Vascular Ultrasound

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The goal of this lesson

• Achieve basic knowledge of vascular ultrasound
• Understand the concept of colour Doppler and Doppler spectrum
• Be able to perform flow measurement and know the related pitfalls
• Know how to use and handle ultrasound contrast
• Hands on session at 1500 in Dept. of Vascular Surgery: Located on 11th floor, entrance 3, central building.

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Ultrasound in vascular surgery

Morphologic and Dynamic flow visualization in human or animals

Velocities
Flow Pattern
- Stenosis

Size
- Aneurysms

Flow detection
- Leakage
- Receptor artery for bypass

Volume flow
- Dialysis

Contrast
- Plaque or thrombus evaluation
- Neovasc.
Vascular ultrasound

• Real time imaging
  – Can be repeated and is harmless
  – Dynamic information
  – Morphology

• Pitfalls
  – Operator dependent
    • Demonstrate and report your variability
      – Bland Altman plots

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From sound to image:
Brightness mode (B-mode)

We assume the speed of ultrasound through the tissue is constant, and we know the generated frequency then we can predict the distance from the source to the reflective boundary.

Distance = (Time \cdot C) / 2

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From sound to image

Transducer: Converts energy into another form of energy

Ultrasound machine interprets the receiving information

Two possibilities to increase signal intensity
- Increase output power, which is often locked
- Increase amplification, which is the gain level (2D)
  but at a certain level signal ≠ noise

Frame rate depends on
- Machine power
- Work load
  Reduce field of view.
  Steady patient!
From sound to image

Superficial imaging:
Depth of penetration depend on frequency.
High frequency low penetration but better image resolution

Abdominal imaging:
Low frequency high penetration – Your neighbour’s bass is more clearly than the treble
The lateral image resolution is poorer the axial image resolution due to higher density of scan lines

Cardiac imaging:
Large field of view compared to the size of the transducer face.
Electronical steering

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From sound to image Operator dependent factors

- Worst images: ultrasound beam is parallel to the interface

- Best images: ultrasound beam is perpendicular to the interface

Clear definition of the arterial walls is a good indication of perpendicular position.
From sound to image – Acoustic impedance: resistance against passage of the sound wave

Difference in acoustic impedance determines reflection rate

Similar acoustic impedance
- Muscle/blood (ratio=0.03)
- Fat/muscle (0.10)
- Low/moderate reflection - ideal for US

Different acoustic impedance
- soft tissue/air (ratio=0.999)
- soft tissue/bone (0.65)
- High reflection – not ideal for US imaging
Heavily calcified arterial Aortic anterior wall
Doppler effect

"the Doppler shift"
The doppler shift depends on the angle $\theta$

Doppler angle $\theta = 90^\circ$ then $\cos(90^\circ) = 0$
Doppler angle $\theta$
Displaying the doppler signal

The Doppler spectrum displays:
- **Time** along the horizontal axis
- **Velocity** (Doppler shift) along the vertical axis
- **Proportion** of blood cells at a particular speed along the third axis – brightness of the display
Blood flow in peripheral arteries

The velocity of blood cells (or Doppler shift freq.) vary with time due to arterial pulsation.

Normal triphasic flow in peripheral artery
1. First phase systolic forward flow
2. Second phase diastolic flow reversal
3. Third phase diastolic forward flow

Forward and reversed flow are seen simultaneously during the diastolic phase.

Reversal flow depends on the peripheral resistance.

After exercise

Low resistance vessel
- Organ supply

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Normal Triphasic flow

After releasing the cuff

Recovery of peripheral resistance

Normal Triphasic flow
Organ supply – Low resistance

A. Mesenterica superior
Transition from laminar to turbulent flow

Laminar or Parabolic flow

Disturbed flow

Blood cells with multiple velocities

Turbulent flow

Spectral broadening

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Triphasic signal ➔ Disturbed flow showing spectral broadening ➔ Finally monophasic flow
Flow profiles in stenoses

- **Velocity increase**
  - fluid travels faster through the narrow section

- **Turbulence**
Velocity profile in arterial stenosis

At 70% reduction of diameter a pressure drop occur - and the stenosis are limiting the flow

This correspond to a 2-3 fold increase in systolic velocity

Blood flow

Velocity

Decrease in diameter

x3

Tri-phasic signal

Stenotic signal

Post-stenotic signal

Monofasic signal

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Contents

• From sound to image – theory 10 min.
• Doppler effect / doppler shift
  – Displaying the doppler signal
  – Flow profiles
• Colour doppler
• Volume measurement
• Contrast-enhanced ultrasound
Colour Doppler ultrasound

B-mode image + Doppler curve = Duplex

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Colour Doppler ultrasound

- B-mode grey-scale image +
- Colour coded Doppler signals in the colour-box

Blood flow towards the transducer is (probably) coded red
Blood flow away from the transducer is coded blue

Primarily used for flow detection
Display of Colour Doppler and spectrum

Angle θ

Framerate

Distance

Sample Volume

Beam path (Steer)

Doppler angle

Correction cursor

Doppler Angle θ

Colour Box

Colour scale

Peak systolic velocity

Mean velocity

FR 33Hz

60°

PHILIPS

KARKIR

L9-3/Vasc Art

TIS0.1 MI 0.2

Peak systolic velocity

Mean velocity

Distance

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Flow measurement

Flow volume = Cross section \cdot Linear velocity

Area = \pi \cdot \frac{1}{4} \cdot D^2
Flow measurement – The display

Dist 0.699 cm
TAMV 13.8 cm/s
Vol Flow 318 mL/min
Area 0.384 cm²

TAMV: Time Averaged mean velocity = Mean velocity for each line of the sonogram averaged over a complete cardiac cycle.

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Flow measurement and pitfalls

- Sample volume
- Doppler angle
- Pulse repetition frequency
- Doppler gain
- Image resolution
- Variation due to pulsation
- The right imaging plane
- Other pitfalls

Related to linear velocity assessment

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Sample volume and Linear velocity

Small sample volume: Reflection will be received from all moving blood cells.

\[ \text{Vol flow} = 318 \text{ mL / min} \]

Small sample volume: Reflection only received from fast the fastest moving blood cells.

\[ \text{Vol flow} = 477 \text{ mL / min} \]
\[ f_d = f_0 - f_1 = \frac{(2 \times V \times f_0 \times \cos \theta)}{C} \]

When calculating the velocity (V) the angle estimation is very important – especially when \( \theta > 60^\circ \).

Example:
Overestimating the angle by 5°
• at 40° leads to an error of 7%.
• at 75° leads to an error of 47%!

Conclusion: Keep the angle < 60°!
Underestimate the true velocity

Align the transducer with reasonable length of the vessel
Pulse Repetition Frequency (PRF) / scale

Especially low flow is not detected

Aliasing – Flow is going backwards

12
45 min later

9
90 min later

135 min later

PRF too high

PRF too low

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Volume measurement - Doppler gain

Too low gain $\rightarrow$ flow may not be detected

The ideal gain level

High gain $\rightarrow$ overloading of the instrument $\rightarrow$ poor direction discrimination

PSV and TAMV increase

Ideal image

Mirror image

PSV and TAMV decrease

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Cross section

Area = $\pi \cdot \frac{1}{4} \cdot D^2$

The error is 0.084 cm or less than 1 mm. or 11 %

The corresponding failure in vol flow is 21 % going from 459 mL to 362 mL
Diameter assessment and Image resolution

L9-3 MHz

No intima

L17-5 MHz

Intima

For superficial structures take the transducer with the highest frequency available
Diameter assessment – when to measure

Cardiac cycle

AORTA
C5-1
22Hz
9cm

2D
Gen
Gn 60
C 56
3/3/3
35 mm/s
Cardiac cycle

Upper LoA = 4.7 mm

Average 1, 94 mm
Challenges in systolgy

Frame rate = 18

Diameter forskel

1 sekund

Tid

By Henrik Sillesen
Cursor position

2-6 mm. Difference!
Diameter assessment – where to measure

The true volume flow
From intima to intima

The most reproducible measurement

Taken the concept of acoustic impedance into account the ideal measurement would be from the most reproducible measurement is from leading edge adventitia ant. wall to leading edge adventitia posterior wall

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Karvæggens bestanddele

Endothelceller

Måler aldrig IMT på forreste væg

Små glatte muskelceller og elastisk fibre

Adventitia består mest af kollagen

Stor forskel i akustisk impedans fra lav til høj → Refleksion ↑
Karvæggen

Tunica media

Leading edge of intima

Lumen

Leading edge of adventitia – anterior wall

Grænsen mellem tunica media og tunica adventitia

Leading edge of intima

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Cursor position

Forreste kant af adventitia

Forreste kant af intima
Volume flow and other pitfalls

Not all vessels are circular

Most scanners assume the mean Velocity of sound is 1540 m/s

→ Systematic underestimation of the Diameter

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3-D Ultrasound

Handheld position

Real time biplane imaging

Pixels total: Scan field Dimensions are known

Pixels outside the segmentation

Pixels inside = AAA

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Repetition - If I want to do it right😊

1. Ultrasound equipment and find the on/off button

2. The right transducer: curved phased or linear array transducer

3. Adjust your B-mode image
   - Depth
   - Focal zone
   - Gain level

4. Apply color doppler image
   - Tilt the transducer or adjust steering level
   - Pulse repetition frequency level
   - Doppler gain level

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5. Spectral doppler analysis
- Parallel to flow direction
and keep the angle to the
Beam path $< 60^\circ$

6. Volume flow measurement
-The most important factor is the diameter assessment
Ultrasound Contrast media

- **Microbubbles** ≈ Red blood cells.
  - Small enough to pass through the capillaries
  - Large enough to retain in the vascular system
    - Blood pool agent → Indicator dilution principal with a wah

- Gas SF$_6$
  - Poor interaction with other molecules
  - Amphophilic shell
    - Stabilizes the gas
    - Flexible molecule

- Completely pulmonary eliminated
Contrast specific imaging

- Insonation power

- Backscatter

- High pressure
  - Oscillation
    - Harmonic frequency
    - Specific signals

- Low pressure

- Instability $\rightarrow$ destruction

Backscatter $=$ Tissue Signal

Oscillation $\neq$ Tissue signal
Contrast specific imaging

• In summary
  – Specific echo signal different from tissue
    • No tissue signals
    • No movement artifacts and blooming effects
  – Independent from blood flow velocity
    • No angle dependent color display
    • Better spatial resolution
    • Detect low flow
  – Good safety profile
    • No burden for the liver or kidneys
    • Allergic reactions are rare
In practice

• High end scanner with a contrast specific application

• SonoVue
  – 20 gauge cannula
  – Forward injection in a cubital vein.
  – 1-2 ml.
  – Last 6 hours after mixture.
  – Anti-histamin and adrenalin.
Contrast-enhanced ultrasound

- If microvascular perfusion is important.
  - Diabetic patients
- If luminal morphology is important
  - Plaque size and neovascularization
  - Thrombus size estimation
  - Near occlusion / complete occlusion
  - Flow detection
Microvasculature

C. Greis / Ultrasound contrast agents as markers of vascularity and microcirculation
A  Healthy volunteer

B  Peripheral arterial
disease

Lindner JR, Portland, Oregon. JACC: Cardiovascular imaging 2008
Flow detection
If you want to know more

• Vascular ultrasound How, why and when
   – Edited by Abigail Thrush and Tim Hartshorne
• Quantitative evaluation of microvascular blood flow by contrast-enhanced ultrasound by C. Greis. Clinical Hemorheology and Microcirculation 49 (2011) 137-149