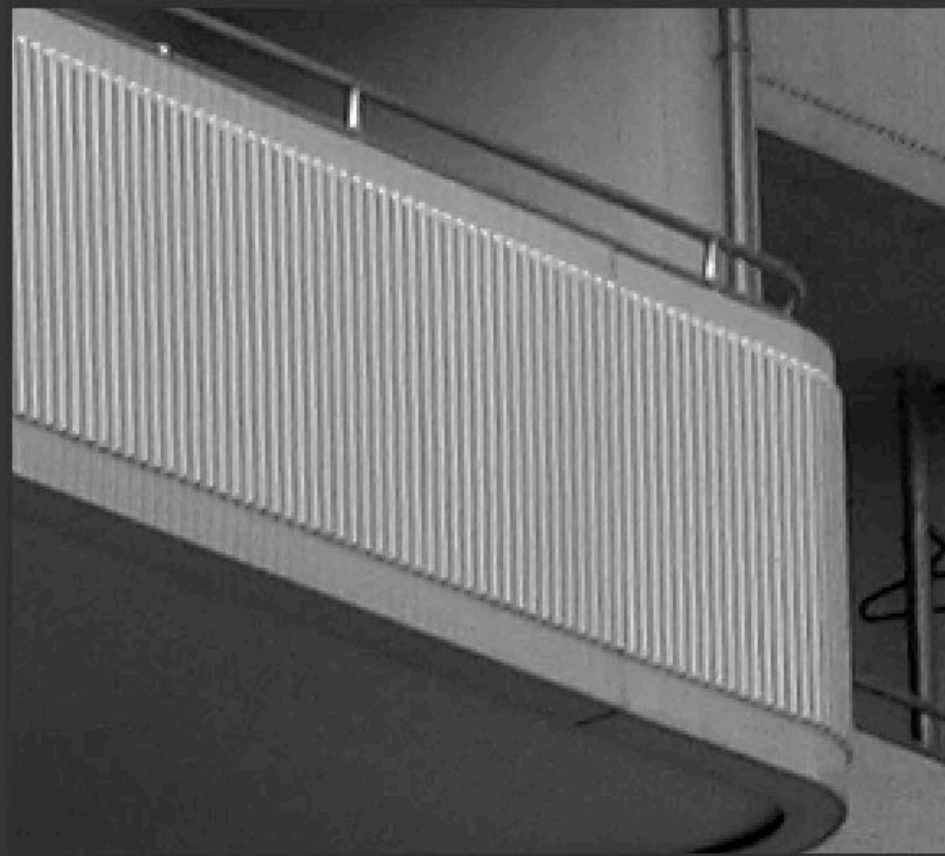
0.6 per λ

Undersampled

Aliasing



Aliasing

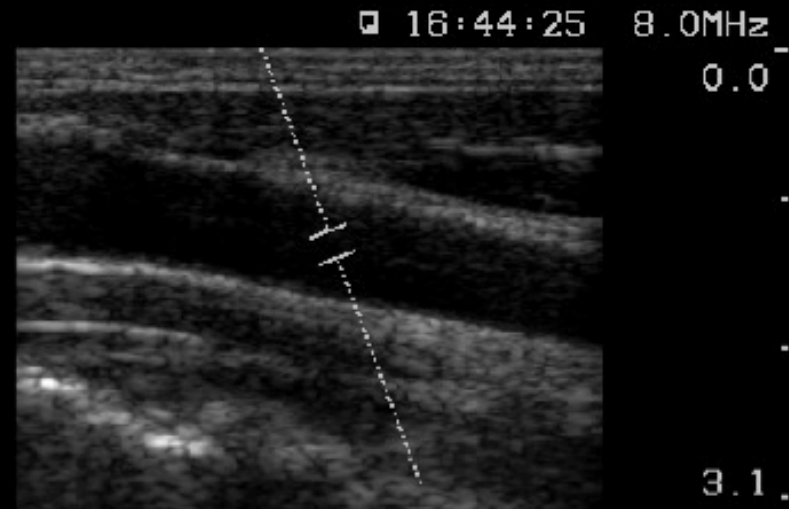


Aliasing

Blood Velocity (cm/s)	$f_T = 2 \text{ MHz}$	$f_T = 5 \text{ MHz}$	$f_T = 7.5 \text{ MHz}$
10	260	650	980
30	780	2000	2900
100	2600	6500	9800
Maximum f_D (Hz) PRF must be at least double (2×) these numbers to avoid aliasing			

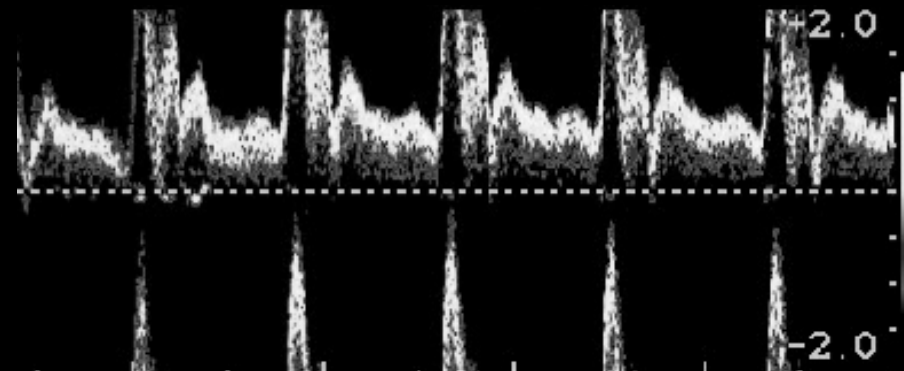
$$f_D = \frac{2v}{c} f_T \cos(\theta_D)$$

Aliasing

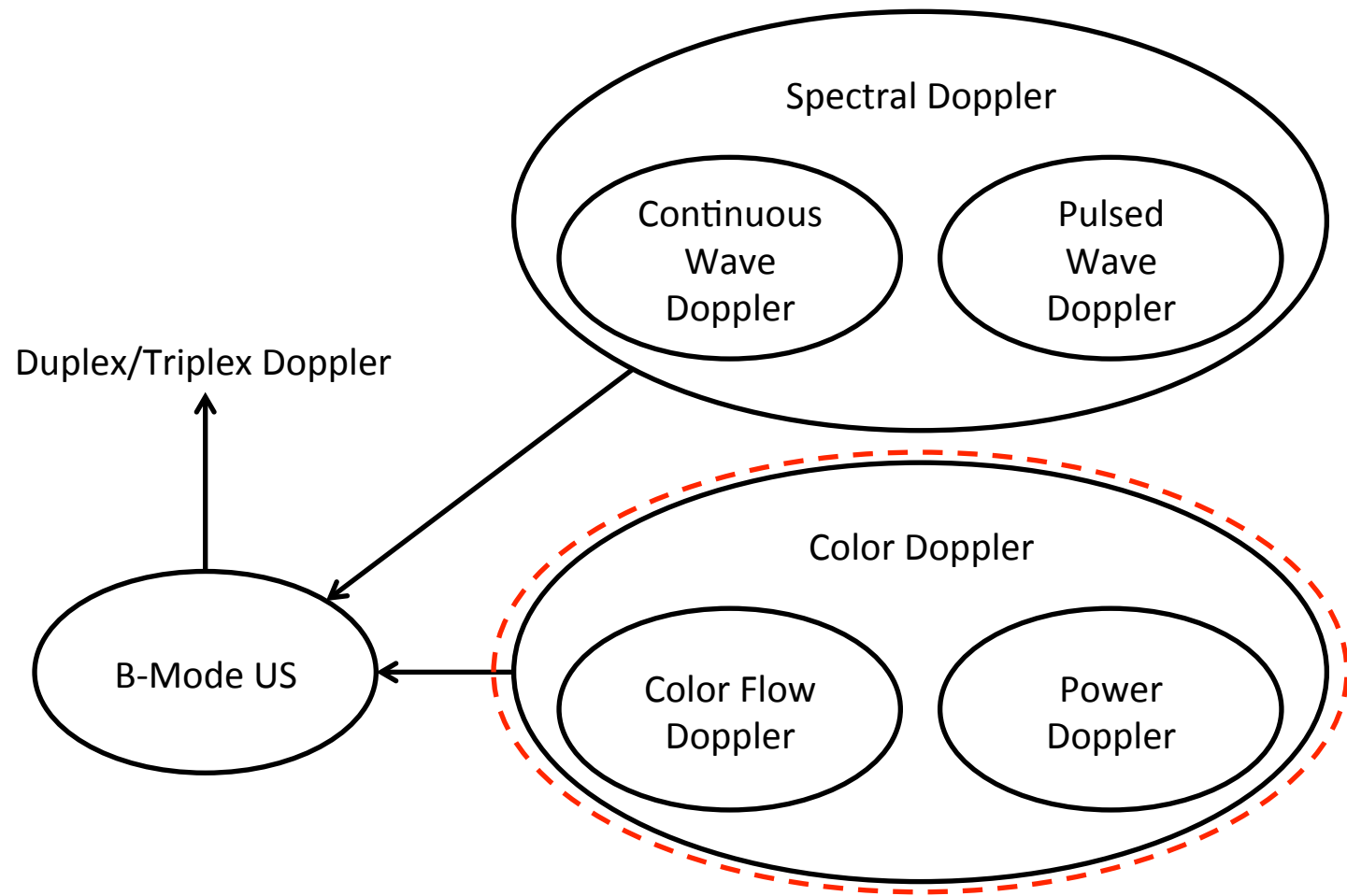


To avoid this artifact:

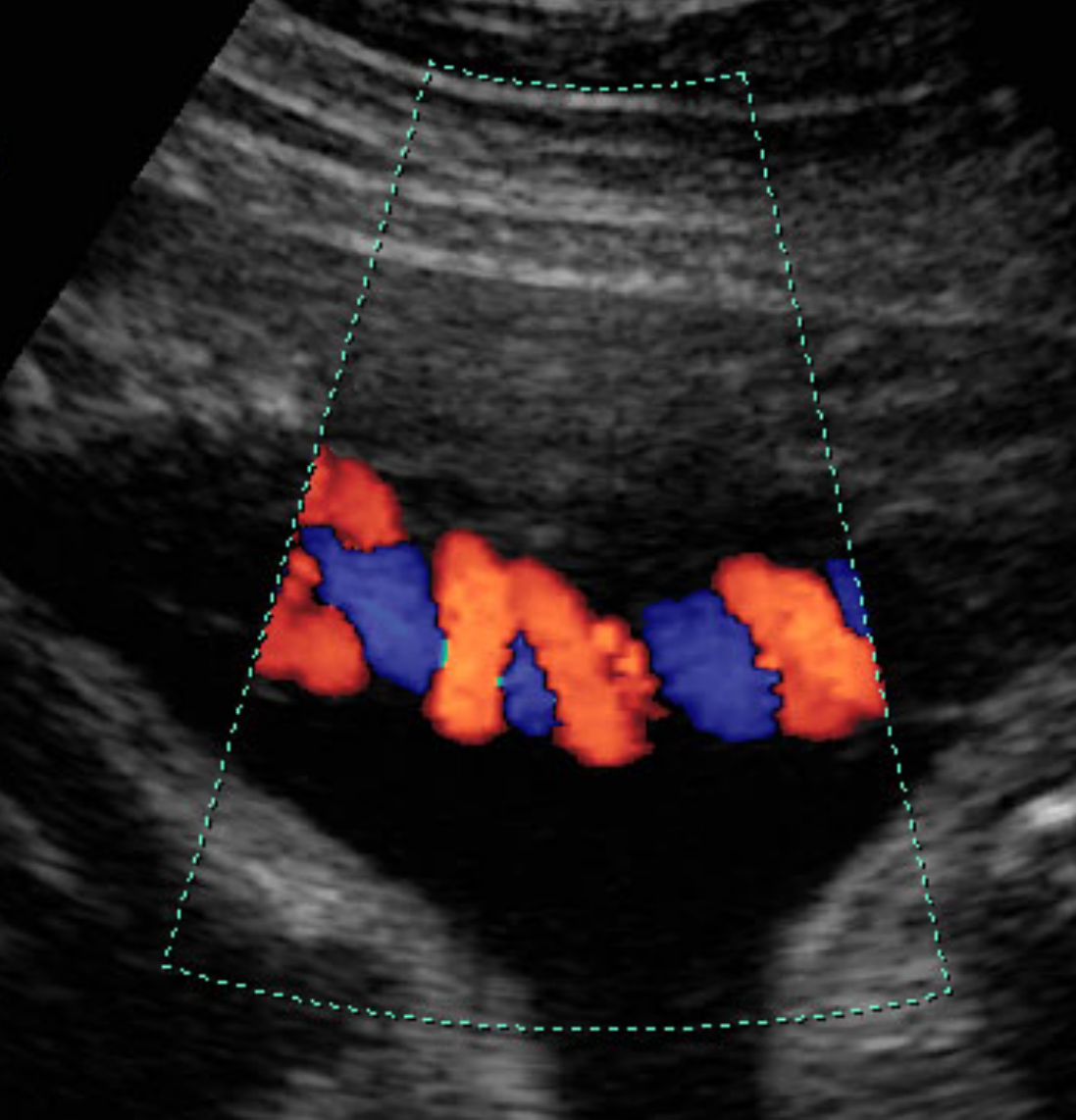
- Image at shallower depth (increase PRF)
- Increase insonifying angle
- Use lower frequency XDCR
- Use continuous wave
- Change the scale
- Change the display baseline



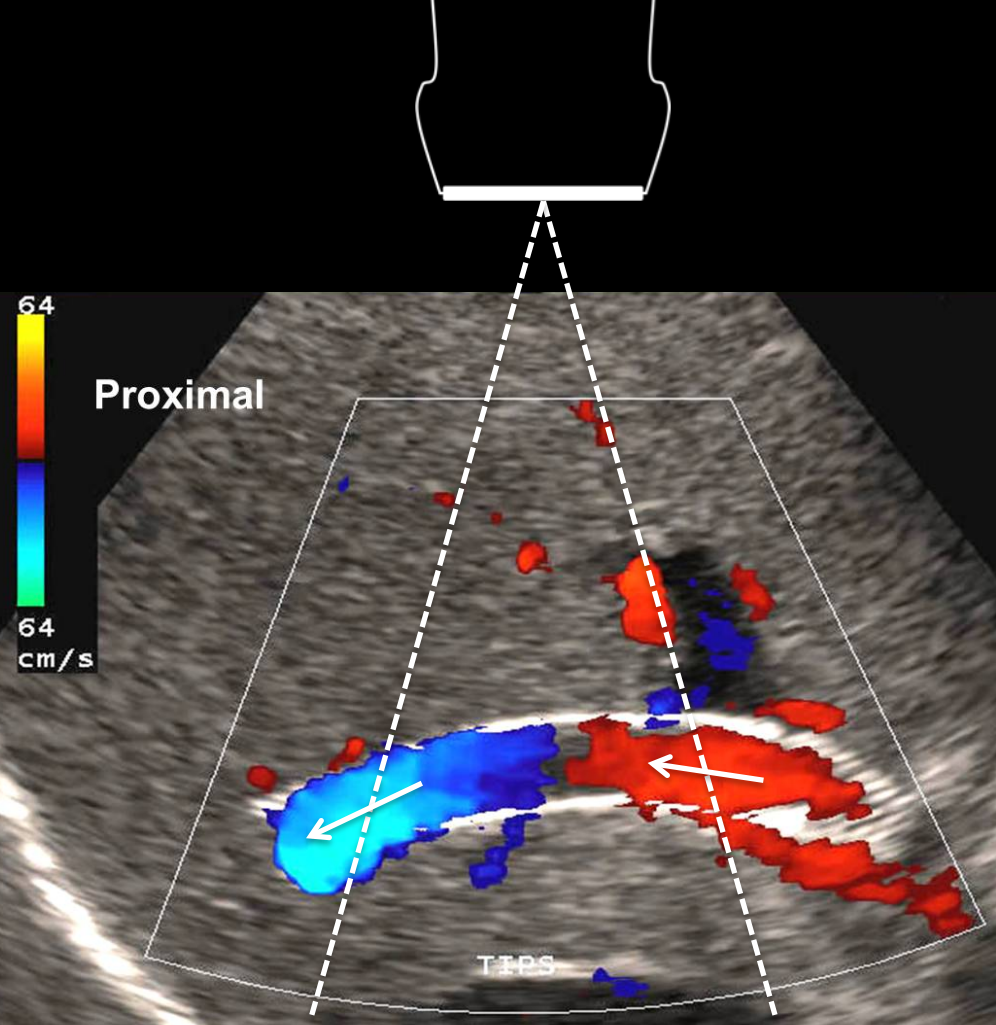
Aliasing



Doppler Ultrasound



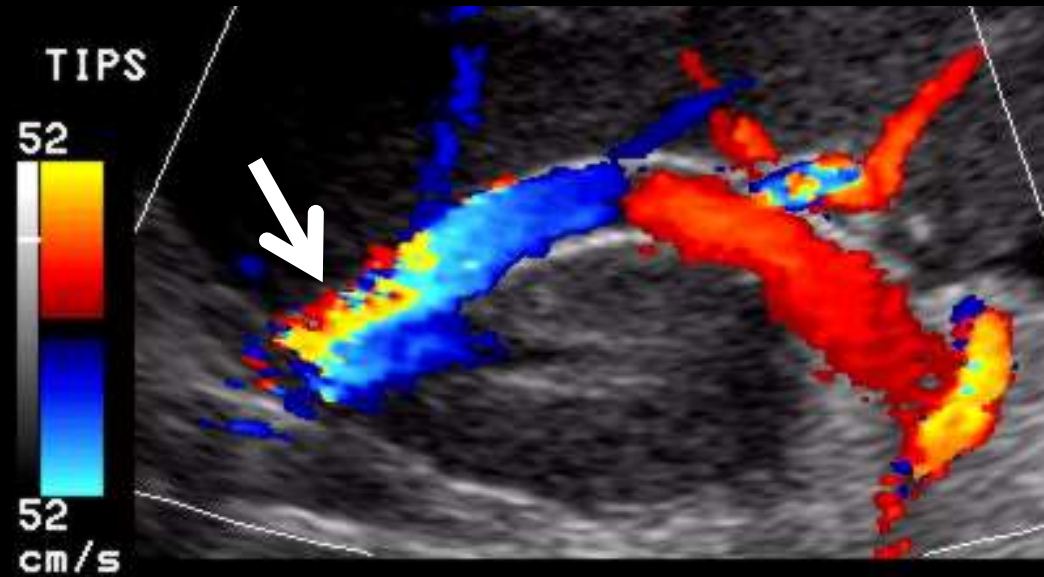
Color Flow Doppler (CFD)



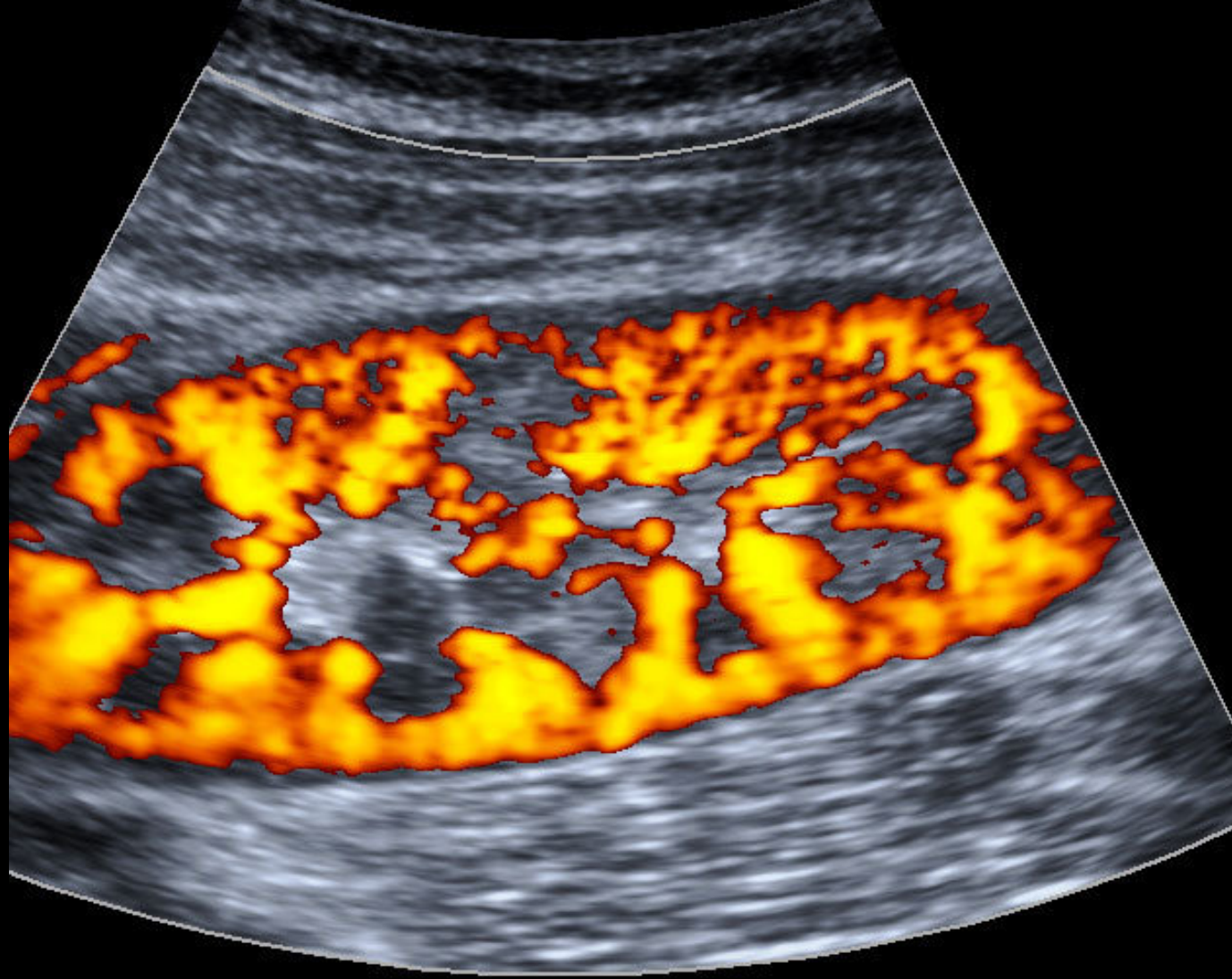
Color Flow Doppler (CFD)

Ways to mitigate aliasing:

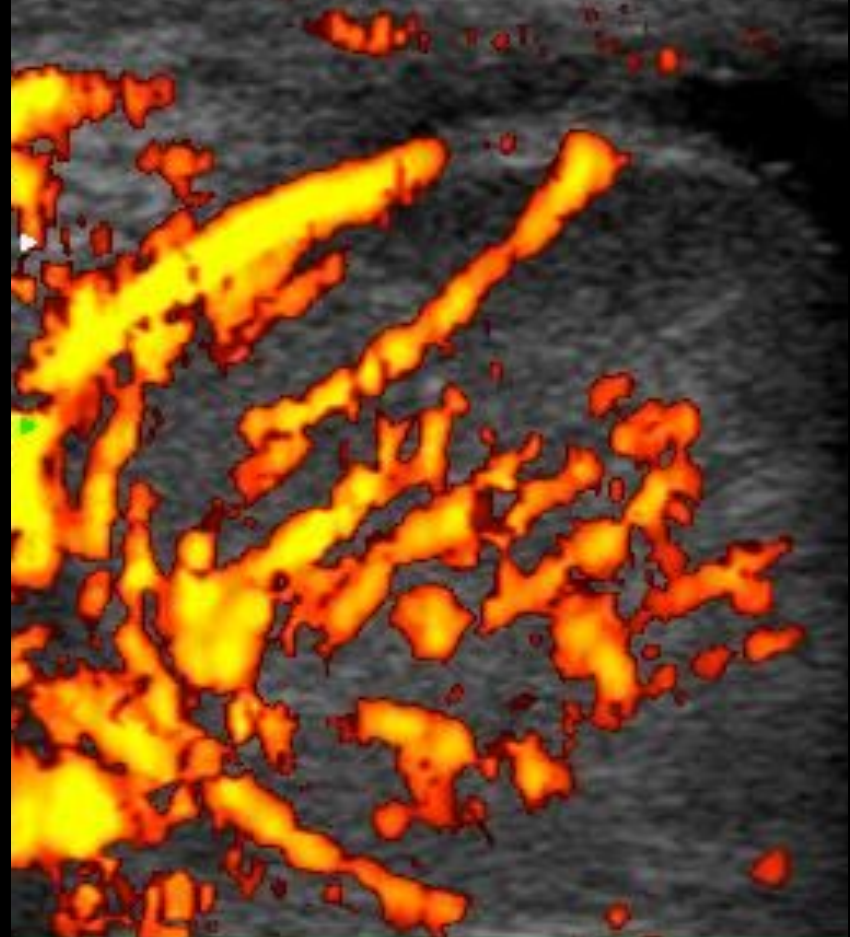
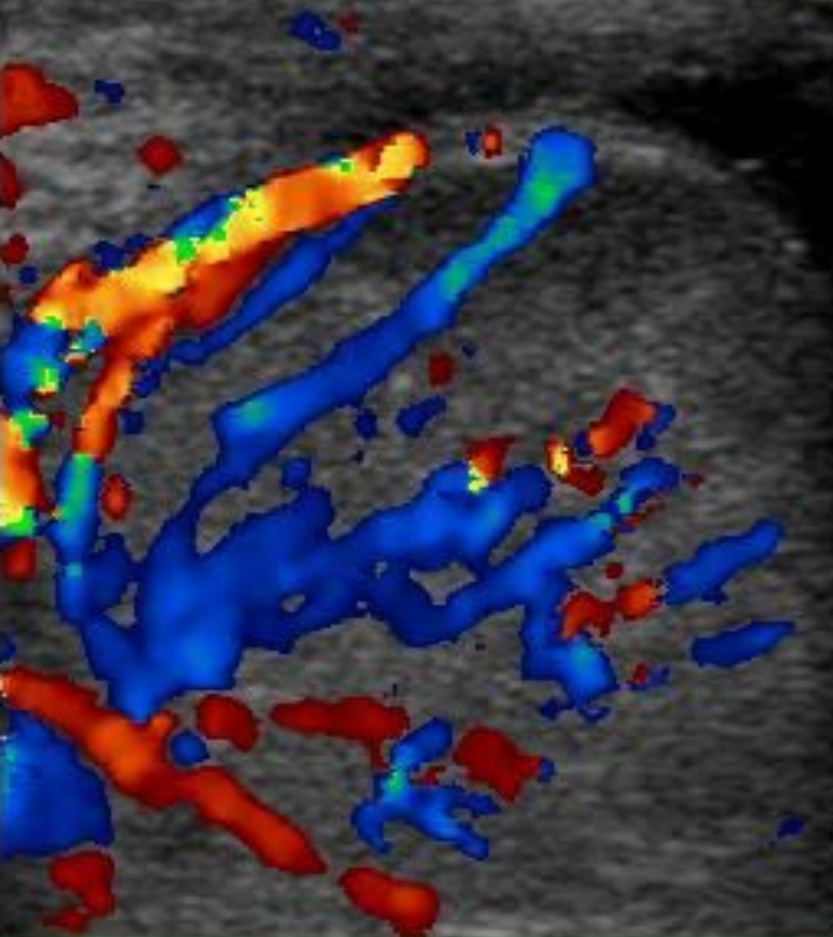
- Image at shallower depth (increase PRF)
- Increase insonifying angle
- Use lower frequency XDCR
- Use continuous wave
- Change the scale
- Change the display baseline



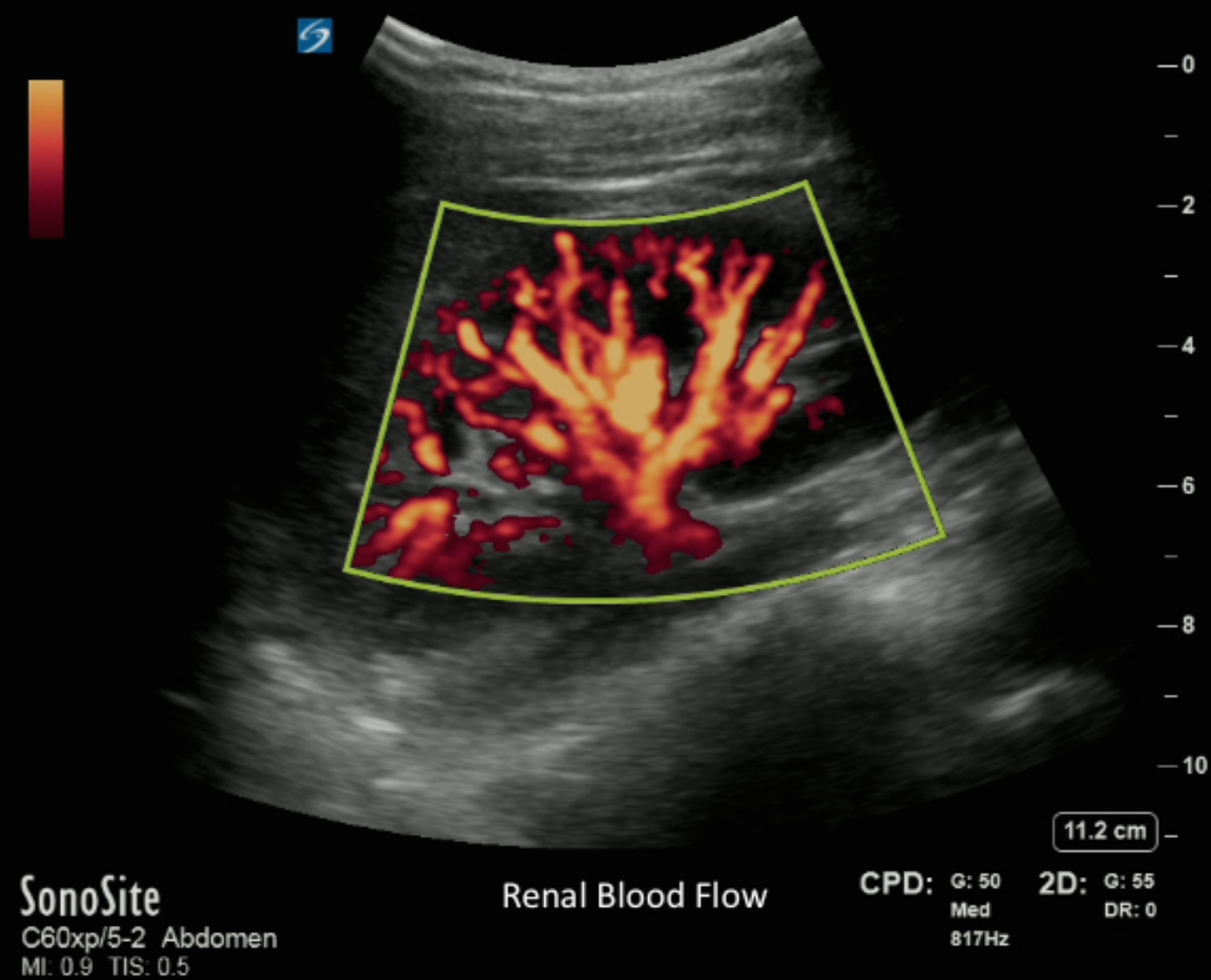
Color Flow Doppler (CFD)



Power Doppler (PD)



Power Doppler (PD)

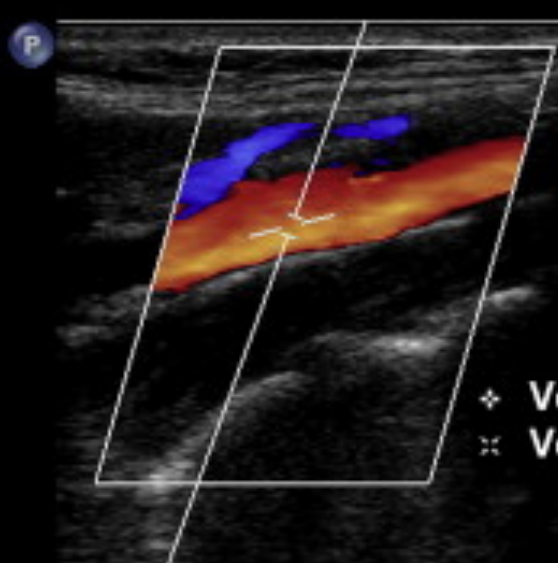


Power Doppler (PD)

FR 21Hz 56°
R1

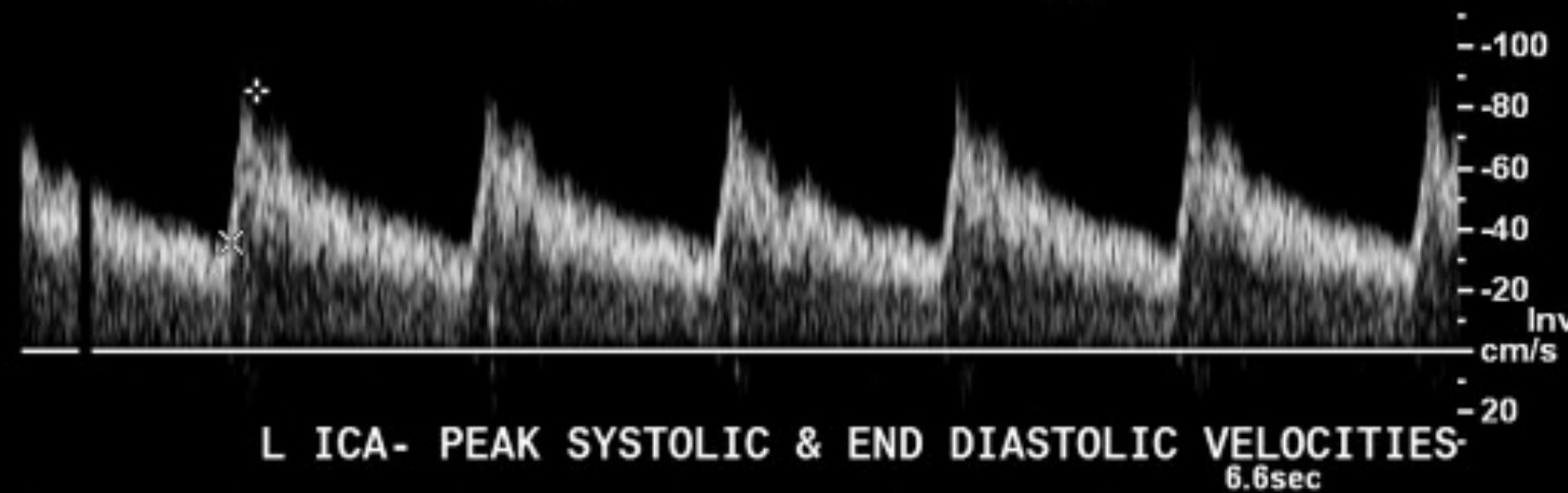
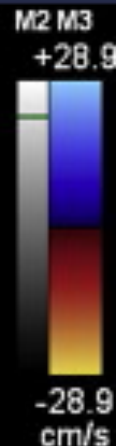
2D
65%
C 50
P Low
Gen
CF
71%
3000Hz
WF 165Hz
Med

L ICA

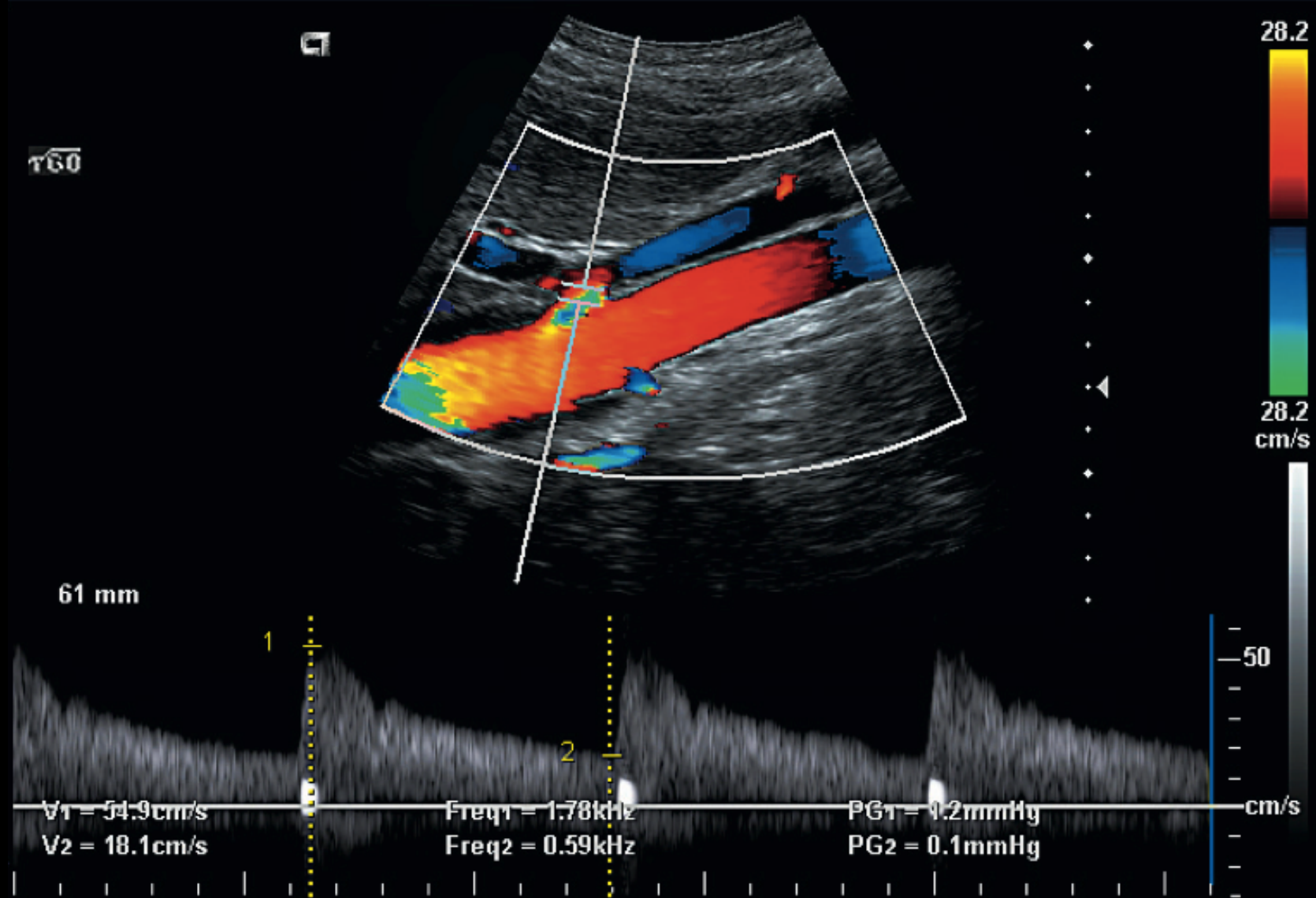


✦ Vel -85.5 cm/s
✧ Vel -35.6 cm/s

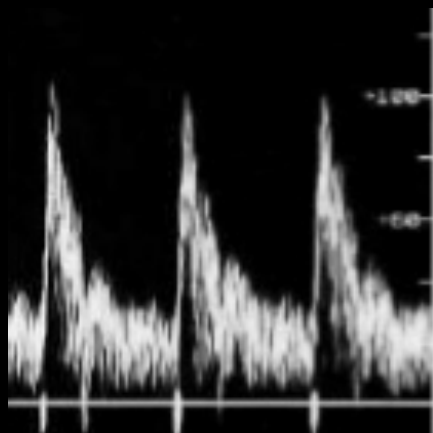
PW
50%
WF 50Hz
SV 1.5mm
M2
3.5MHz
1.6cm



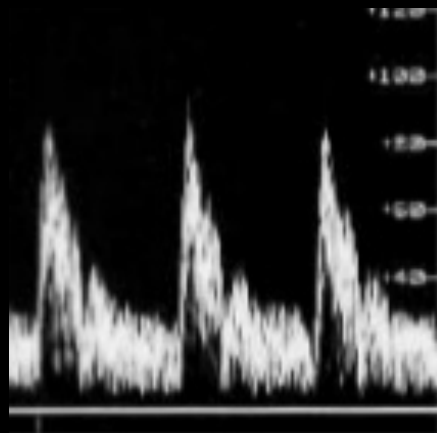
Triplex Scanning



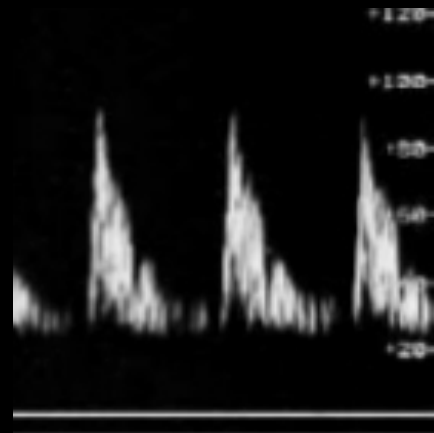
Triplex Scanning



WF 50Hz

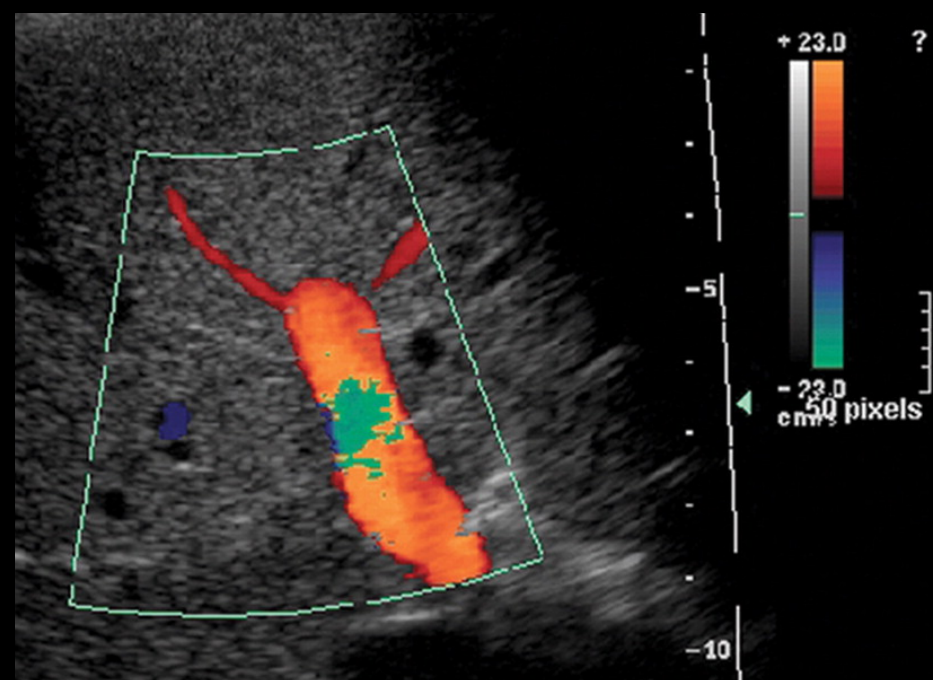
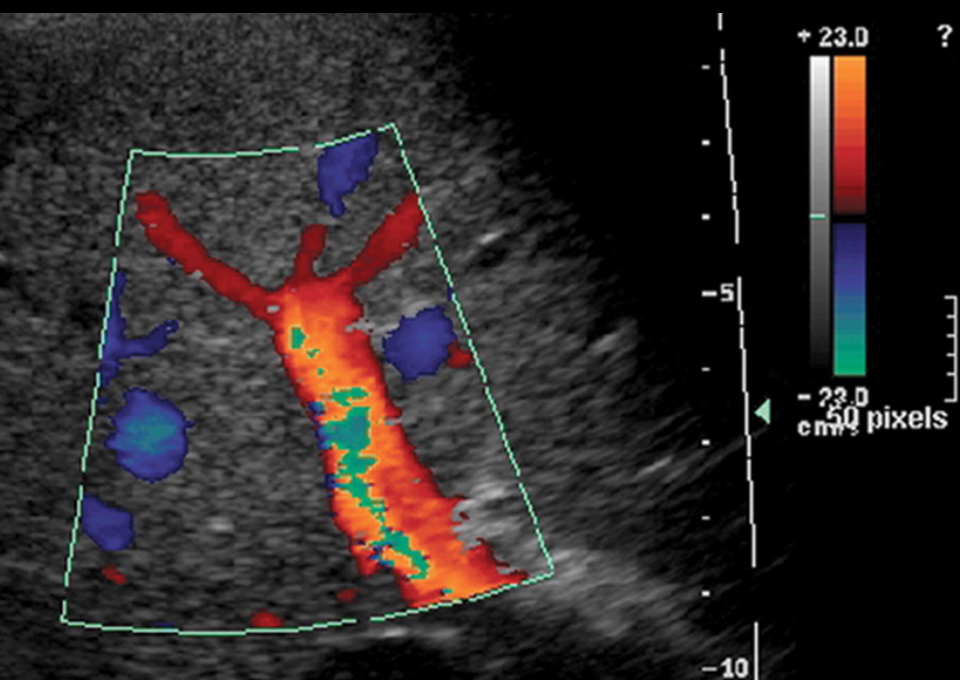


WF 75Hz

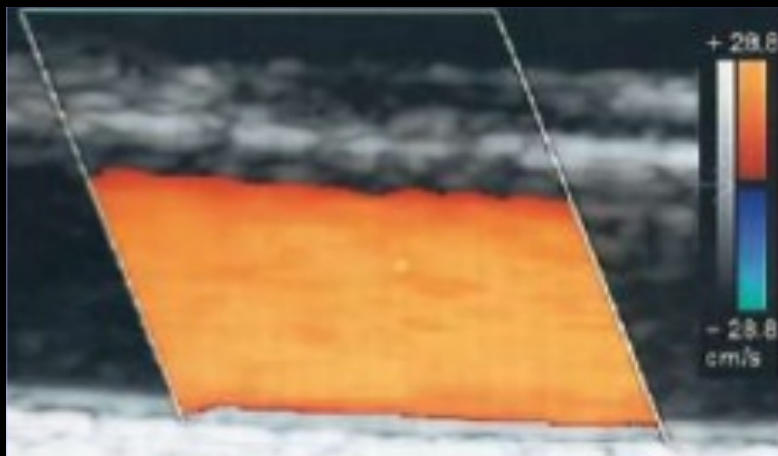
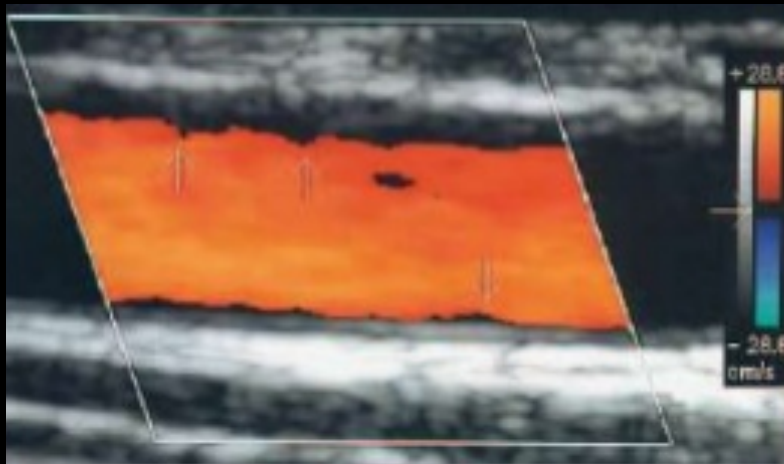


WF 550Hz

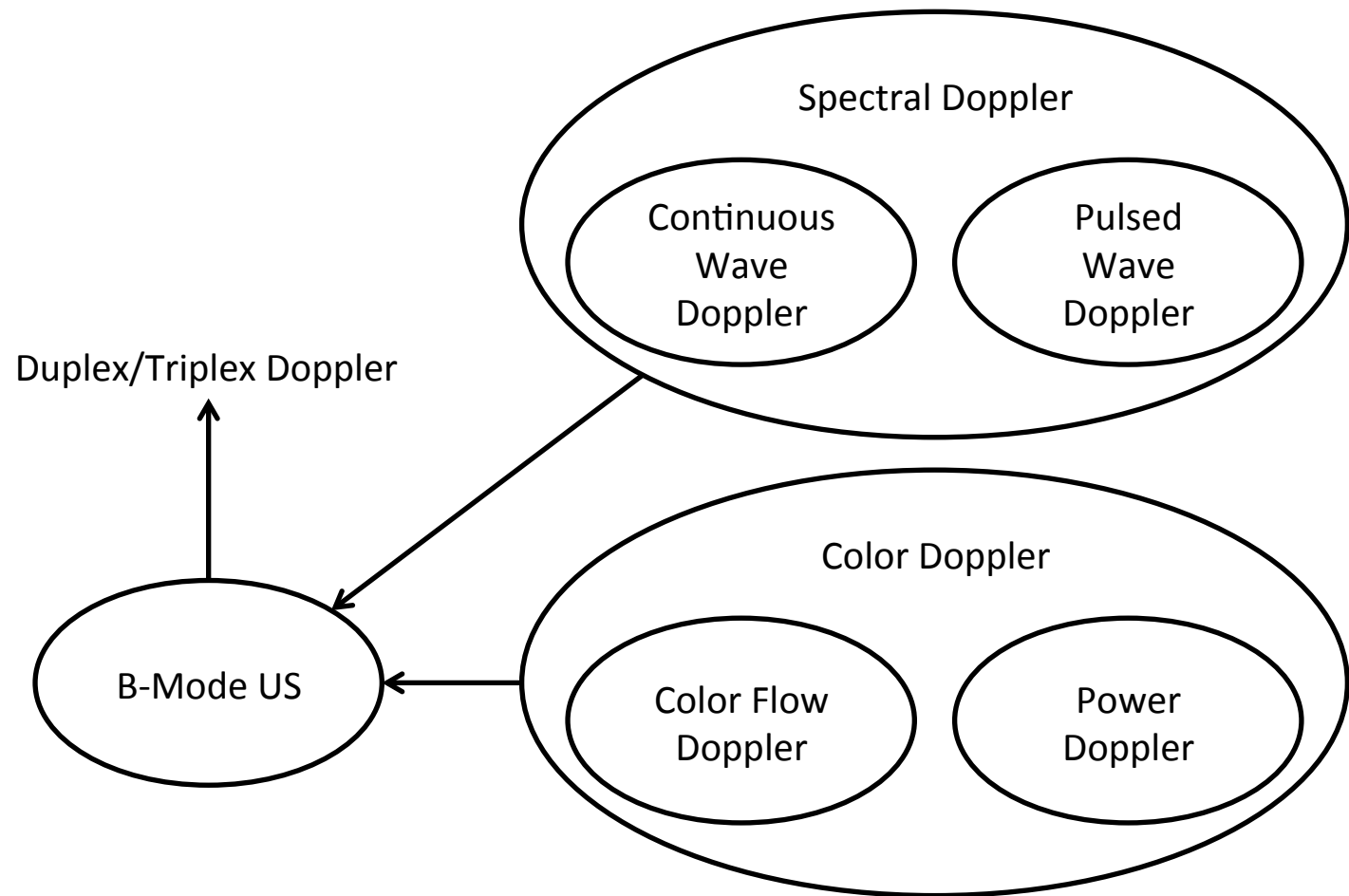
Wall (High Pass) Filter



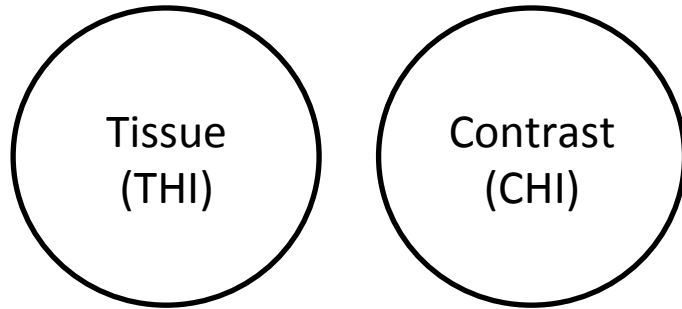
Wall (High Pass) Filter



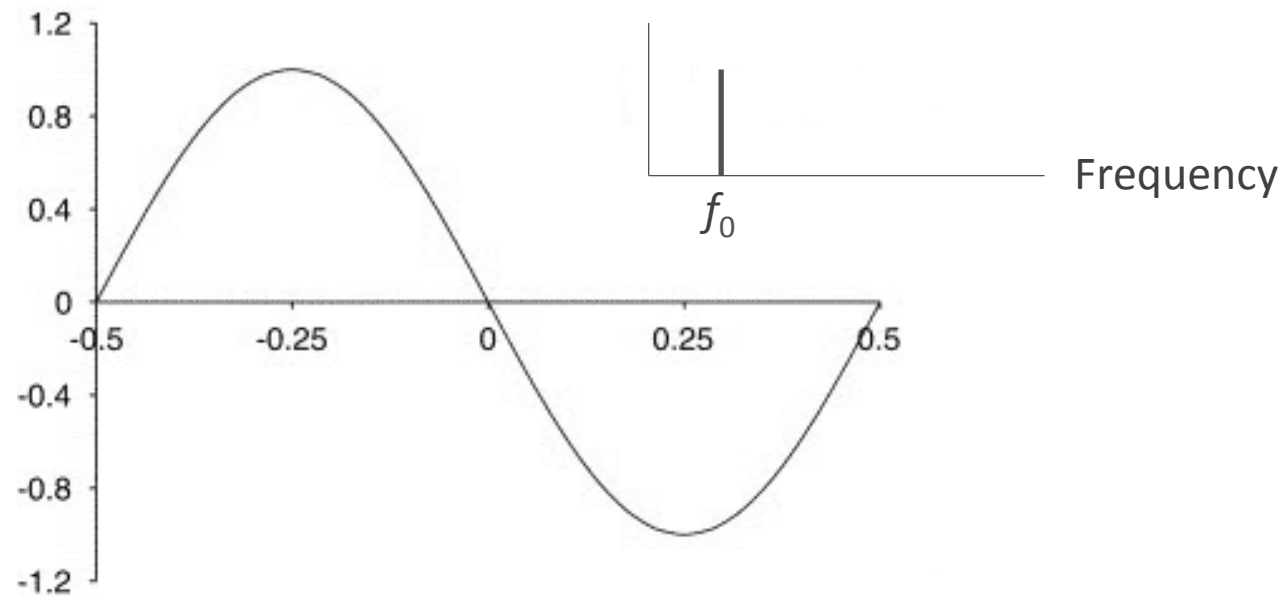
Wall (High Pass) Filter



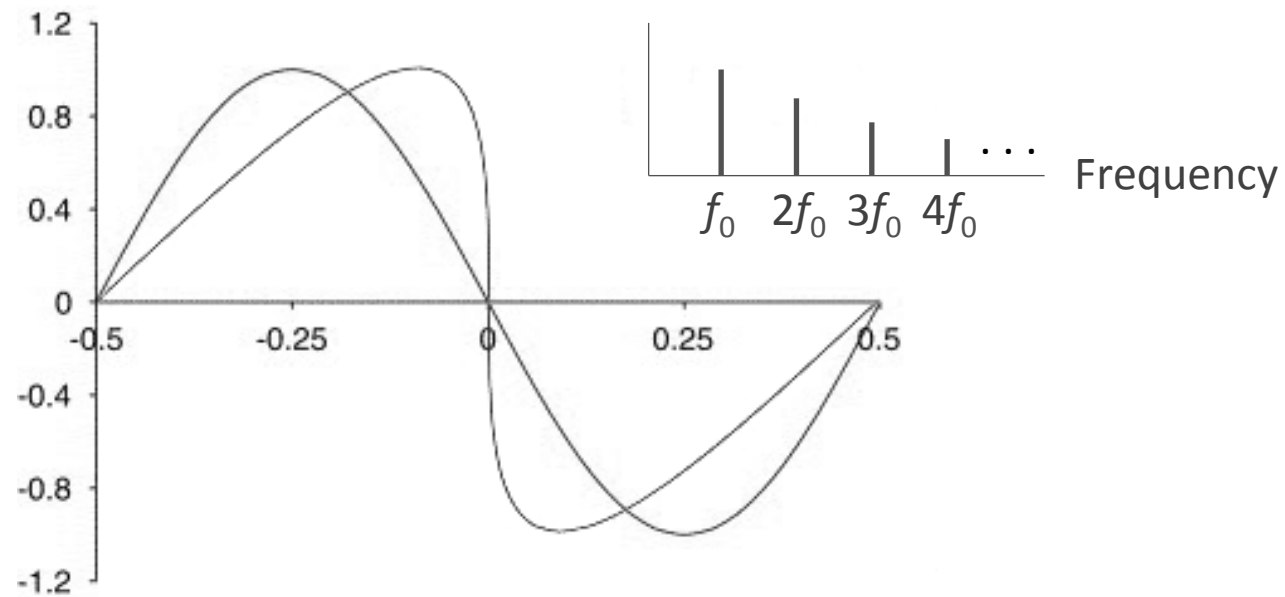
Doppler Ultrasound



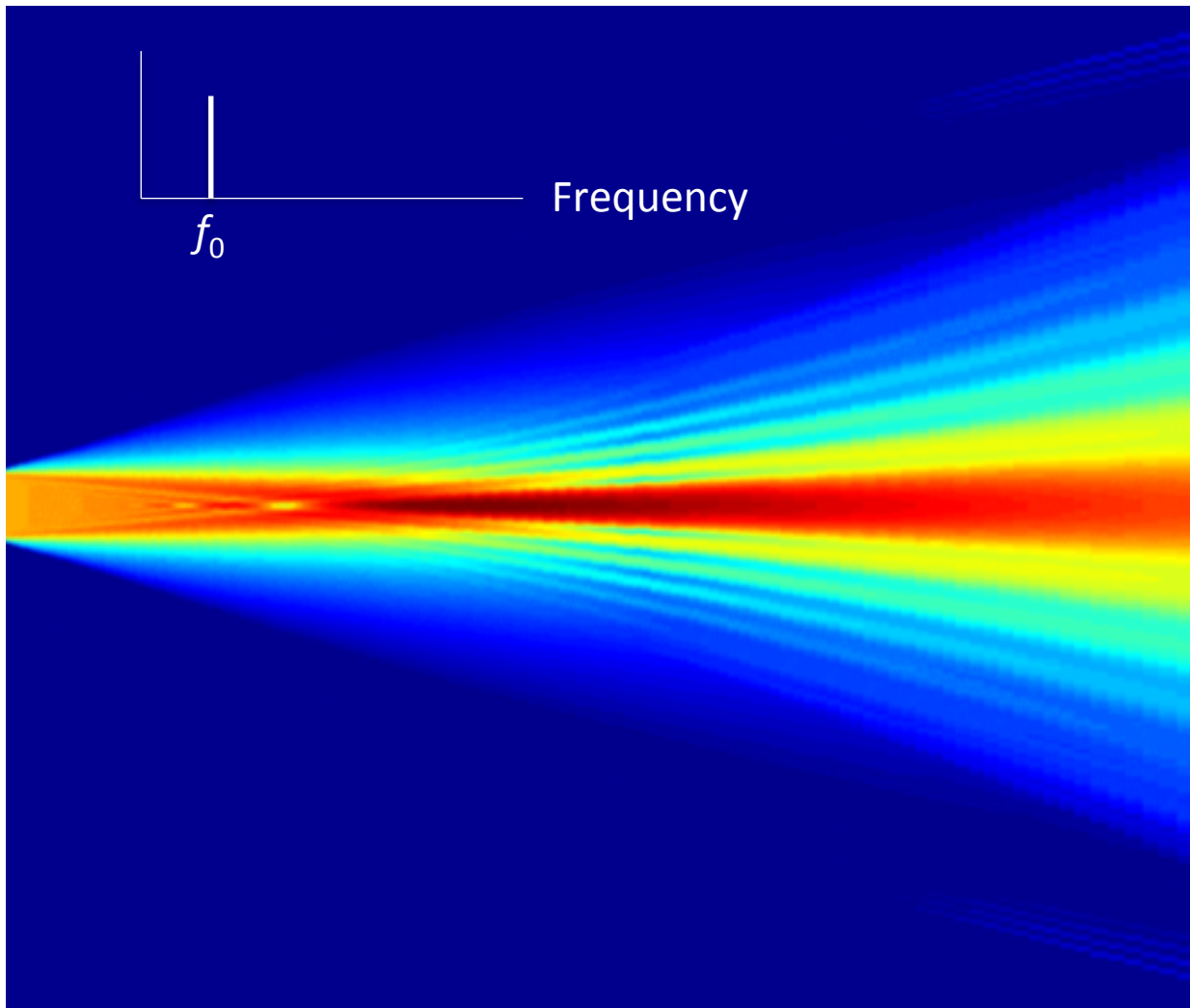
Harmonic Imaging



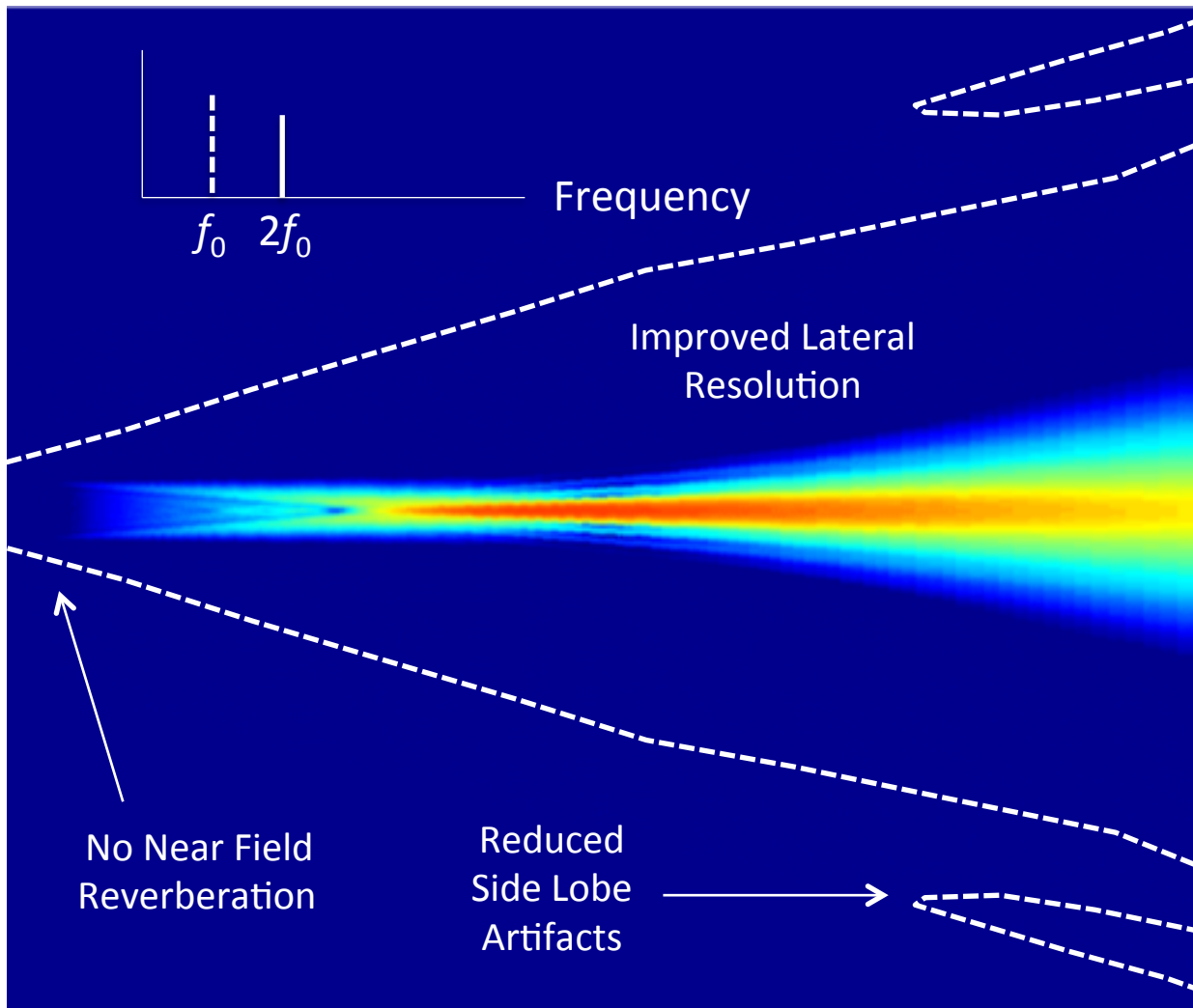
Tissue Harmonic Imaging (THI)



Tissue Harmonic Imaging (THI)



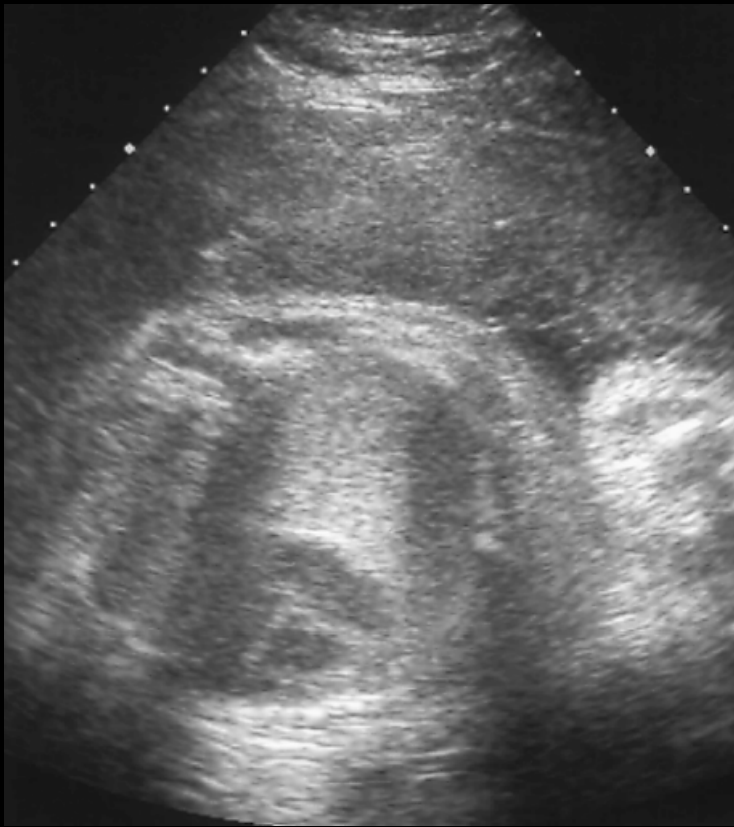
Tissue Harmonic Imaging (THI)



Tissue Harmonic Imaging (THI)

Conventional

THI

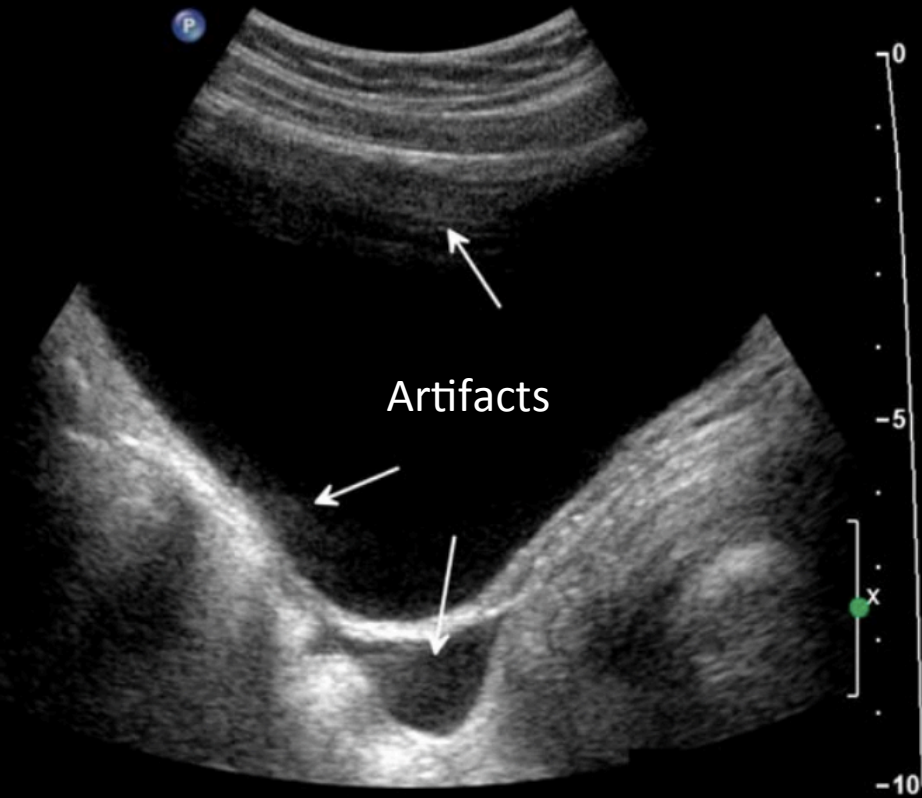


4 MHz/4 MHz

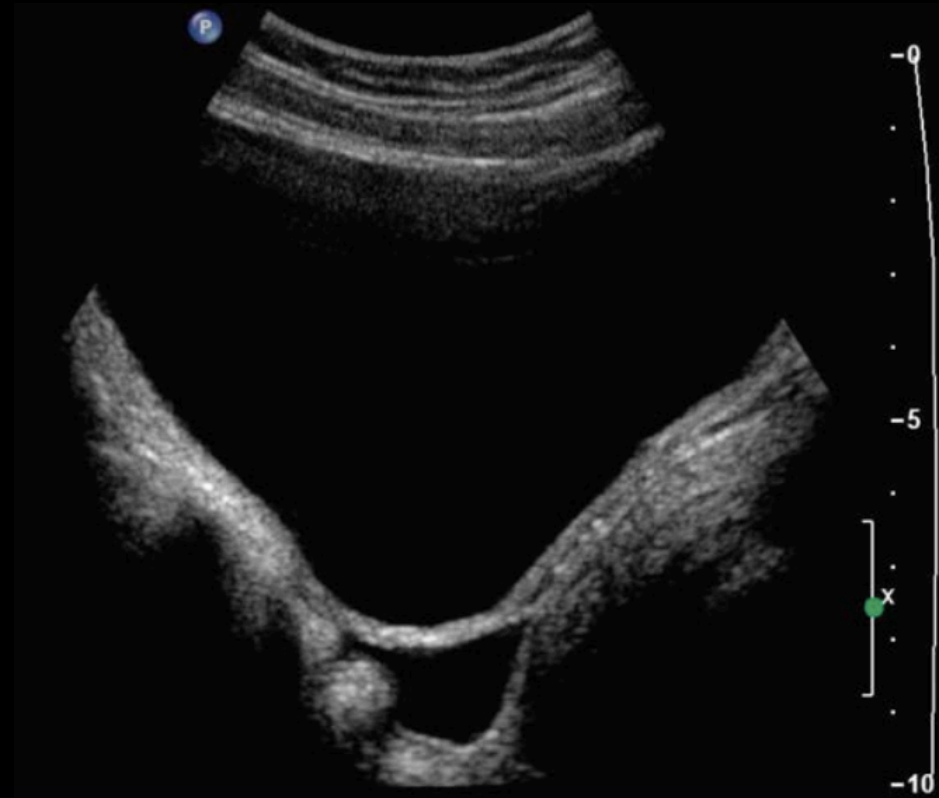
2MHz/4 MHz

Tissue Harmonic Imaging (THI)

Conventional

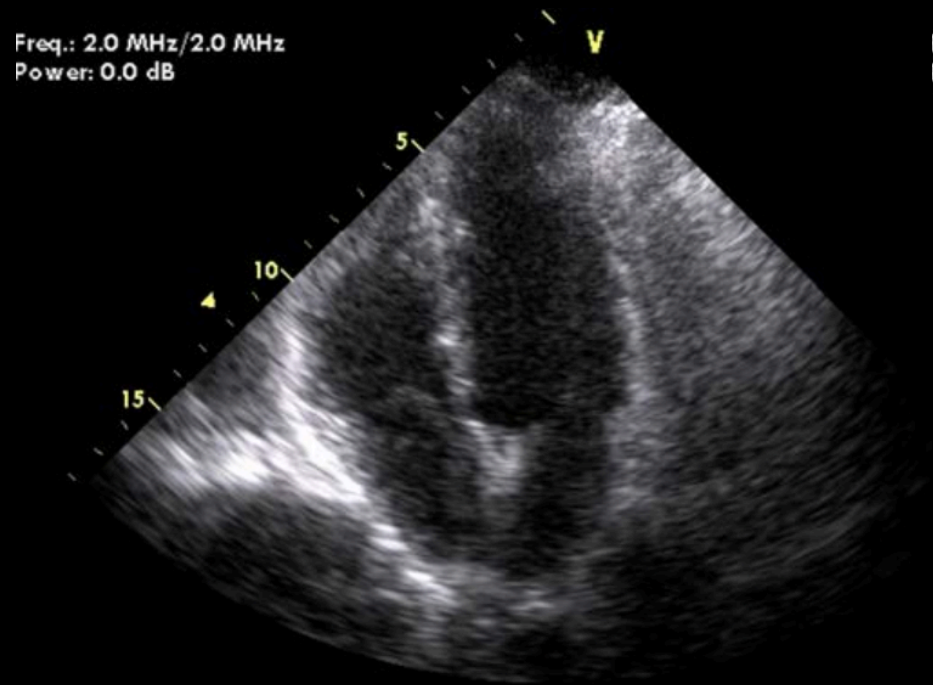


THI

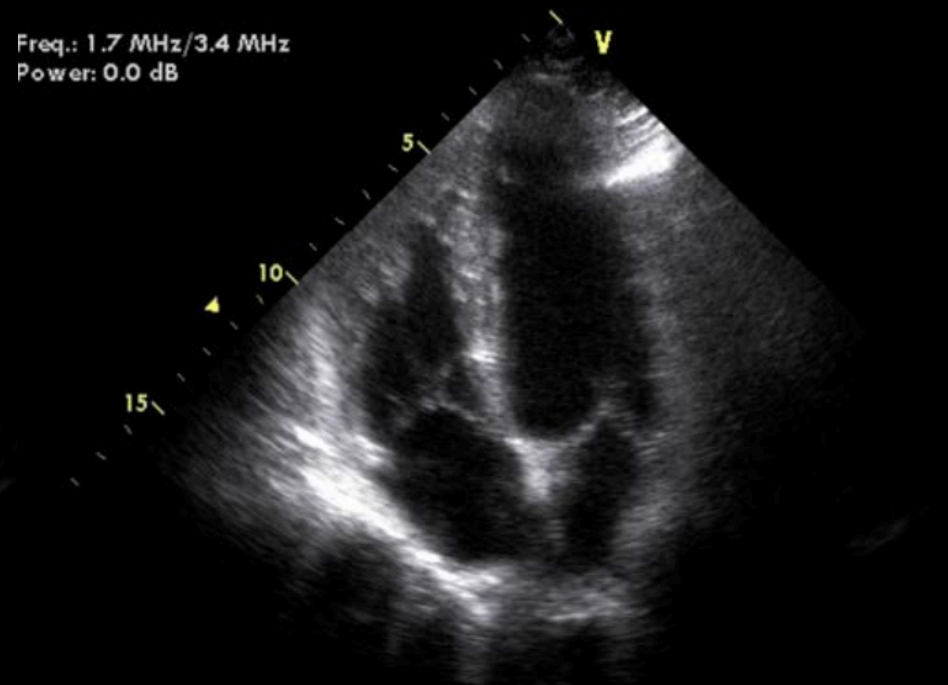


Tissue Harmonic Imaging (THI)

Conventional

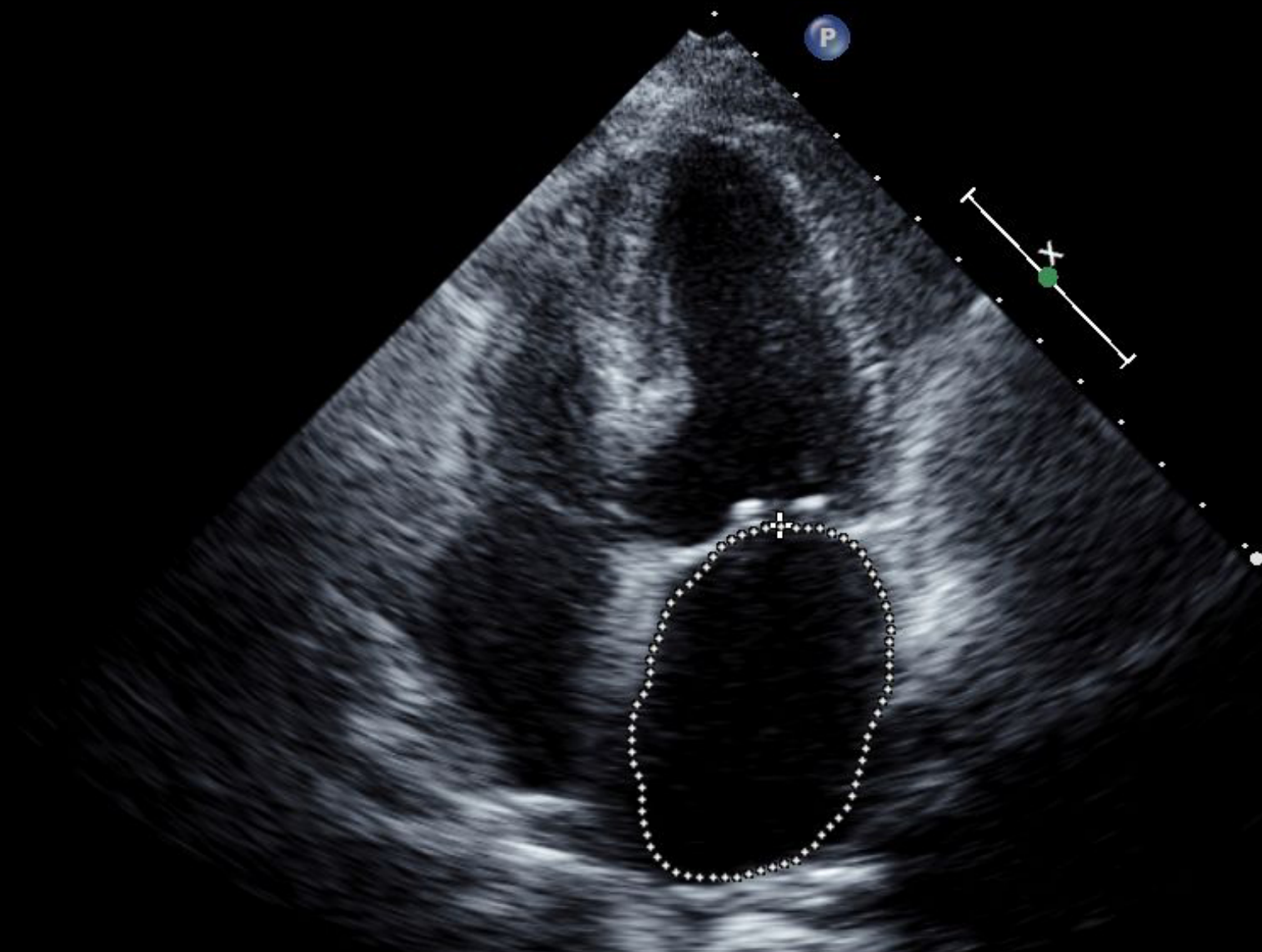


THI



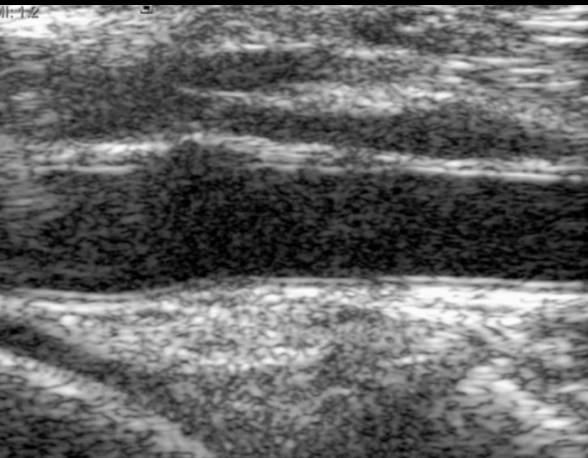
Tissue Harmonic Imaging (THI)

2D
63%
K 50
M Niedrig
HAllg

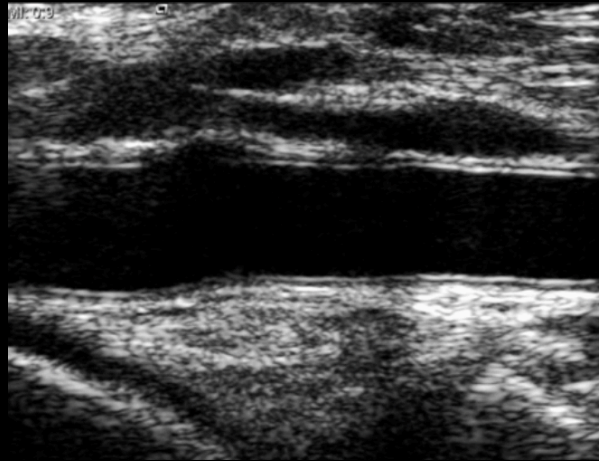


Tissue Harmonic Imaging (THI)

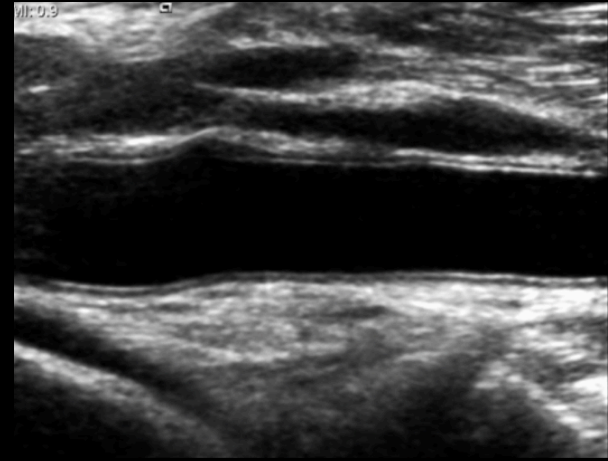
Conventional



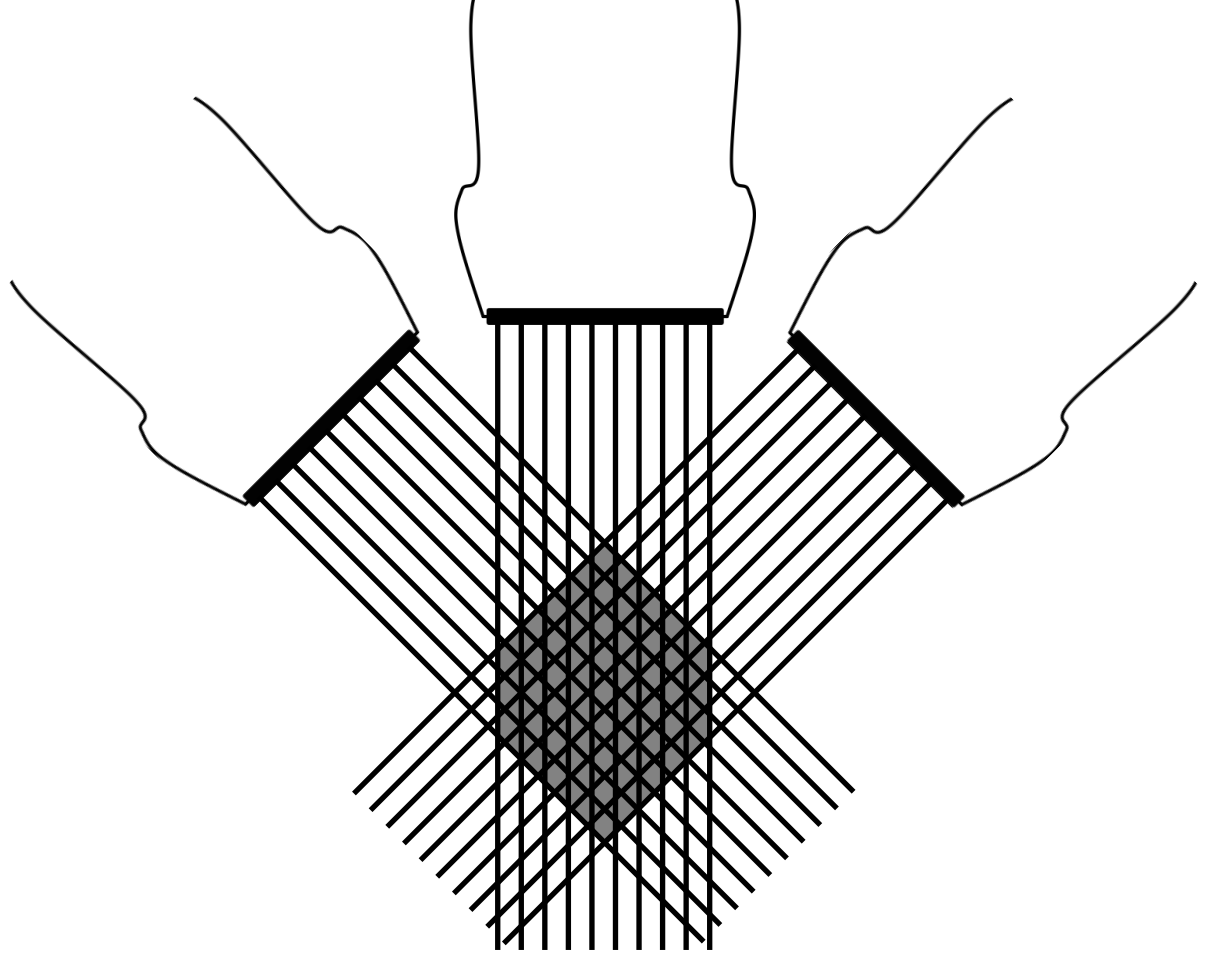
THI



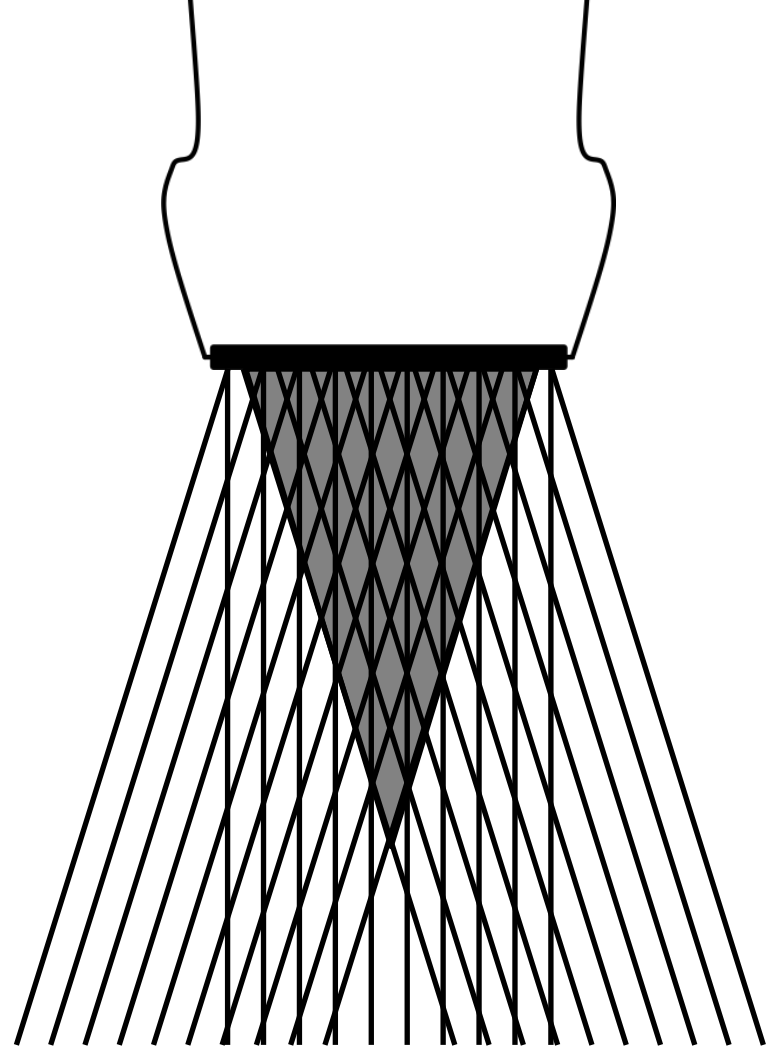
THI + Compound Imaging



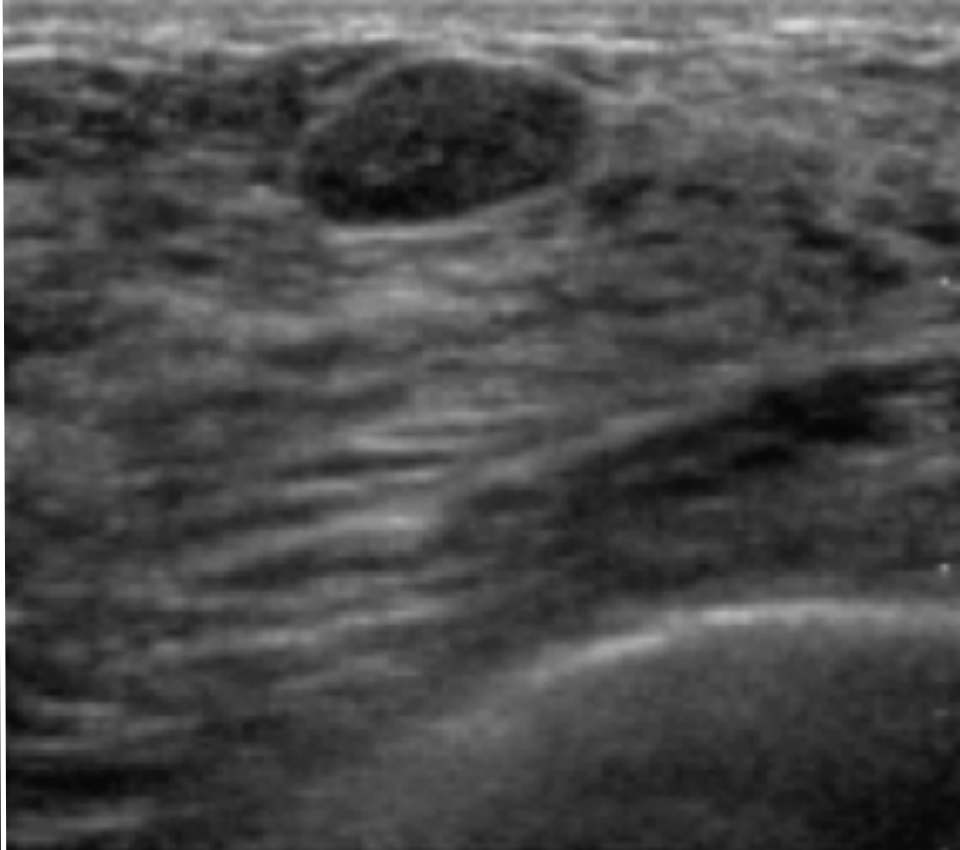
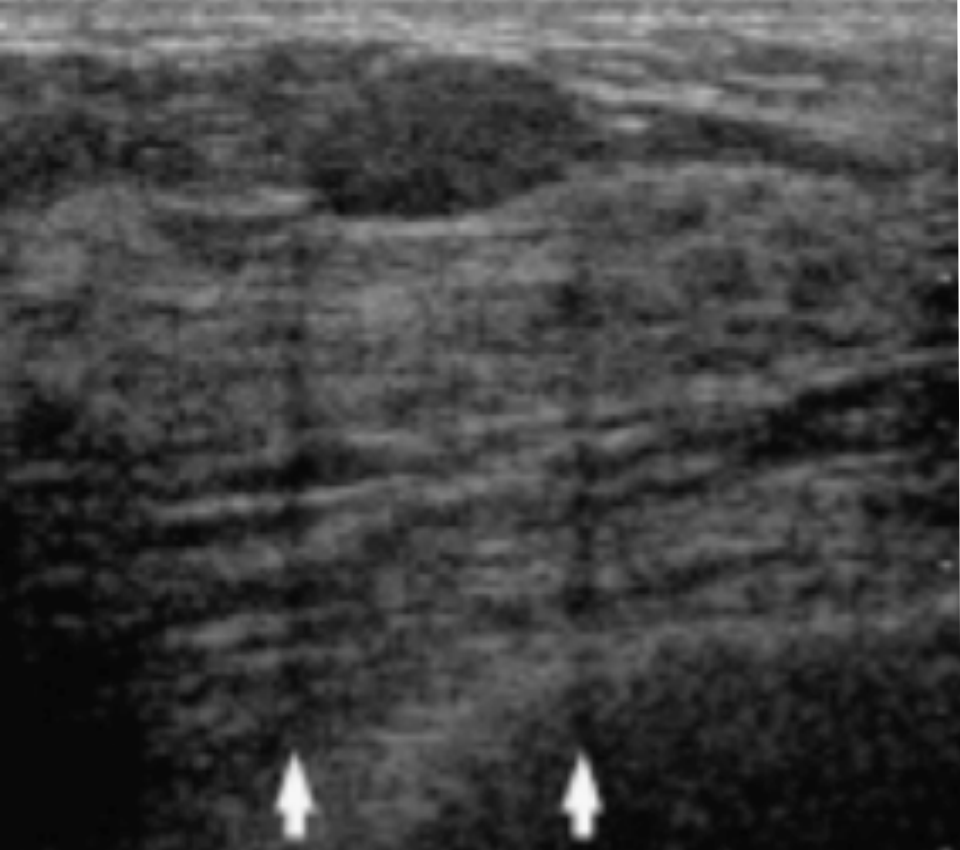
Tissue Harmonic Imaging (THI)



Spatial Compounding

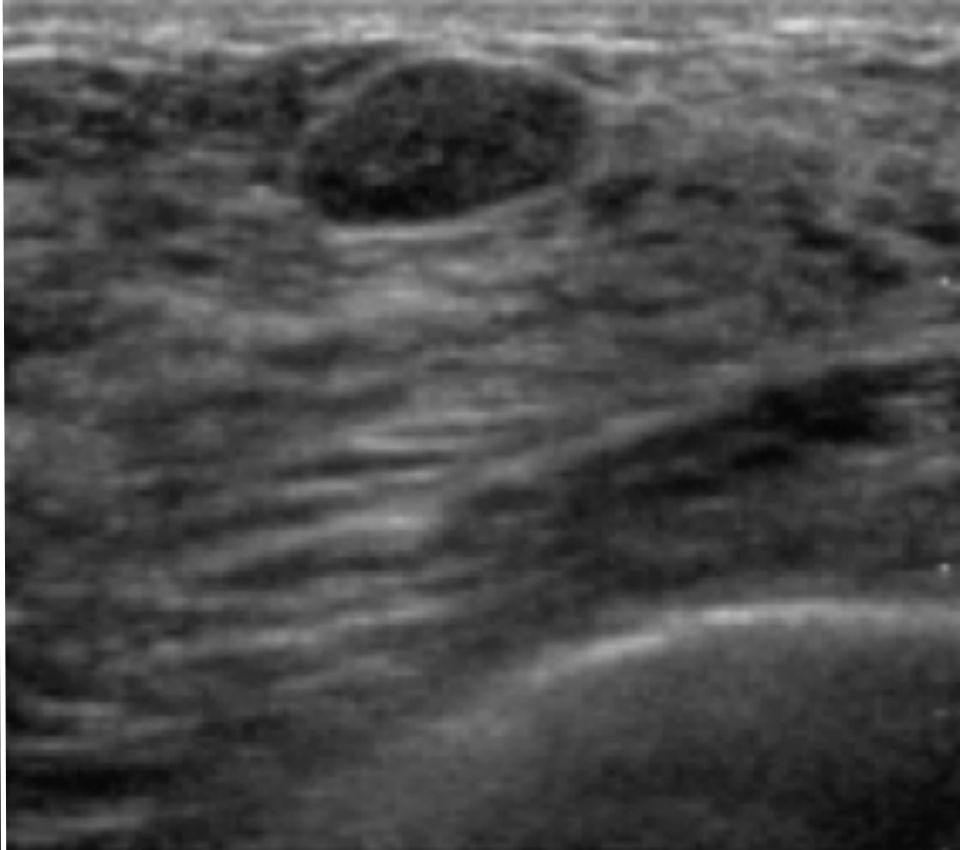
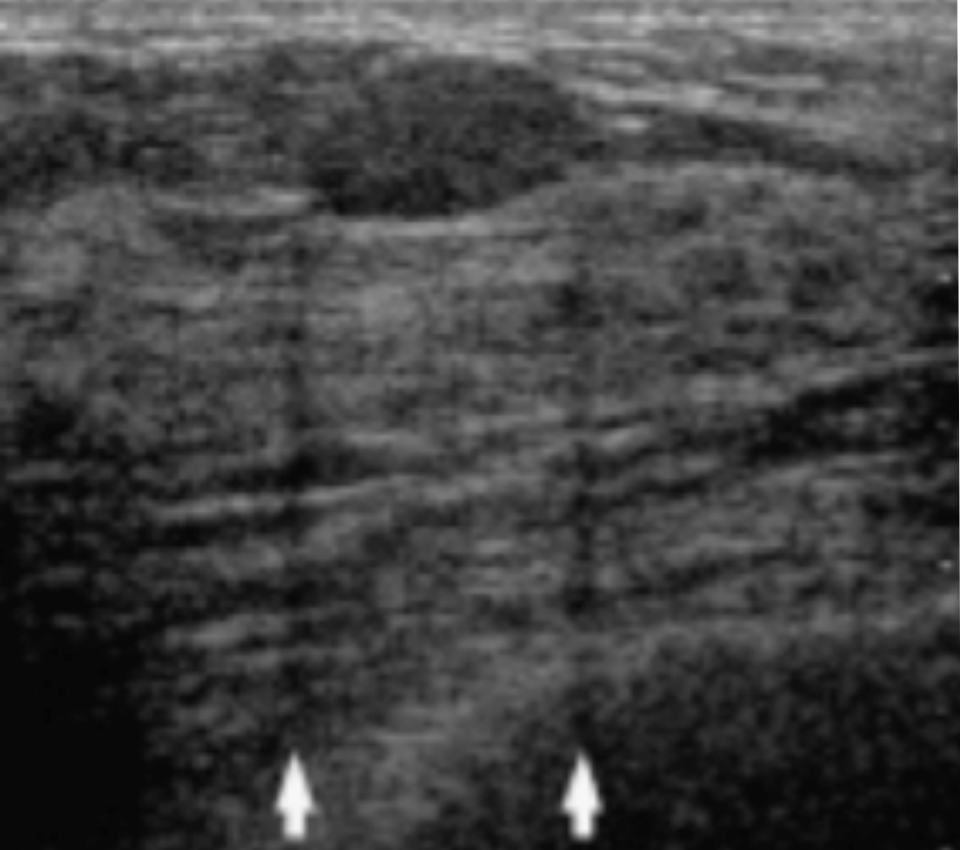


Spatial Compounding



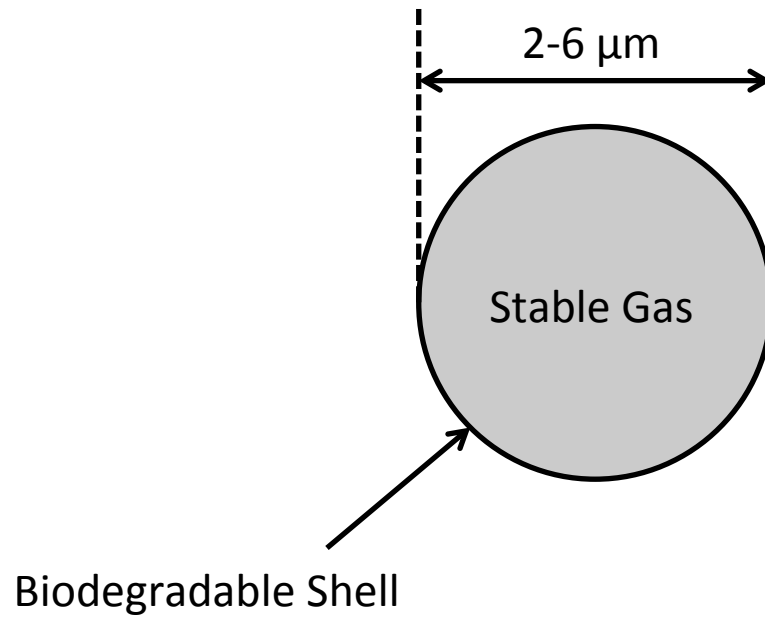
- + Better SNR
- + Higher echo amplitudes
- + Continuous curved surfaces
- + Speckle reduction

Spatial Compounding

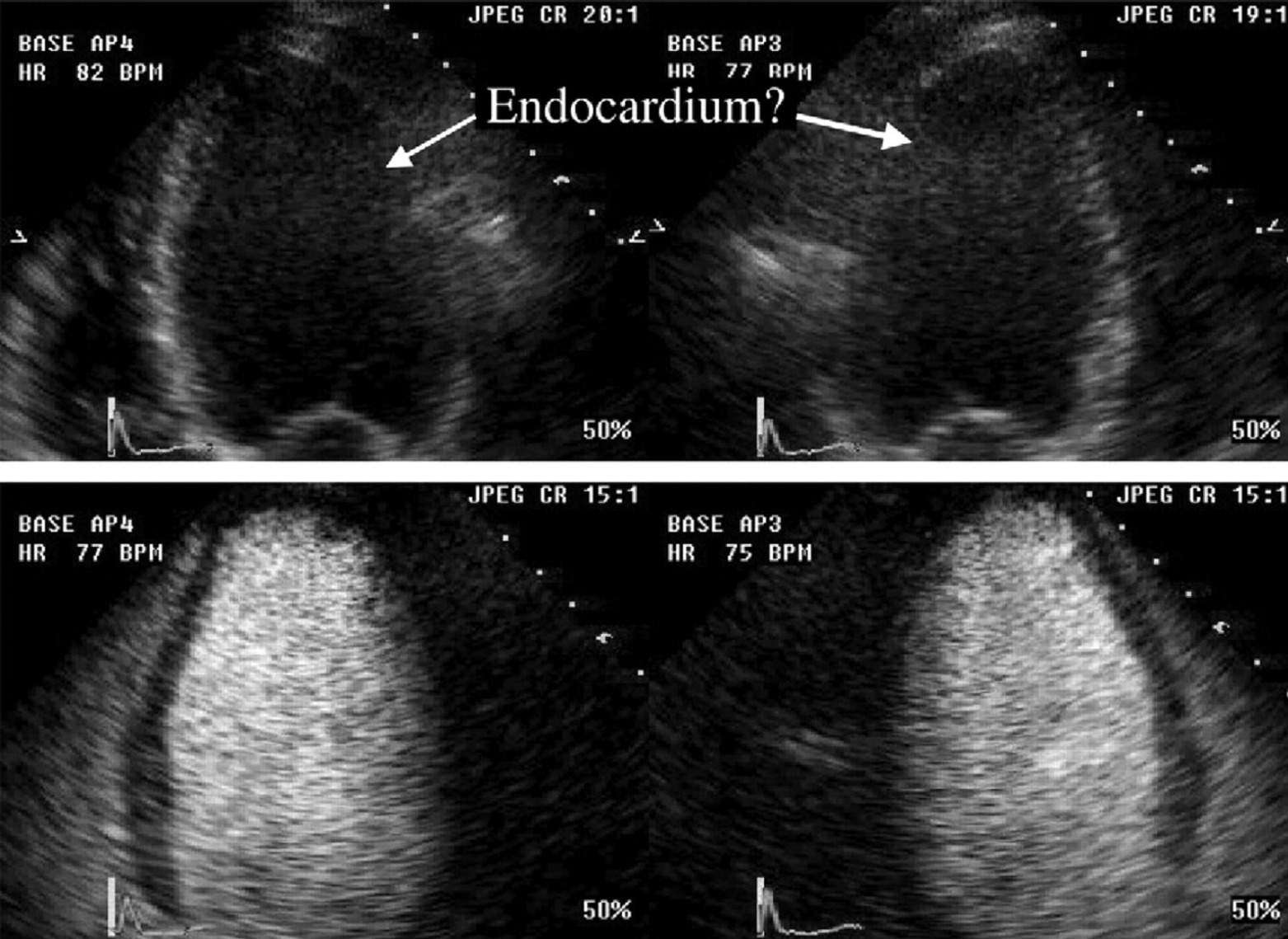


- Persistence from averaging
- Temporal resolution loss
- Motion blurring

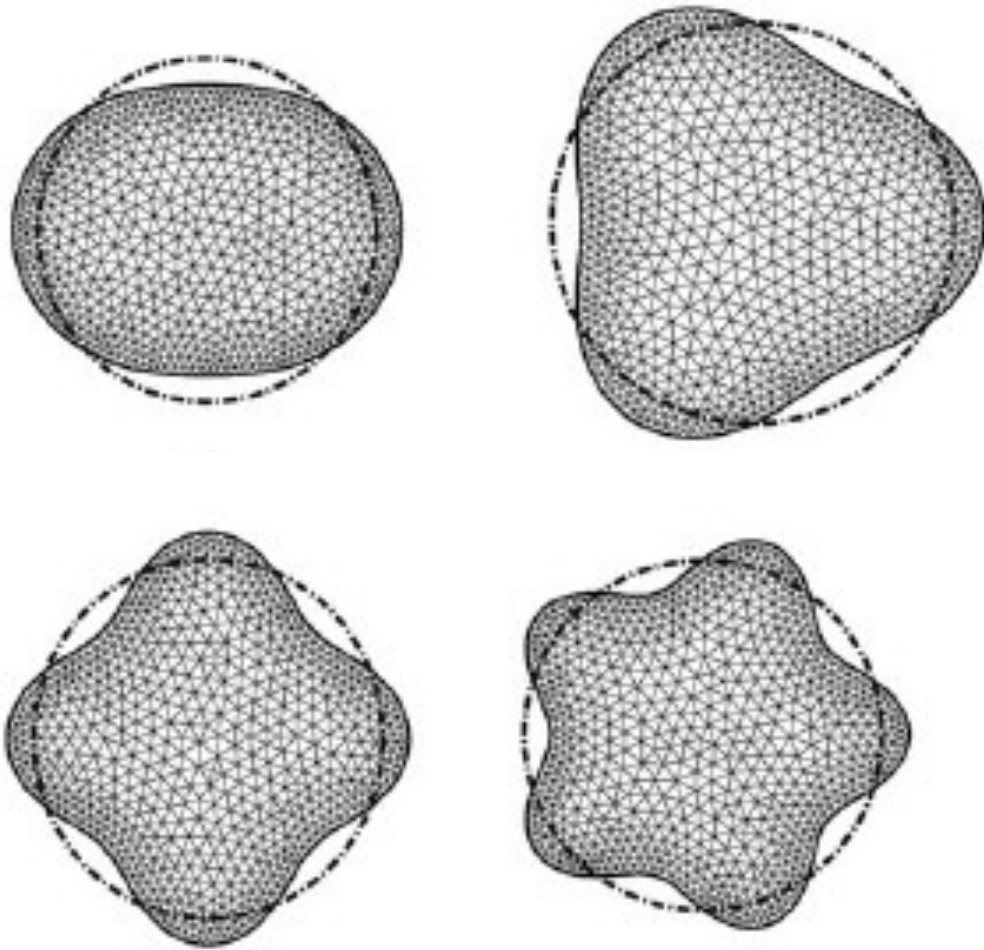
Spatial Compounding



Contrast Enhanced Ultrasound (CEUS)

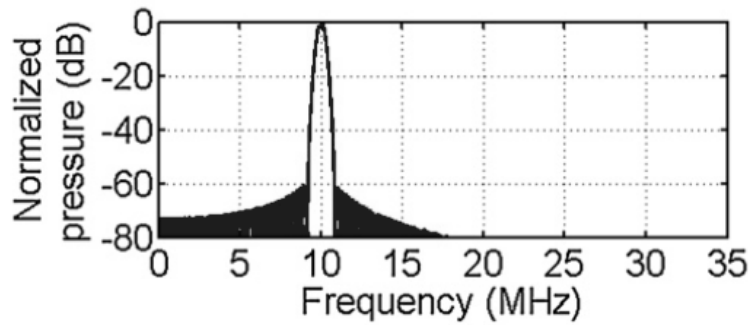


Left Ventricular Opacification (LVO)

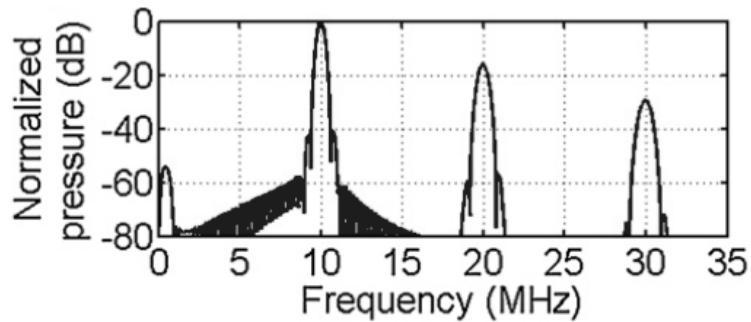


Contrast Harmonic Imaging (CHI)

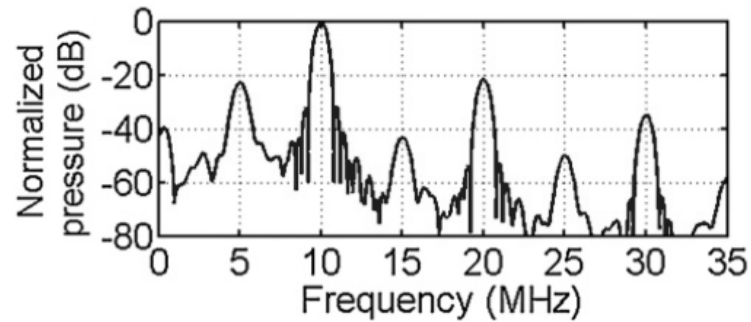
Increasing Pressure
↓



Rayleigh Scattering
(Linear)

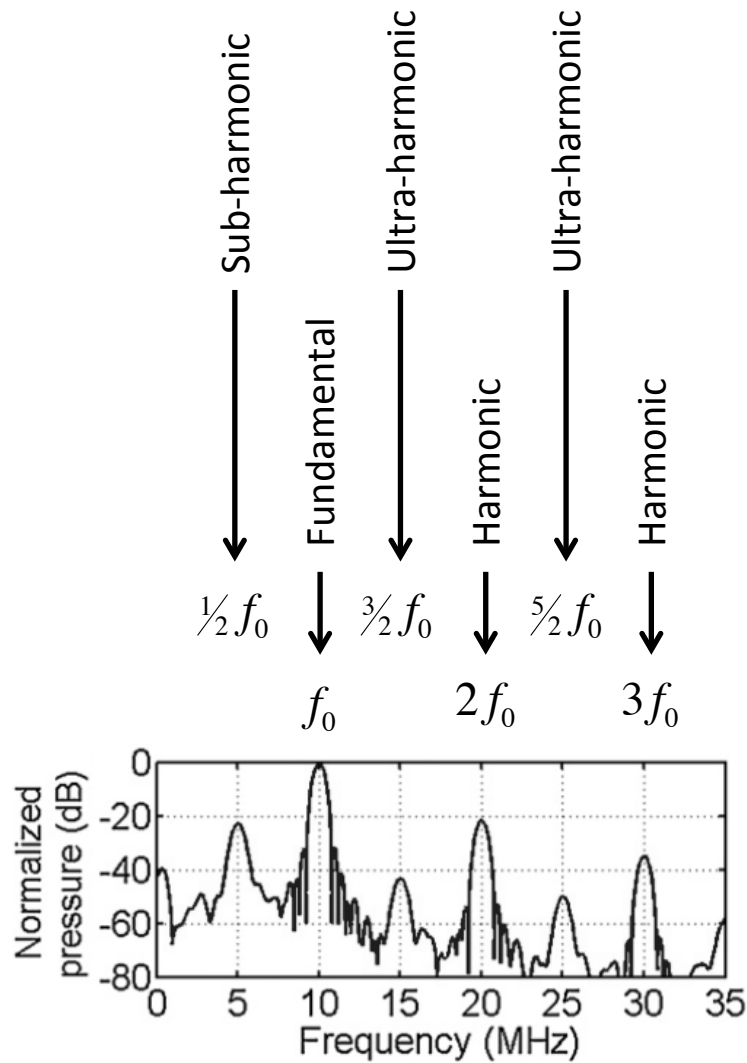


Tissue Harmonics
(Nonlinear)



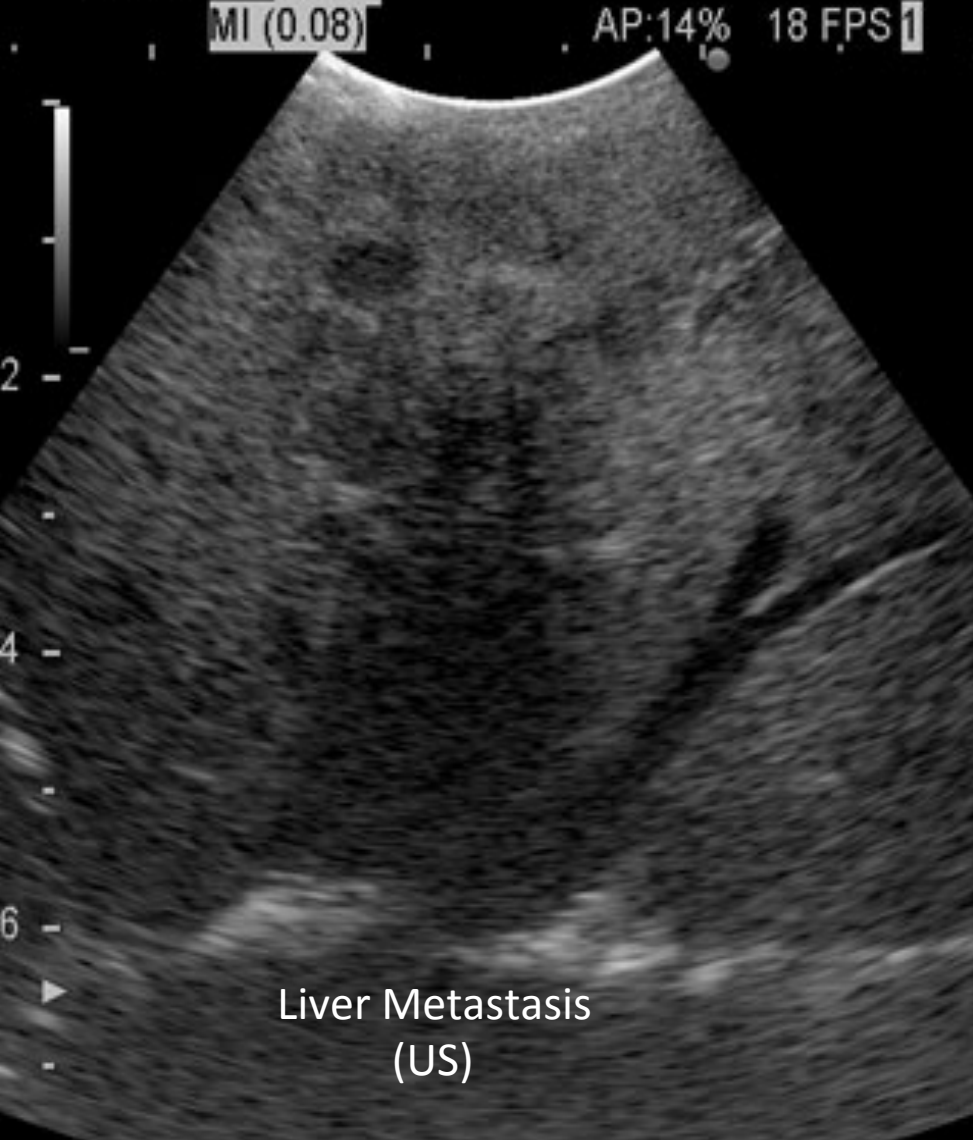
Contrast Harmonics
(Nonlinear)

Contrast Harmonic Imaging (CHI)



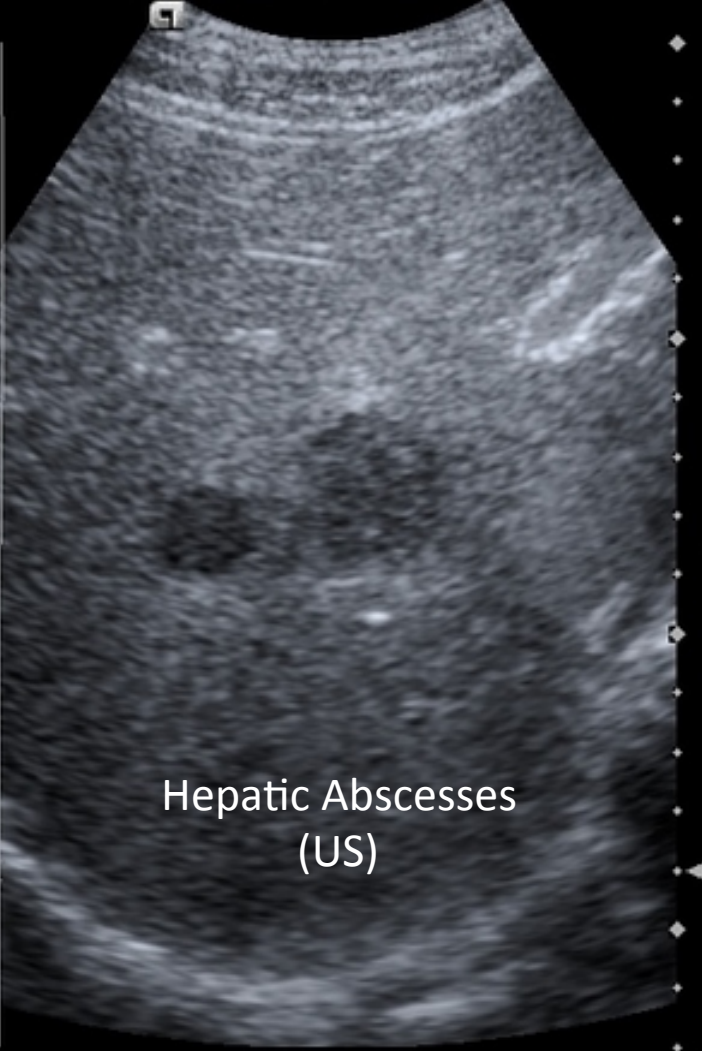
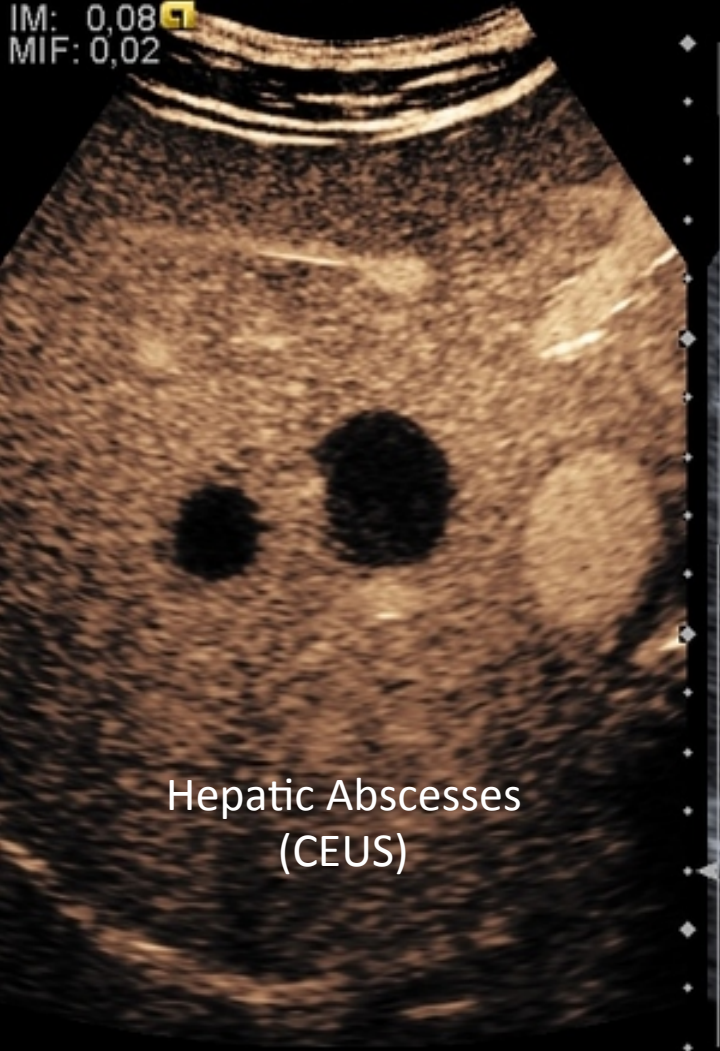
Contrast Harmonics
(Nonlinear)

Contrast Harmonic Imaging (CHI)



Contrast Harmonic Imaging (CHI)

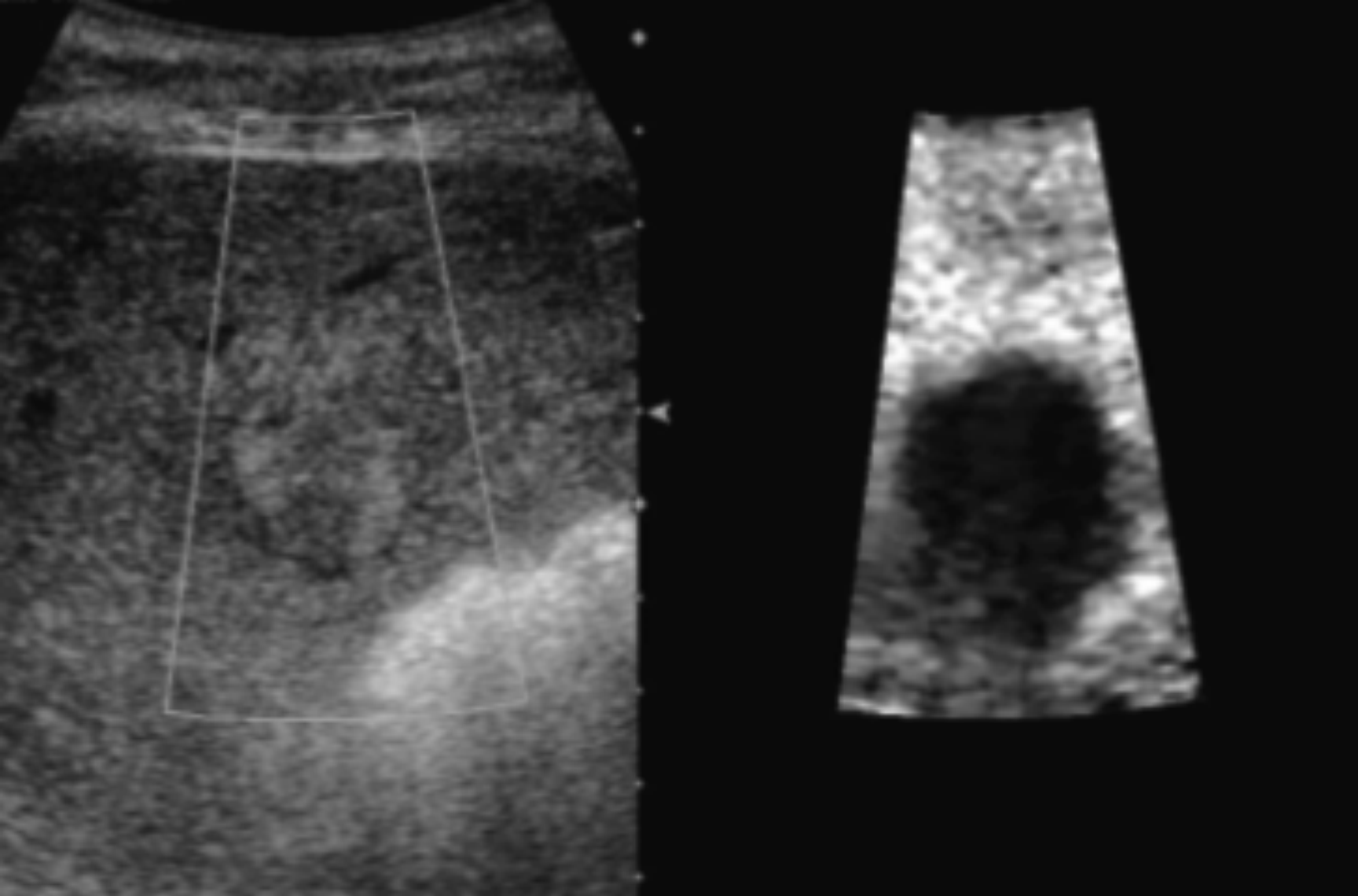
IM: 0,08
MIF: 0,02



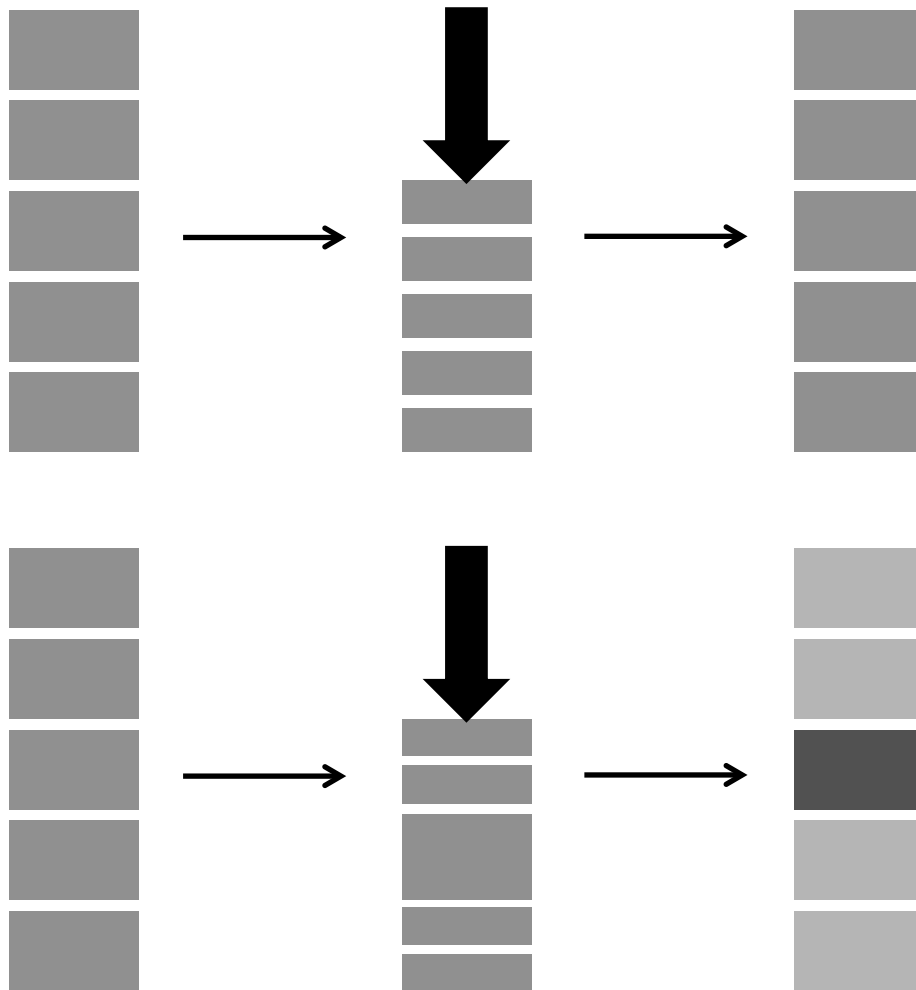
CPS
CA

00:02:31 9cps 17cm

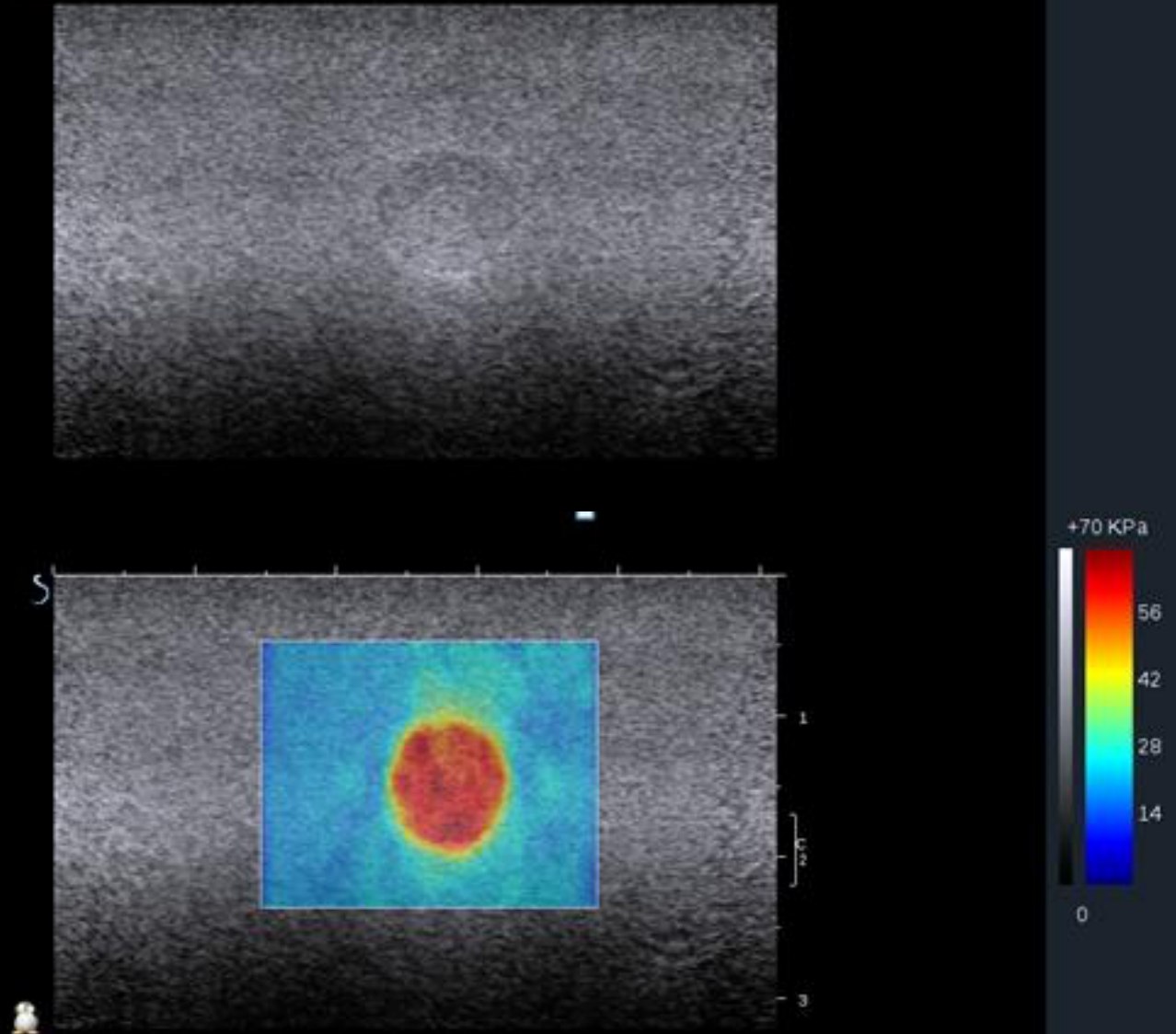
Contrast Harmonic Imaging (CHI)



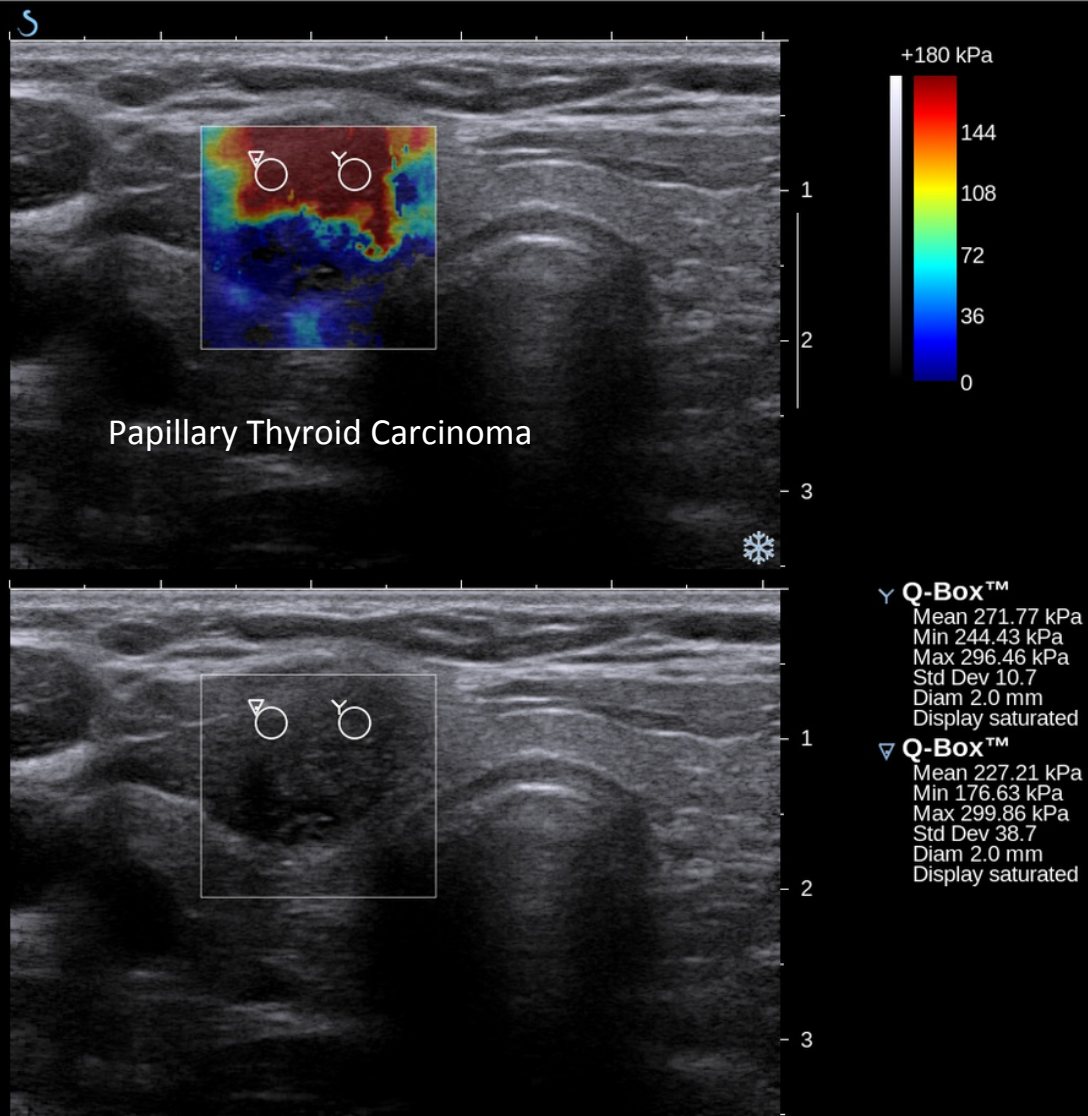
Ultrasound Elastography



Ultrasound Elastography

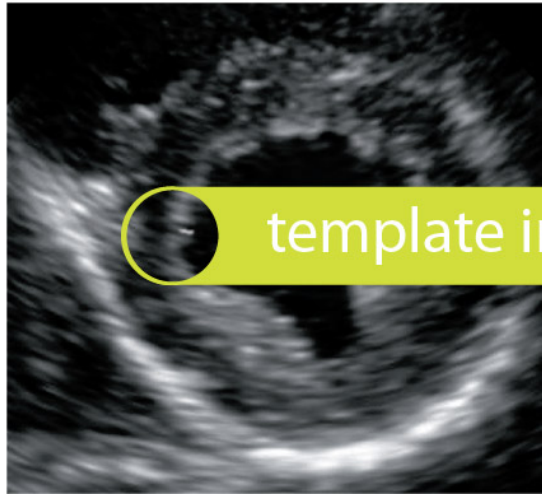


Ultrasound Elastography

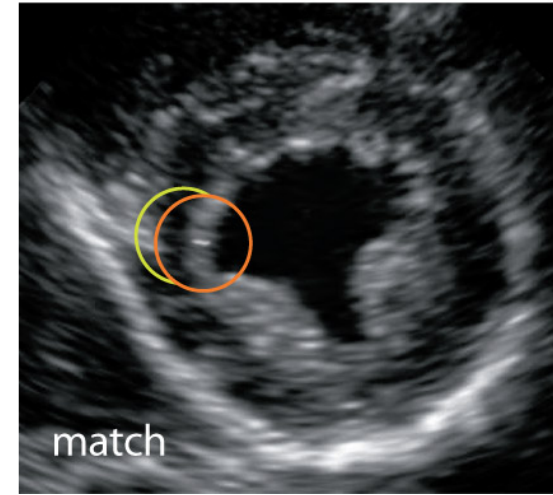
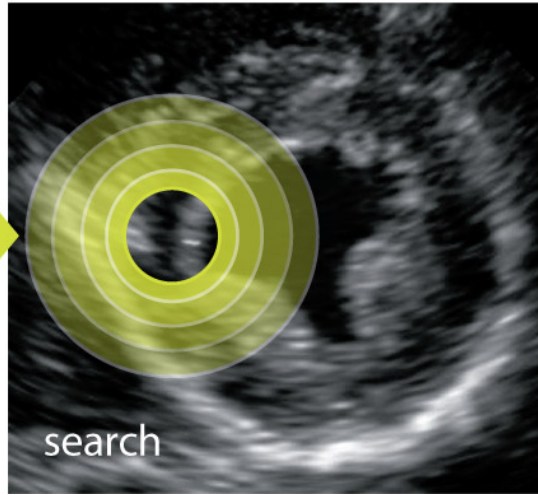


Ultrasound Elastography

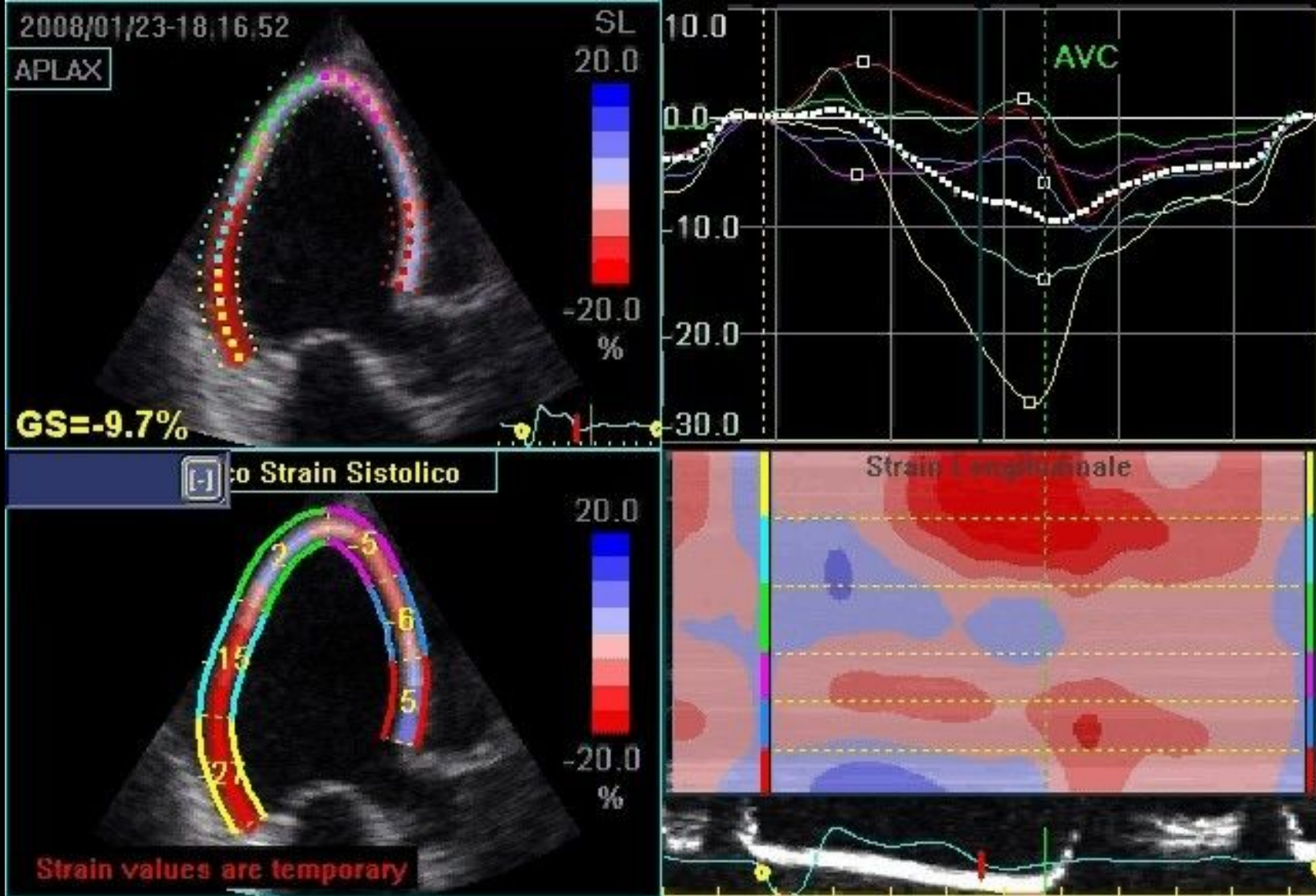
Current frame



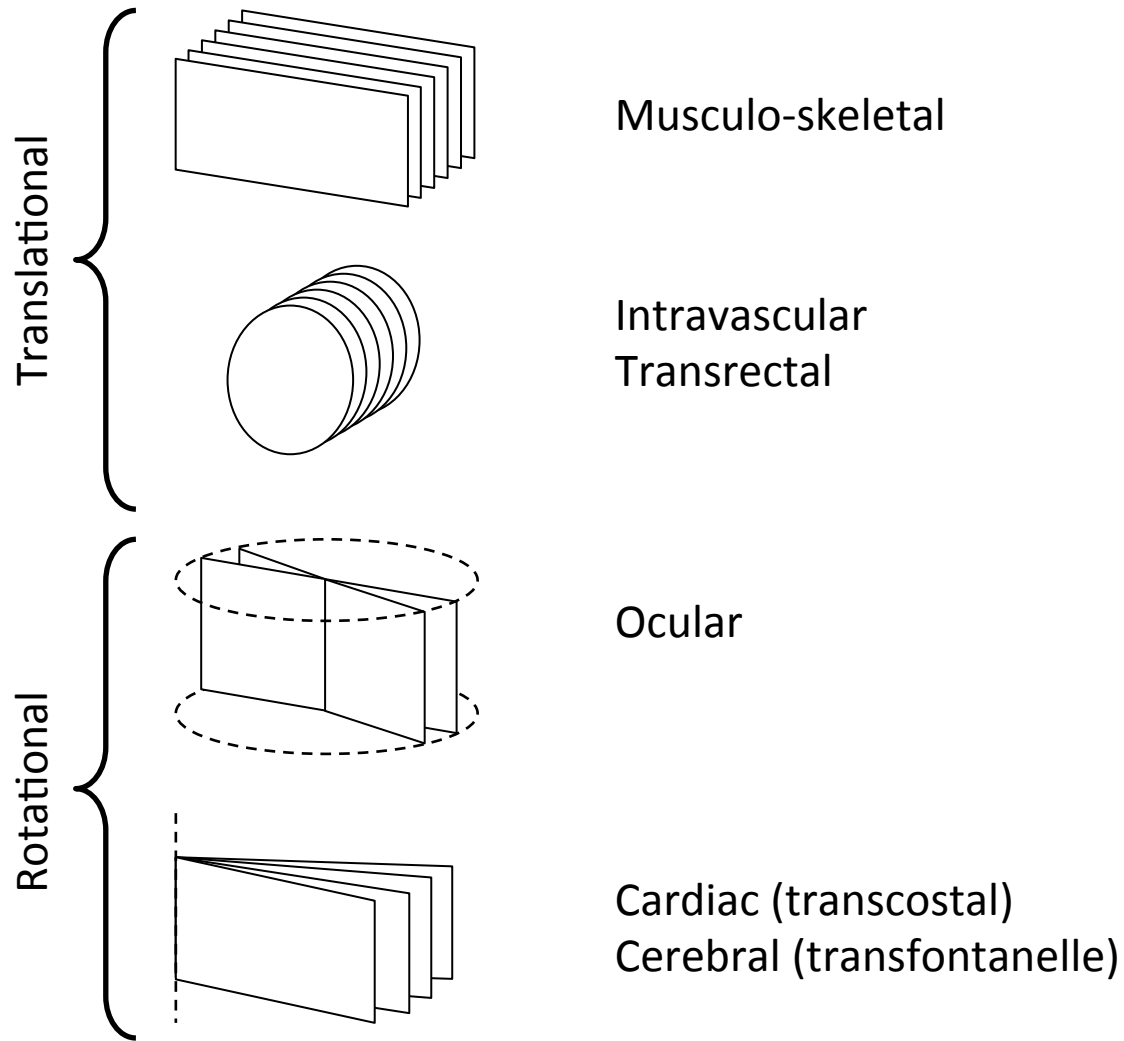
Next frame



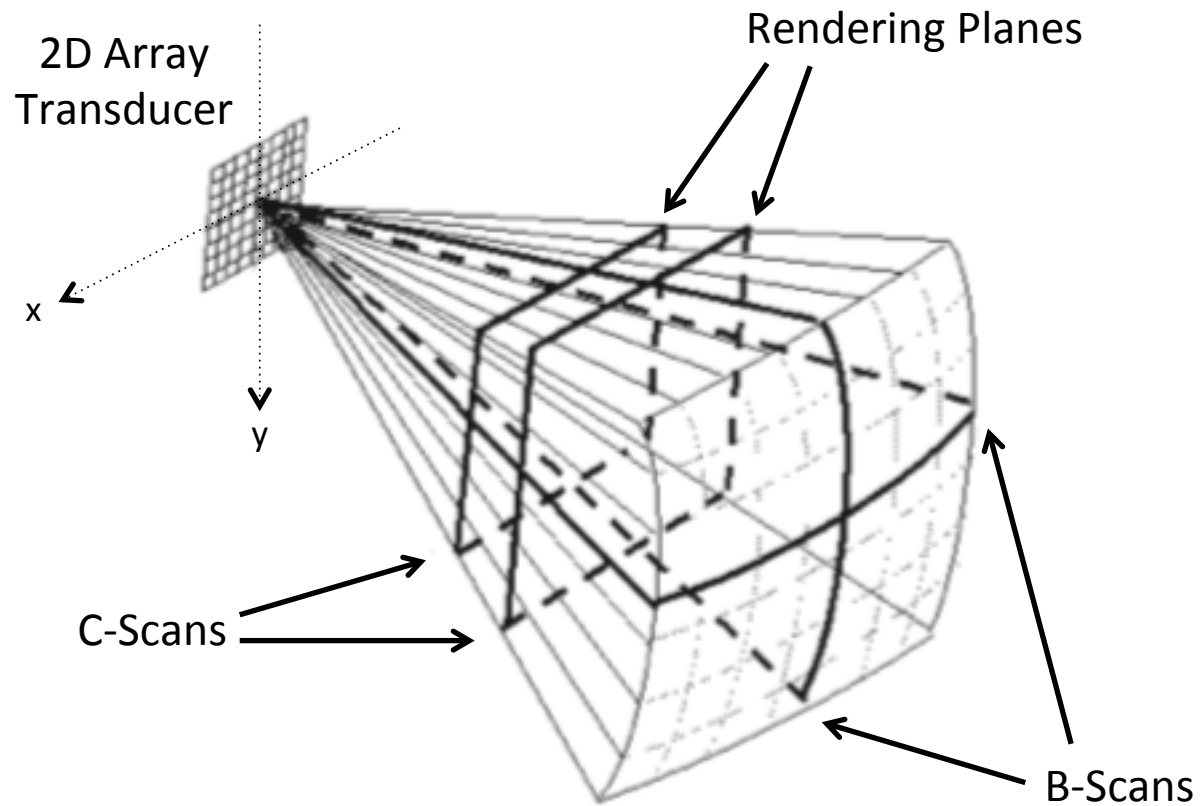
Speckle Tracking



Strain Imaging



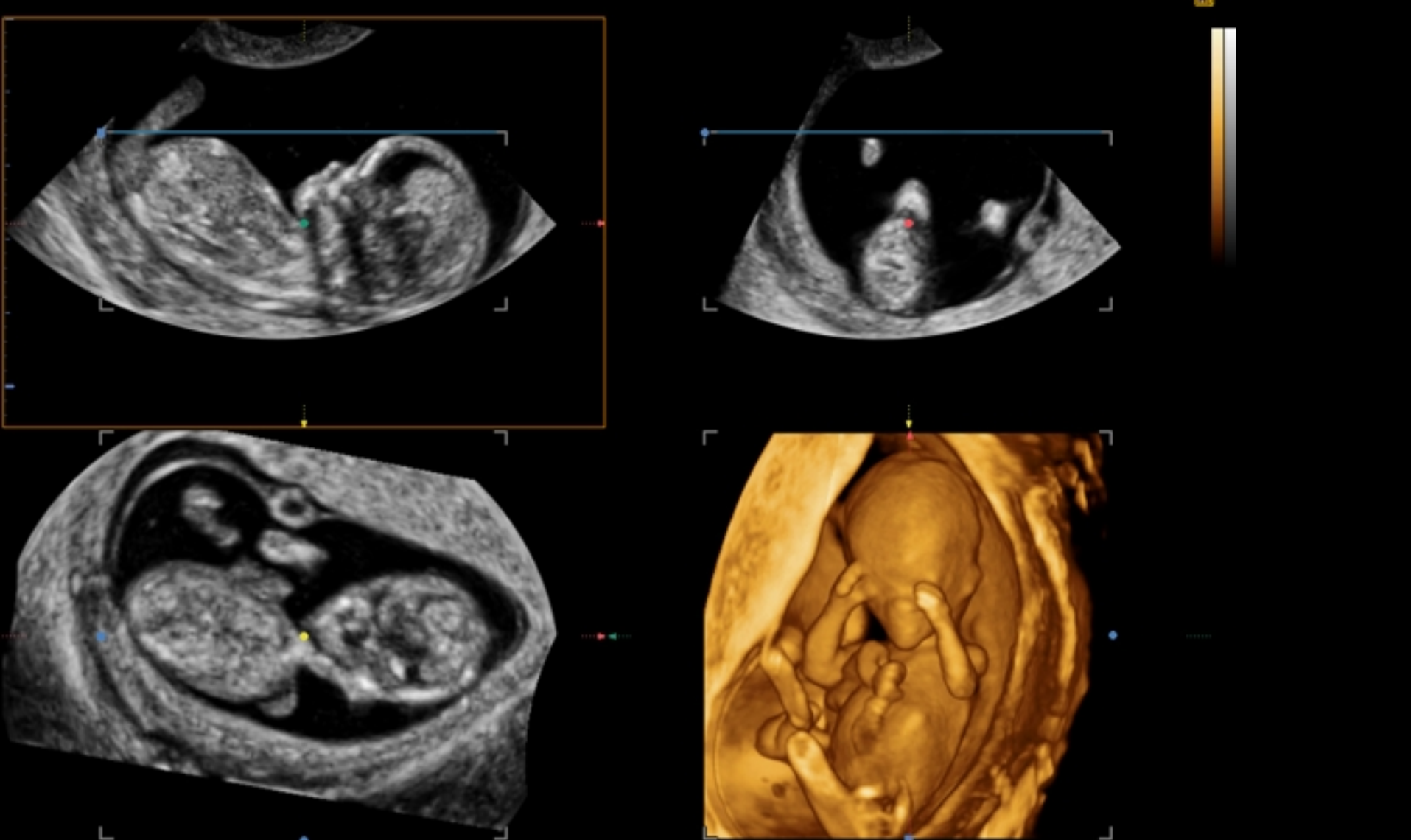
3D/4D Volumetric Imaging



3D/4D Volumetric Imaging



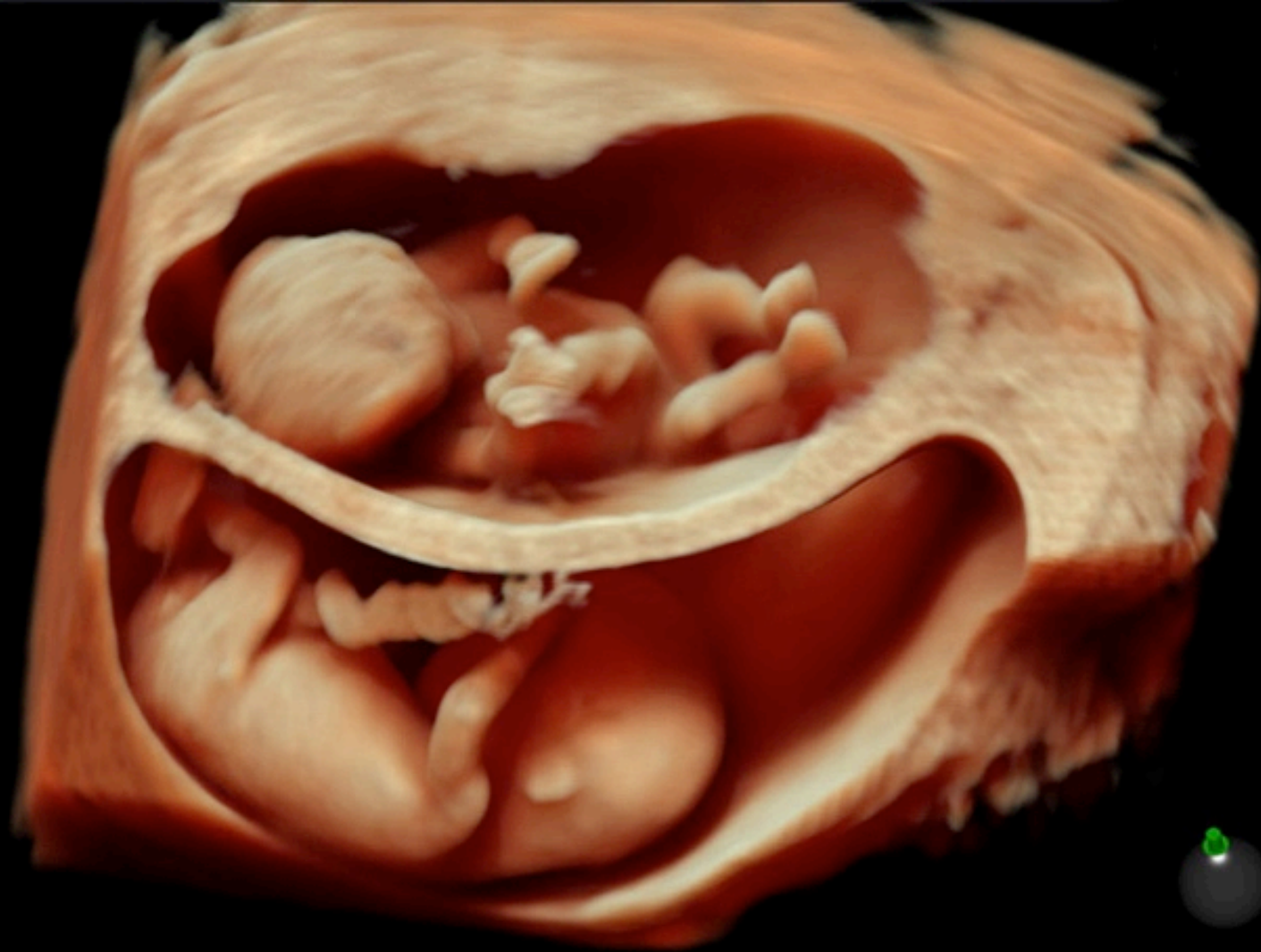
3D/4D Volumetric Imaging



3D/4D Volumetric Imaging



3D/4D Volumetric Imaging



3D

3D/4D Volumetric Imaging

05/03/2008 12:54:14
Octave
Frek.: 1.7 MHz/3.5 MHz
FPS: 19.8
Dybde: 16.0 cm

L

V

R

T

B

5

10

15

1:1 HR 76

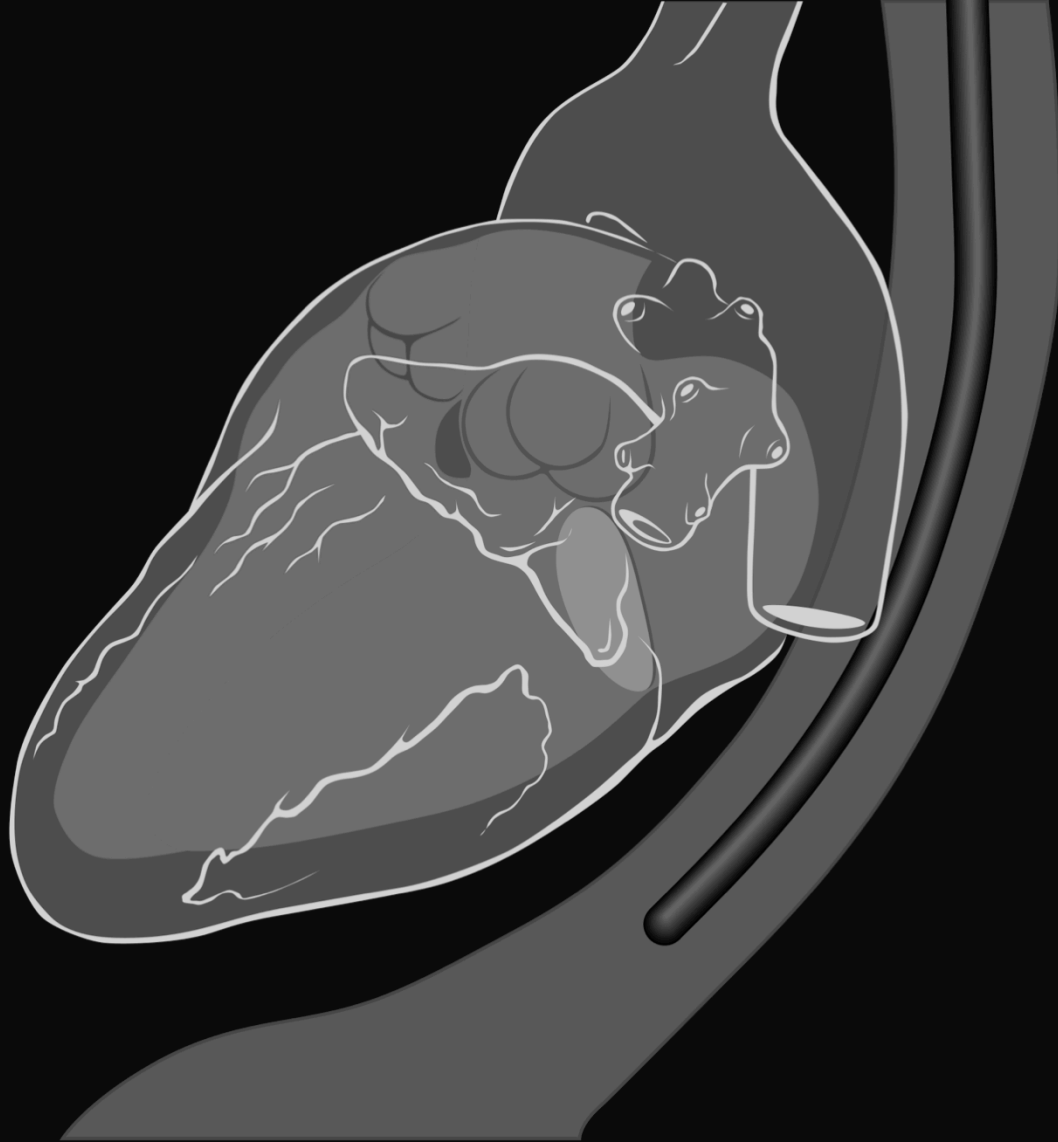
3D/4D Volumetric Imaging

Transesophageal Echocardiography (TEE)

Transvaginal Ultrasound (TVUS)

Transrectal Ultrasound (TRUS)

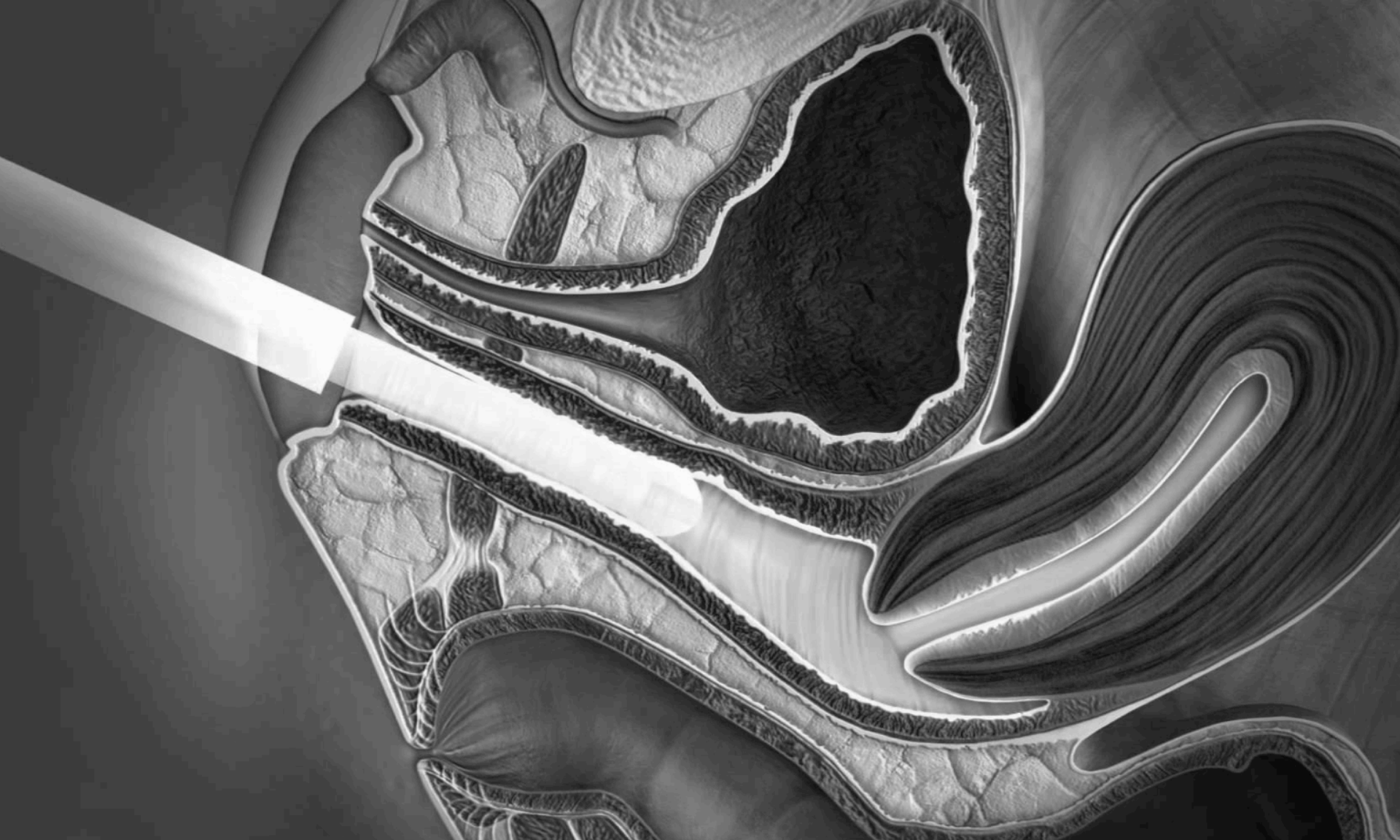
Semi-Invasive Imaging



Transesophageal Echocardiography (TEE)



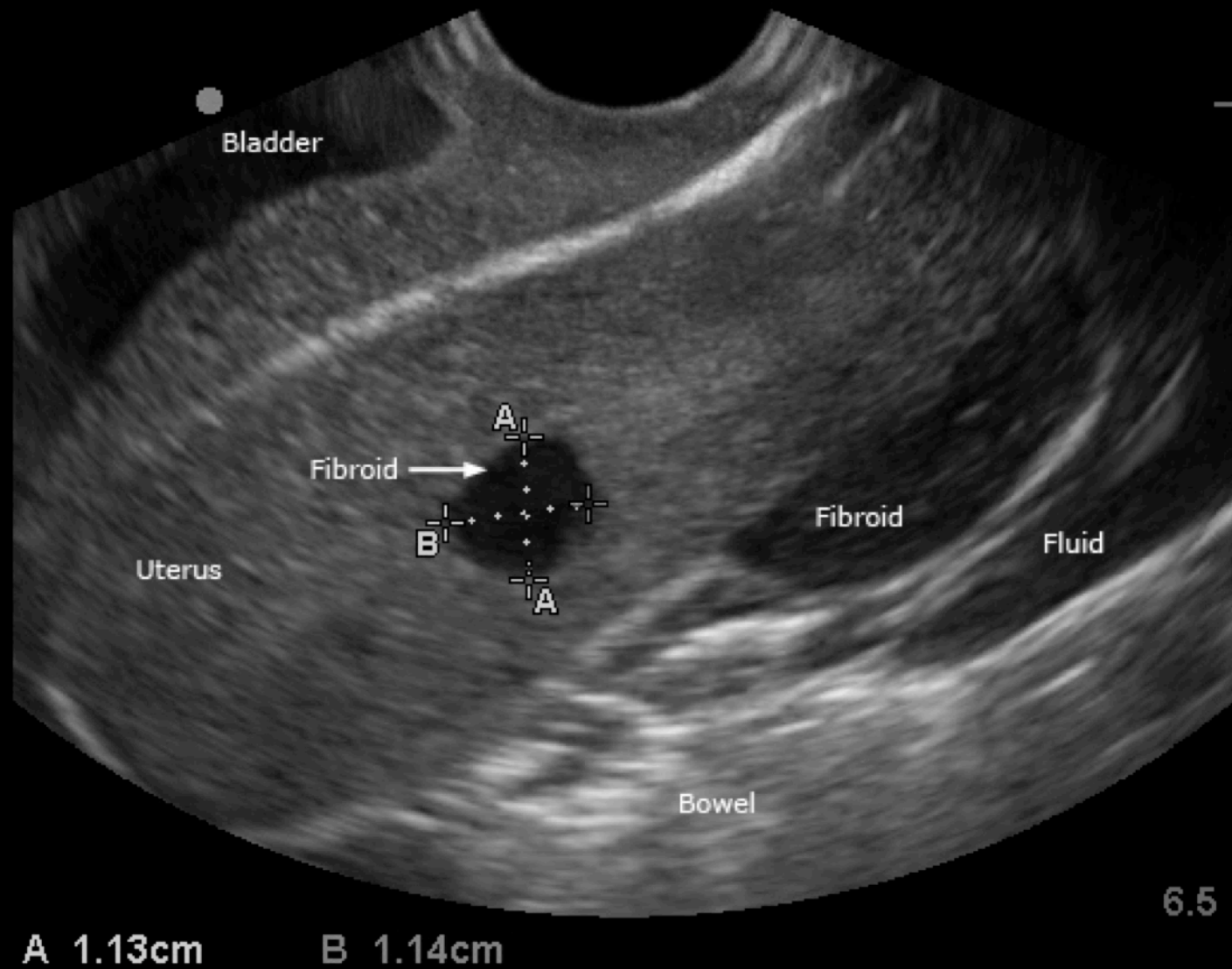
Transesophageal Echocardiography (TEE)



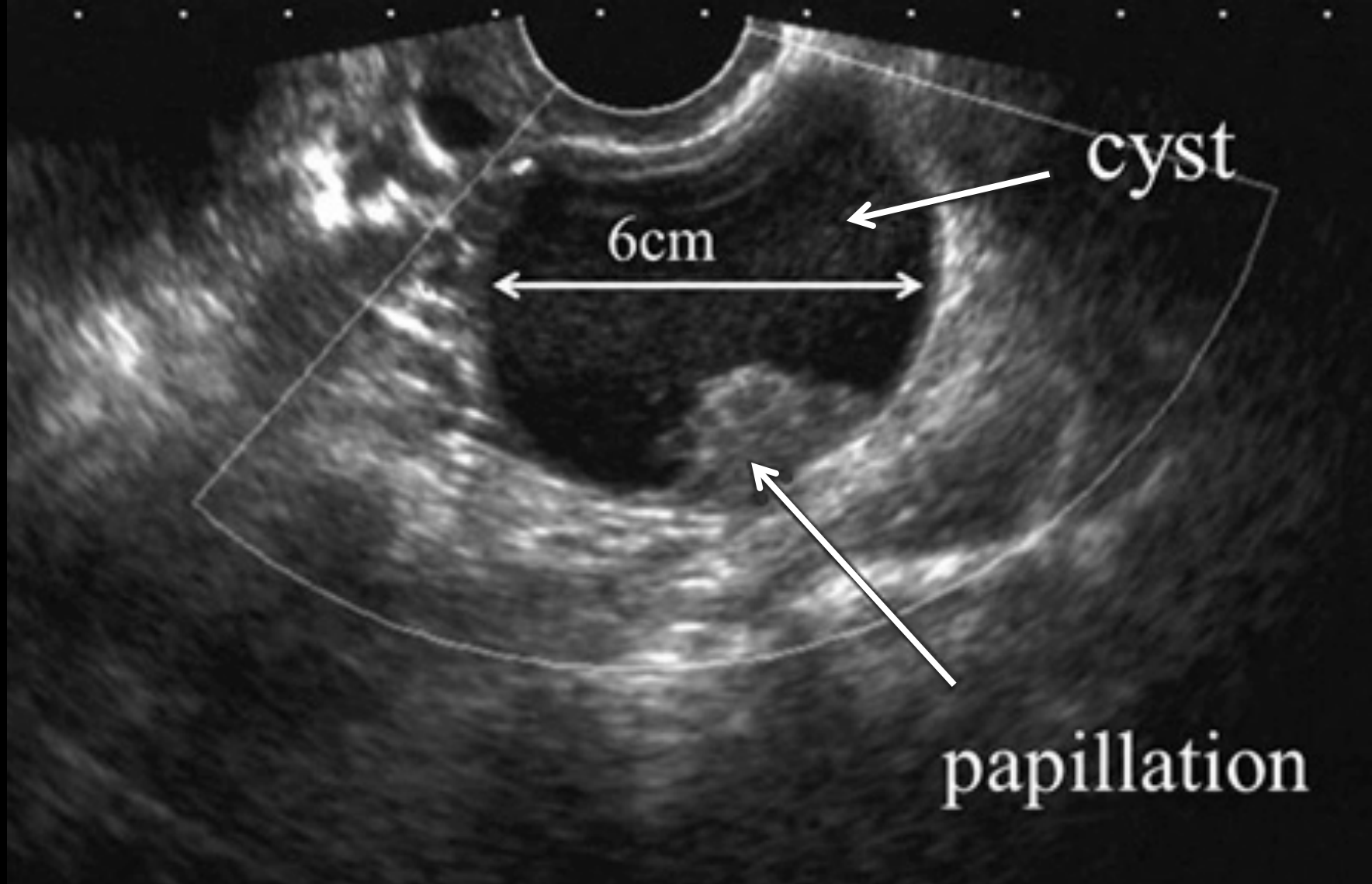
Transvaginal Ultrasound (TVUS)



Transvaginal Ultrasound (TVUS)



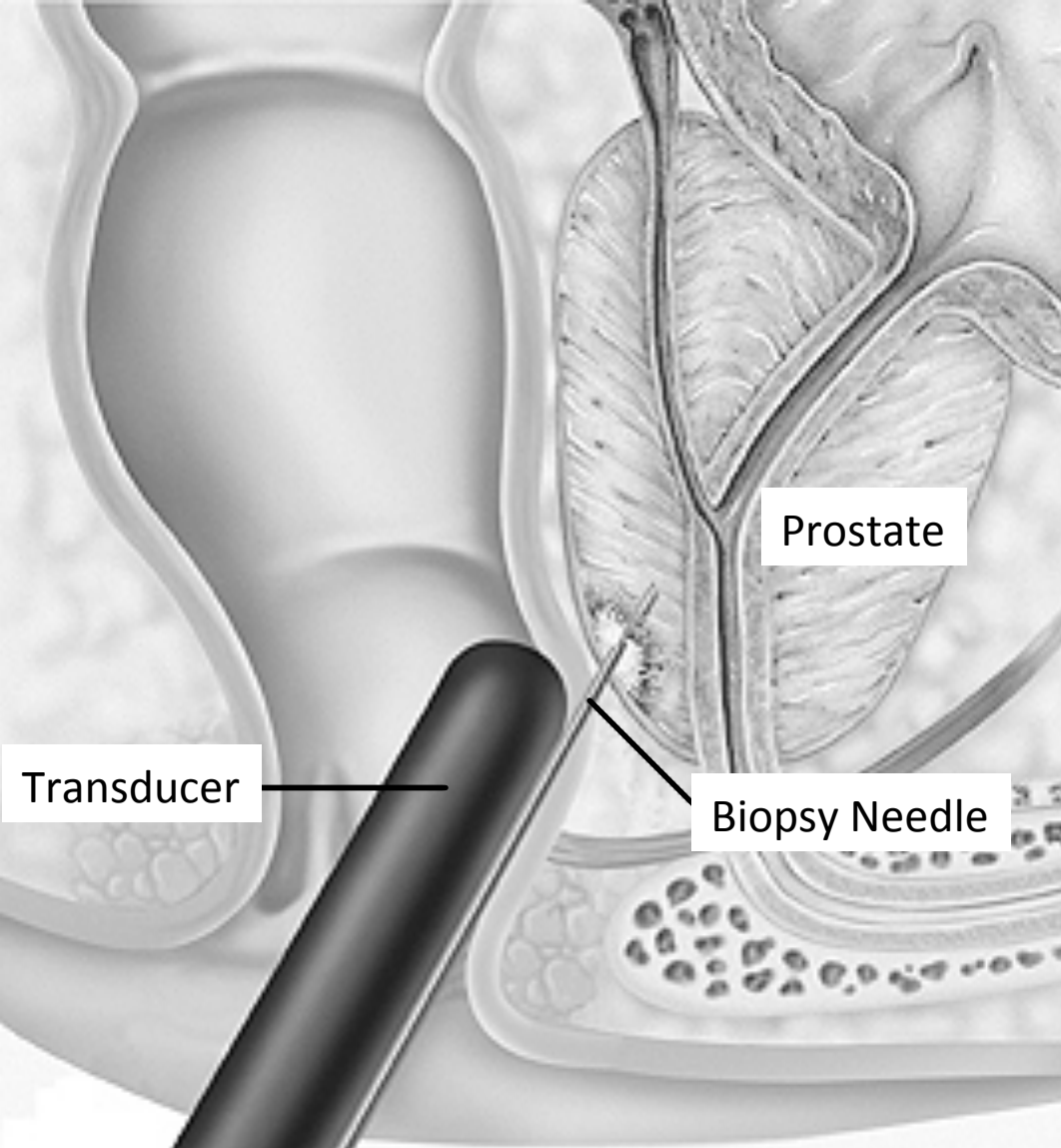
Transvaginal Ultrasound (TVUS)



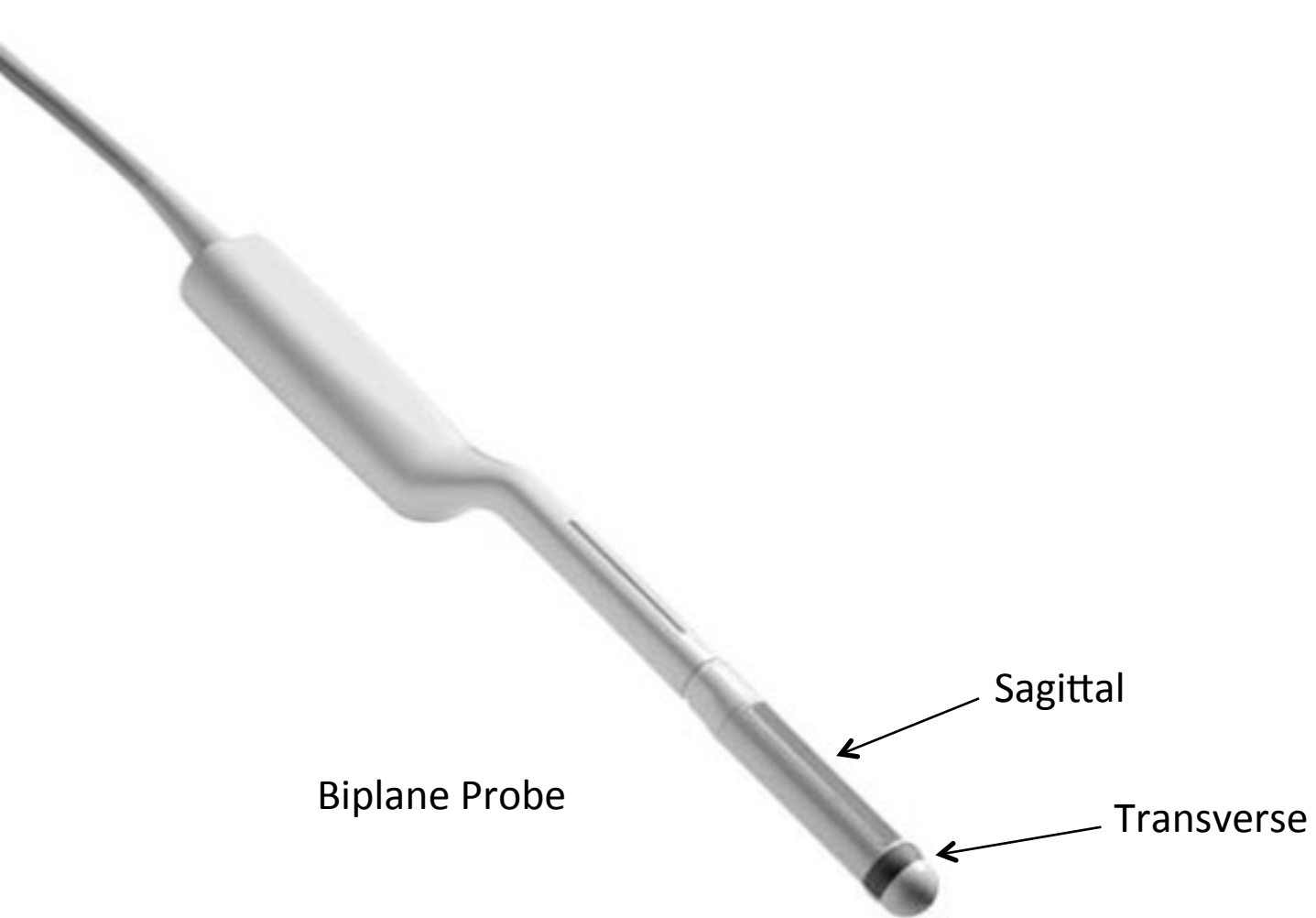
Transvaginal Ultrasound (TVUS)



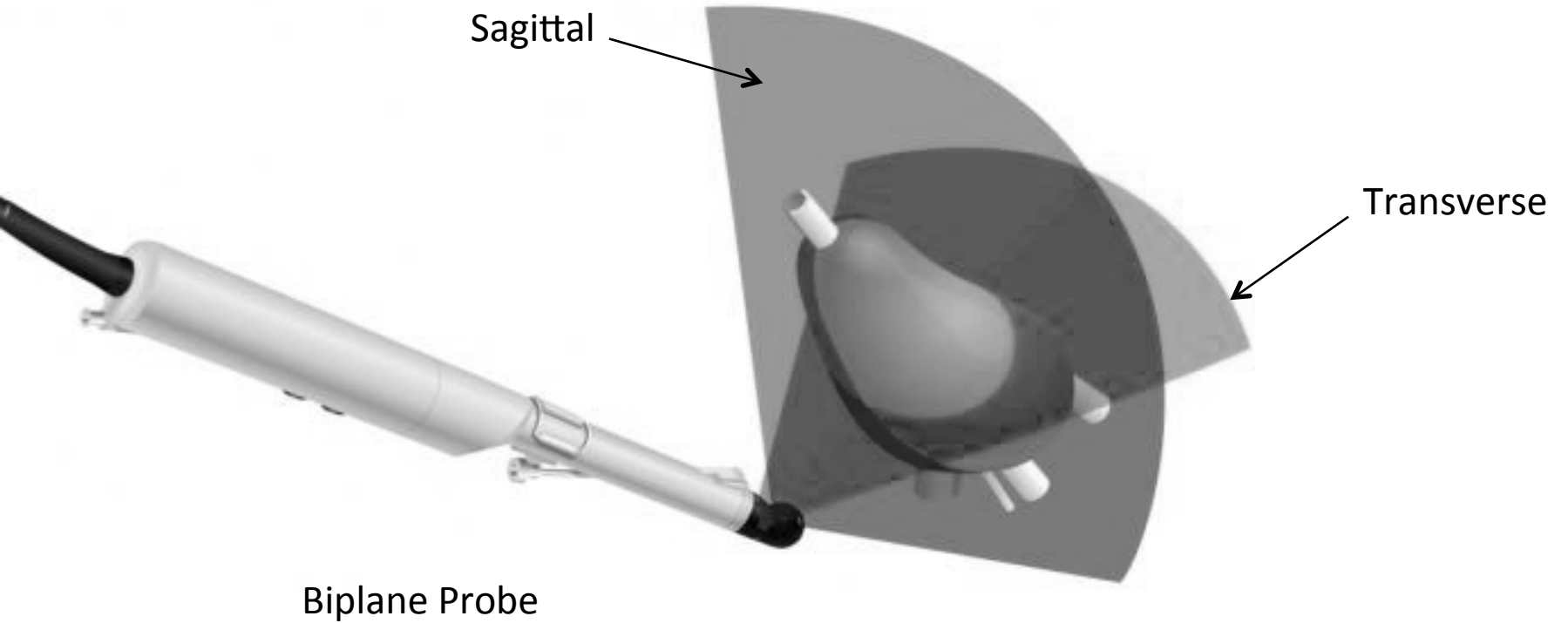
Transvaginal Ultrasound (TVUS)



Transrectal Ultrasound (TRUS)

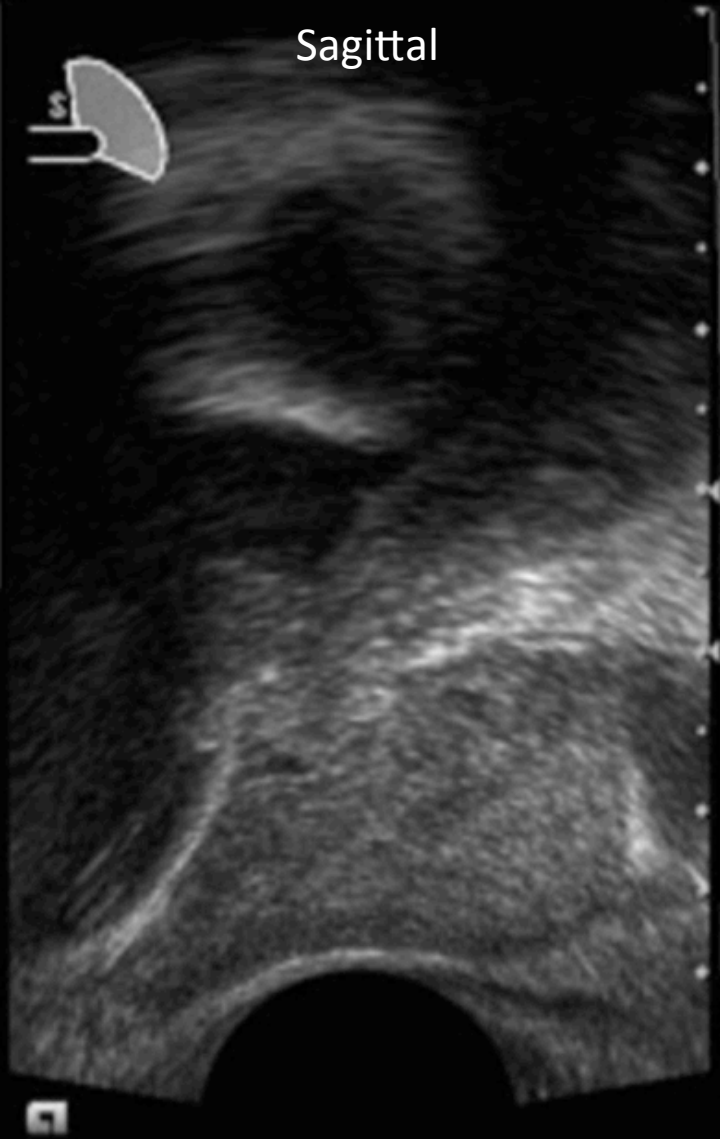


Transrectal Ultrasound (TRUS)



Transrectal Ultrasound (TRUS)

Sagittal



Transverse



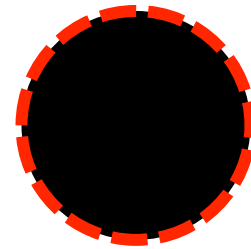
Transrectal Ultrasound (TRUS)

Intravascular Ultrasound (IVUS)

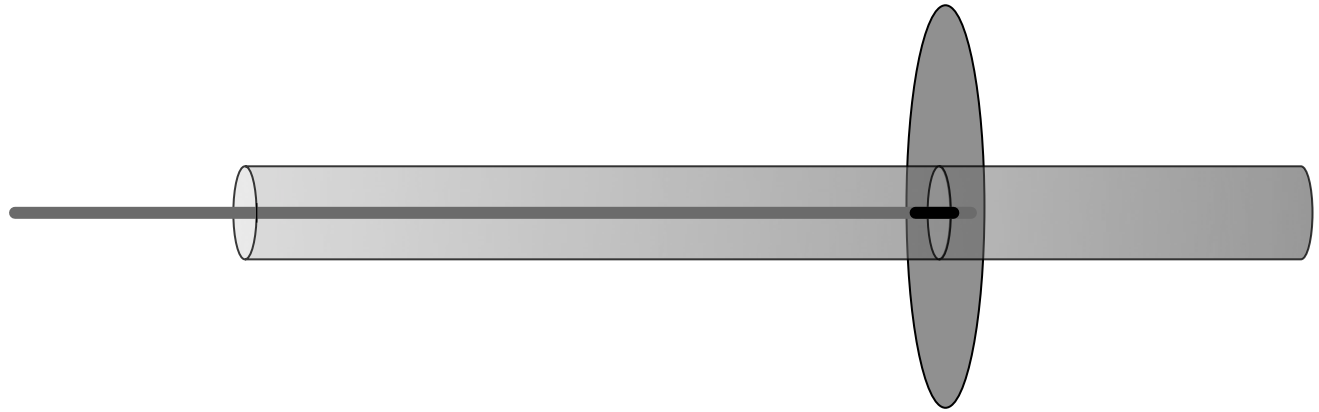
Intracardiac Echocardiography (ICE)

Intraoperative Ultrasound (IOUS)

Invasive Imaging



Intravascular Ultrasound (IVUS)

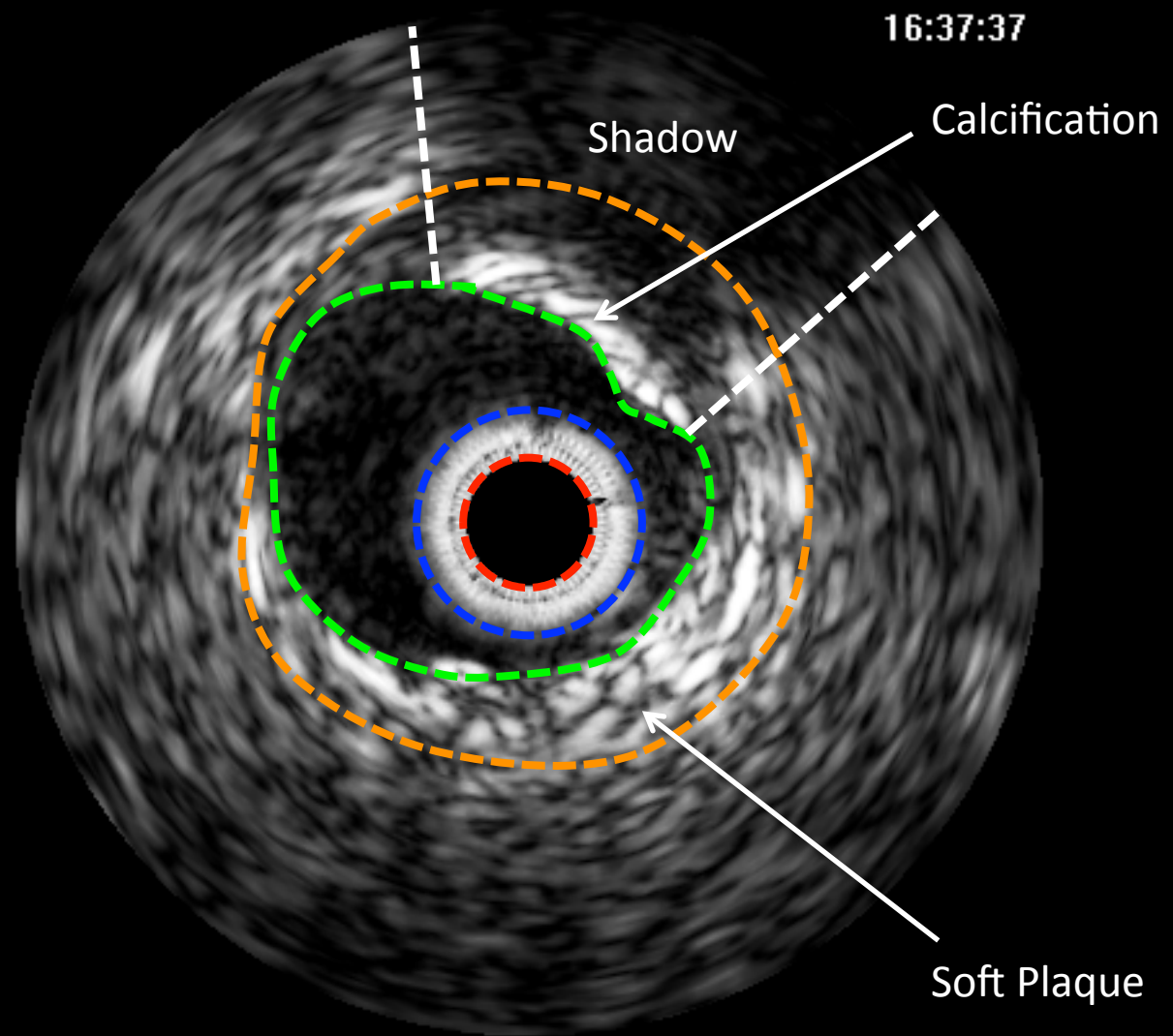


Intravascular Ultrasound (IVUS)



Intravascular Ultrasound (IVUS)

Transducer
Near Field
Lumen
Vessel Border



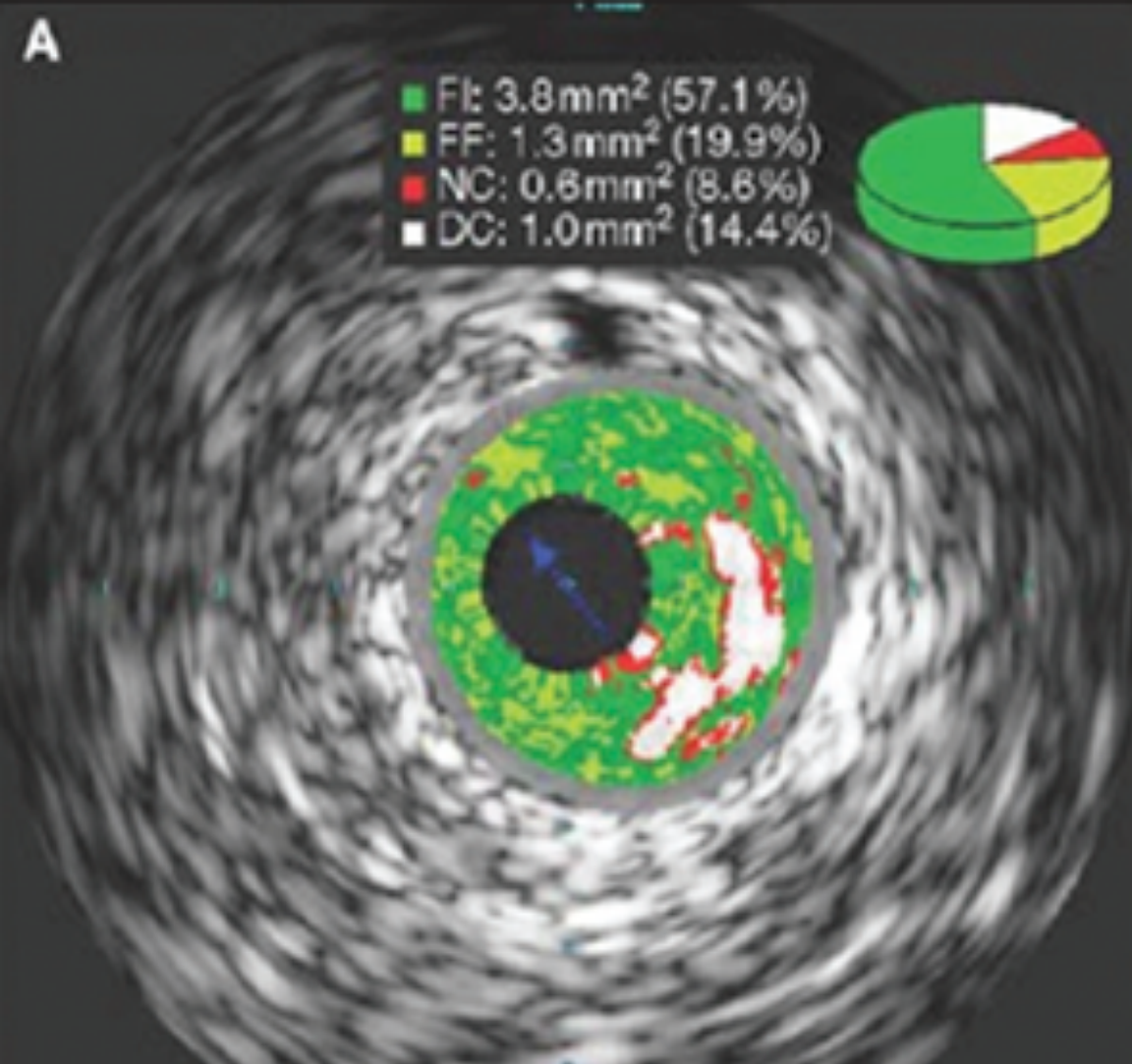
Intravascular Ultrasound (IVUS)

16:37:37

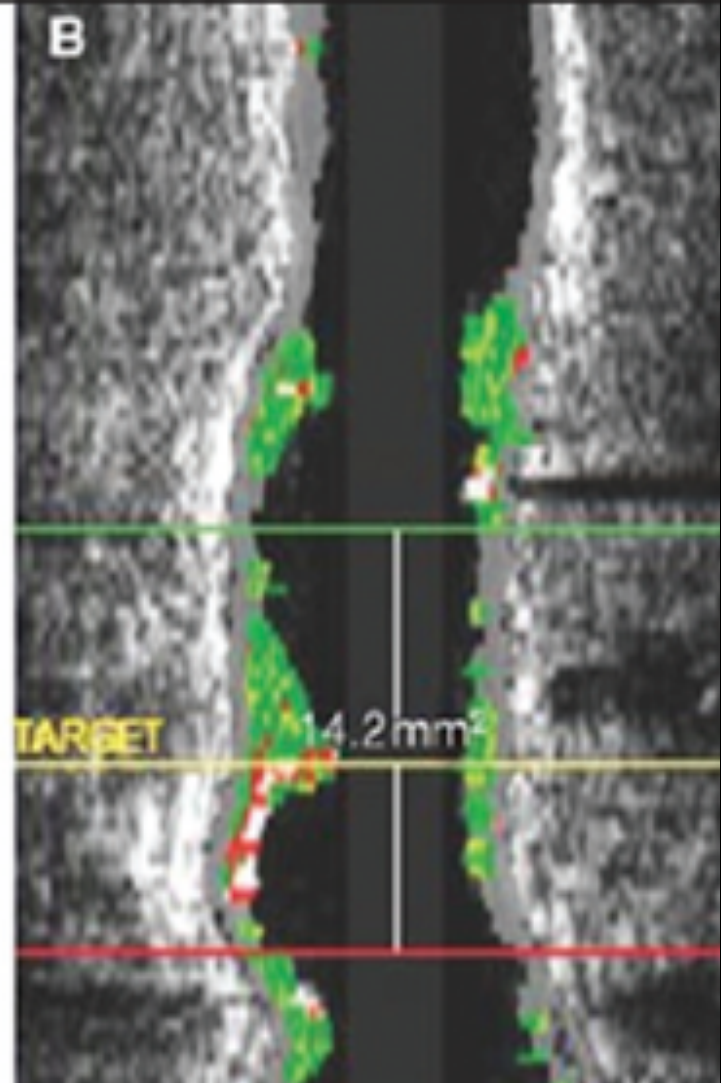


Intravascular Ultrasound (IVUS)

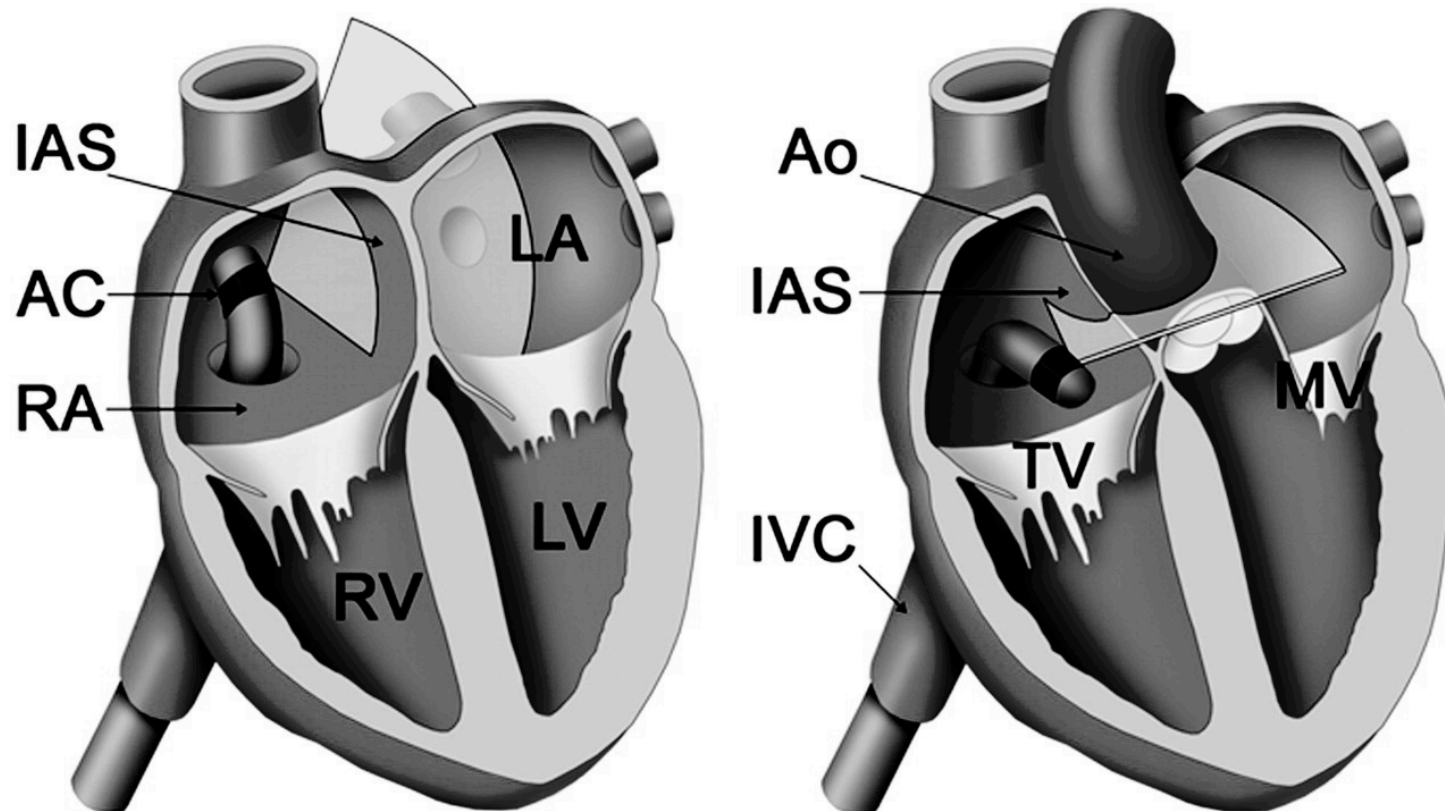
A



B



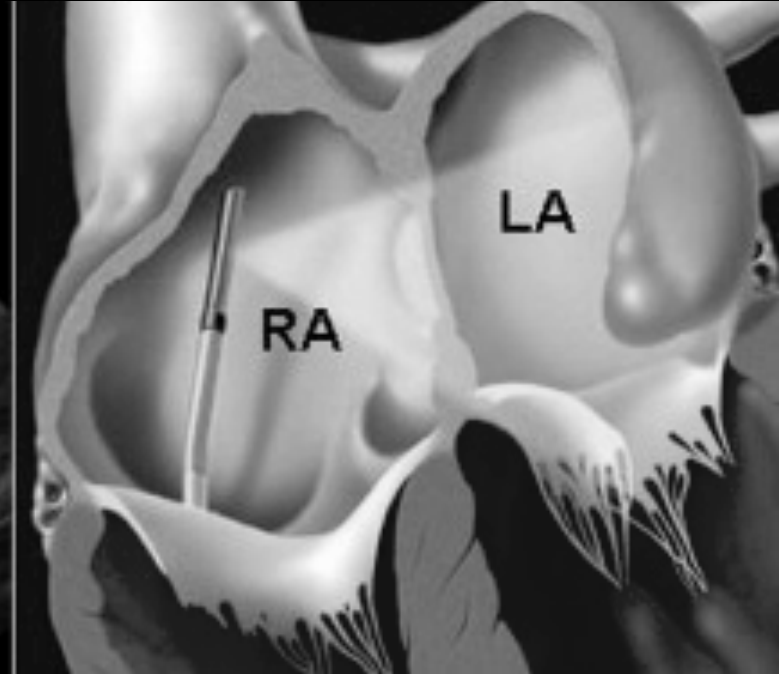
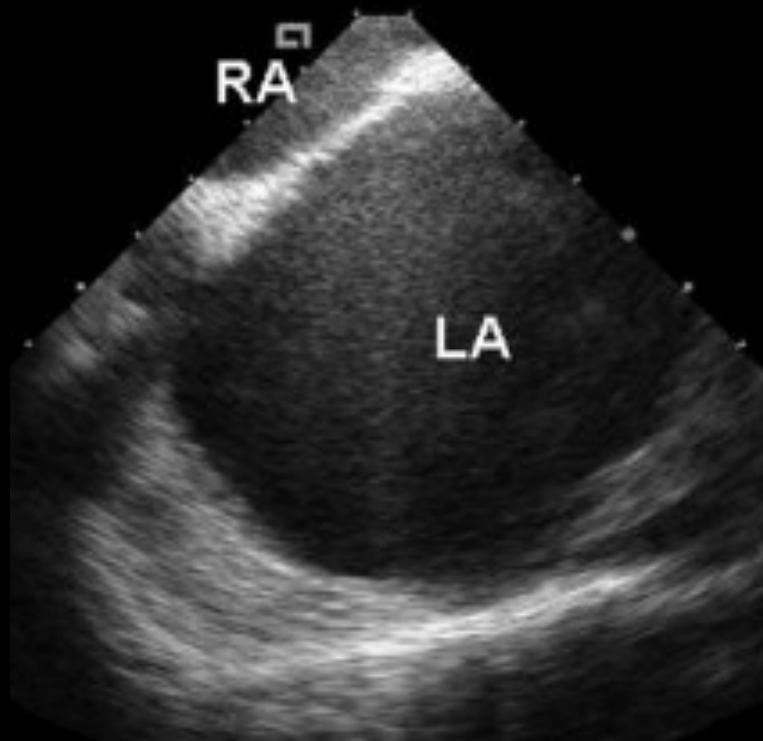
Intravascular Ultrasound (IVUS)



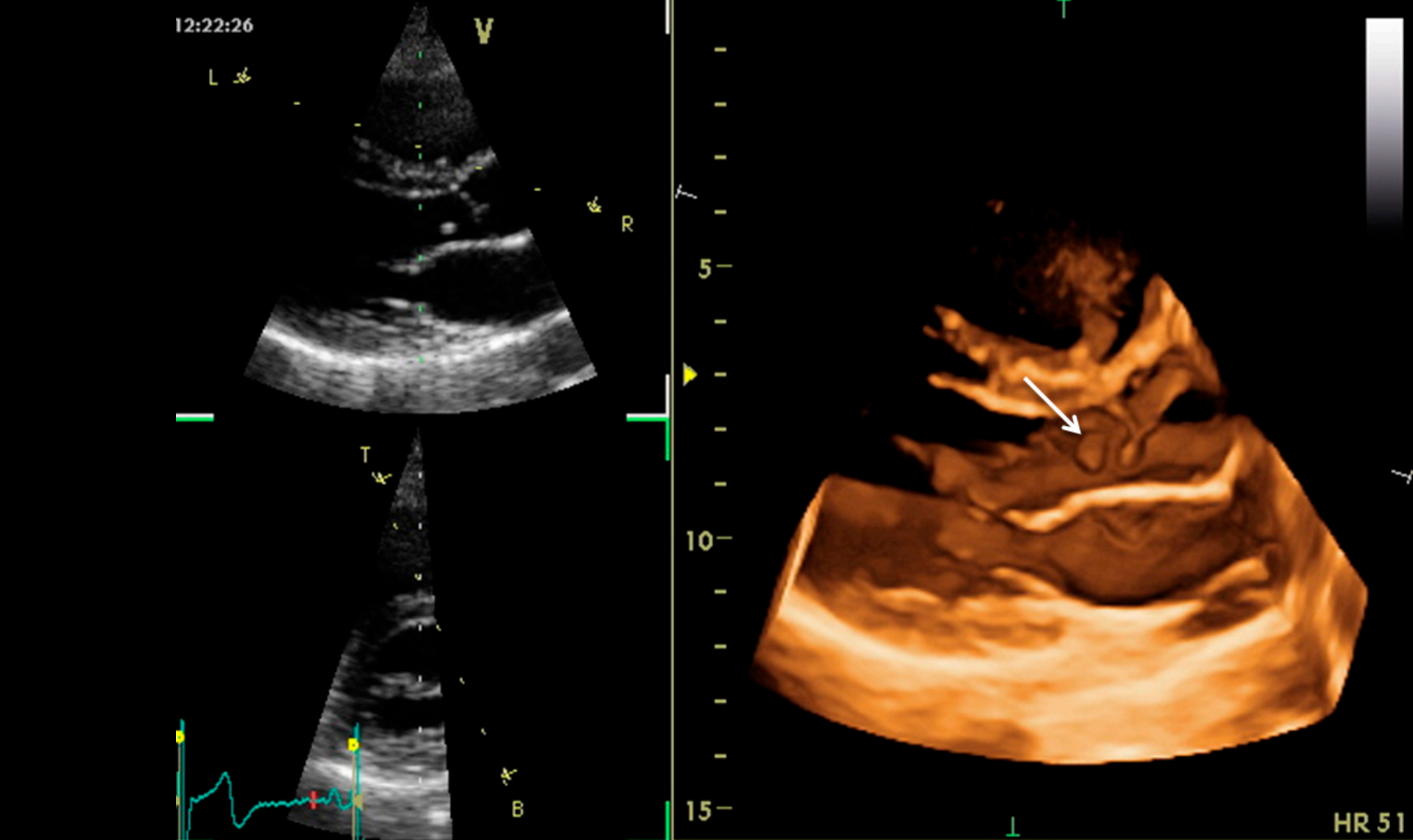
Intracardiac Echocardiography (ICE)



Intracardiac Echocardiography (ICE)



Intracardiac Echocardiography (ICE)



Intracardiac Echocardiography (ICE)



Burr
Hole



T-Shaped



Craniotomy



Intraoperative



Hockey
Stick



Biplane



Laparoscopic



Linear
Array



Laparoscopic



Robotic
Drop-in

Intraoperative Ultrasound (IOUS)

Through-Transmission Imaging

Ultrasound Computed Tomography (UCT)

Vibro-acoustic Imaging

Harmonic Motion Imaging

Coded Excitation

Time Reversal

Ongoing Studies

The Doppler Effect
Spectral Doppler
Continuous Wave Doppler (CWD)
Pulsed Wave Doppler (PWD)
Color Flow Doppler (CFD)
Power Doppler (PD)
Duplex/Triplex Ultrasound
Wall Filter
Tissue Harmonic Imaging (THI)
Contrast Harmonic Imaging (CHI)
Spatial Compounding
Ultrasound Elastography
Speckle Tracking
3D/4D Ultrasound

Summary