Applied Principles of Ultrasound Physics

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Ultrasound Propagation thru Tissues

The reflected wave (echo) carries information about tissues where it originated.
Seven Acoustic Variables describing sound waves

<table>
<thead>
<tr>
<th><strong>Period</strong></th>
<th>Time that it takes a wave to vibrate in a single cycle (single pulse duration), or the time from the start of a cycle to the start of the next cycle (pulse repetition period); measured in microseconds for medical diagnostic ultrasound.</th>
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</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>The number of cycles that occur in one second; measured in Hertz (1 cycle / 1 second = 1 Hertz); range kHz (therapeutic) and MHz (therapeutic and diagnostic ultrasound).</td>
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<tr>
<td><strong>Amplitude</strong></td>
<td>The difference between the maximum positive or negative values over undisturbed value for pressure (measured in Pascals), density (measured in g/cm³), or particle motion or distance (measured in mm or cm).</td>
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<tr>
<td><strong>Power</strong></td>
<td>The rate of energy transfer, i.e. rate at which work is performed; measured in Watts; range under 700 mW for diagnostic ultrasound.</td>
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<tr>
<td><strong>Intensity</strong></td>
<td>The concentration of energy in the sound beam, i.e. power distribution in the area the beam is applied to; measured in W/cm².</td>
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<tr>
<td><strong>Wavelength</strong></td>
<td>The spatial length of a single complete pulse cycle; inversely related to frequency; measured in mm or cm.</td>
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<tr>
<td><strong>Propagation speed</strong></td>
<td>The distance that ultrasound travels in one second; measured as in m/s; average speed of ultrasound in soft tissues is 1540 m/s or “a mile a second”.</td>
</tr>
</tbody>
</table>
Diagnostic Ultrasound
range 1 MHz – 12 MHz
(Intravascular ultrasound >20 MHz)

thousand times a second = 1 kHz
million times a second = 1 MHz

Continuous Wave

- No depth information
- No imaging possible
- Only flow detection

Pulsed Wave

- Depth discrimination
- Imaging (echo strength)
- Flow detection

Depth is calculated from the average speed of sound in soft tissues: 1540 m/s (a mile a second) and time from firing a pulse to registering returned echoes (i.e. round trip time).

Christian Doppler
1803-1853

Transcranial Doppler Sonography
Edited by R. Aaslid
Springer-Verlag Wien New York

1982
GEBURTSHAUS DES PHYSIKERS
CHRISTIAN DOPPLER
ENTDECKERS DES NACH IHN BENANNTEN
ASTROPHYSISCHEN PRINZIPS

GEB: 29. NOVEMBER 1803 - GEST: 17. MÄRZ 1853

Zu seinem hundertsten Geburtsfeste
die Gesellschaft für Salzburger Landeskunde.
What is Doppler Shift?
Transcranial Doppler

Depth 50 mm

Gate 10 mm

Single Channel Multi-Depth Sampling

Single gate TCD

Multi-gate Spectral Doppler

Multi-Transducer Linear Array

Conventional vs ZS Acquisition

Key Elements of Duplex Imaging

Gray image = B-mode
Color flow = Doppler

B-mode – brightness of returned echoes
Doppler – frequency shift from moving blood

Brightness (B-mode) Ultrasound

- Weak reflectors
- Red blood cells
- Adventitia
- Calcium
- Bright reflectors
- Artifact

Key Elements of Duplex Imaging

Time Gain Compensation (TGC)

Partial volume averaging

scanning plane

object above

object below

plaque

superimposed flow

Refraction

- speed 1 = speed 2
- speed 1 > speed 2
- speed 1 < speed 2

Rayleigh Scattering

- wavelength and emitted pulse amplitude
- red blood cell
- reflected echo amplitude and direction

Refraction artifact

Mirror artifact

Which Artifact Does this Image Show?
Flow Velocity Increase

single most valuable predictor of stenosis severity
Spectral Broadening vs Narrowing

The Spencer’s Curve