Ultrasound Imaging of Blood Vessels

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Contents
This lecture aims to introduce to you the following existing ultrasound techniques for vascular imaging:

- B-mode images
- Doppler
- Contrast agent imaging
- Intravascular ultrasound

Ultrasound Fundamentals

- Ultrasound (US) as mechanical waves (≥20kHz)
- Wave frequency, speed and amplitude
- Propagation, reflection, and scattering
- Acoustic impedance: \( Z = \rho c \)

B-mode images

- Pulse-echo

B-mode images are good at showing some structures, but blood appears dark in B-mode images as it only contains some weak scatterers—blood cells. How to image blood flow?

Doppler

- Velocity
- Signal Power
- Blood flow detection
- Filter

Doppler for blood flow—Constant Wave (CW) Doppler

- CW Doppler detects all the velocities in the beam
- More than one velocity and these velocities change with time
- These velocities can be separated by spectrum, which contains diagnostic information

Flow spectra

Time dependent flow spectra

Pulse Doppler

- CW Doppler has no range resolution
- If transmit a pulse can get range information from time of flight
- How can a pulse give a frequency—by measuring phase
- Phase: relative position of waveform

Colour Doppler: colour code flow and superimpose on B-mode images
- Red: flow towards the probe
- Blue: flow away from the probe

However, spatial resolution relatively poor, due to long pulses used for reasonable sensitivity

Contrast Agent Imaging
Contrast agent imaging

- A chance observation during a clinical investigation in 1970s in which Dr. Joyner noted a transient increase in the ultrasound signal following each dye injection through cardiac catheter.

- Encapsulated gas bubbles:
  - Shell: lipid, serum albumin, liposome, etc.
  - Gas: perfluoropropane, air, sulphur hexafluoride.

- Figure: Micrograph of OPTISON with red blood cells (Amersham).

Bubble oscillation:
When excited by ultrasound, bubbles oscillate and produce strong echoes.

Low velocities in microvasculature:

<table>
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<tr>
<th>Velocity</th>
<th>Signal Power</th>
<th>Blood flow detection – with bubbles</th>
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<tbody>
<tr>
<td>Noise level</td>
<td>Filter</td>
<td>Nonlinearity</td>
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<tr>
<td>Tissue clutter signal</td>
<td>+30dB</td>
<td>LINEAR</td>
</tr>
<tr>
<td>x1 y1 = F(x1)</td>
<td></td>
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<tr>
<td>x2 y2 = F(x2)</td>
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<td>C y1 = F(C x1)</td>
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<tr>
<td>x1 + x2 y1 + y2 = F(x1+x2)</td>
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</tbody>
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Value of contrast agents:

- Courtesy of Dr. Becher.

- Another example: Perfusion imaging.
Quantitative imaging of tissue perfusion with contrast agents.

- Figure: Time-course of tissue perfusion.

- Panel A (right): Ultrasound images showing the presence of microbubbles binding to the arterial endothelium in a balloon-injured carotid artery.
- Panel B (right): Ultrasound images showing the absence of microbubbles in the control noninjured carotid artery.

Targeted imaging using endosonally delivered contrast agents:


- Ultrasound images showing the presence of microbubbles binding to the arterial endothelium in a balloon-injured carotid artery (Panel A, right) and the absence of microbubbles in the control noninjured carotid artery (Panel B, right).

- Scanning electron microscopy (Bar = 10 µm; magnification 1420 ×) revealed sites of injury with endothelial denudation and attachment of microbubbles (black arrows) to the denuded endothelium only in the injured vessel (A) and normal appearing endothelium in the control vessel (B).


Summary:

- Ultrasound fundamentals
- B-mode images
- Doppler
- Contrast agent imaging
- Intravascular ultrasound

- Particular imaging:
- OPENDIGITAL imaging of tissue perfusion with contrast agents

- Targeted imaging using endosonally delivered contrast agents.