B- Mode Ultrasound
Optimization for Imaging Plaque Features

John B. Bennett, PhD, RVT

As we know, there are known knowns. There are things we know we know.
We also know there are known unknowns. That is to say we know there are some things we do not know.
But there are also unknown unknowns, the ones we don’t know.

Donald Rumsfeld, 2002

What would Nascet look like today?
Statins?
Antiplatelets?

B-Mode Ultrasound
Optimization for Imaging Plaque Features

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Disclosures
• Consultant
  – Viasonix Vascular

Sound Waves:
Alternating Regions of High & Low Pressure
Frequency & Wavelength

High frequency has short wave length
Low frequency has long wavelength

1 Cycle per second = 1 Hertz

Piezo Electric Crystal

Transmit Power controls Amplitude of Wave

Sound Waves in Tissue: Scatter

The Mechanism responsible for the vast majority of returning echoes

The Display

The strength of the returning waves (echoes) are displayed as:
- Amplitude (A-Mode) OR,
- Gray Scale or Brightness (B-Mode)

Side Bar: Acoustic Impedance

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Z + d x V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>7 x 10^-6</td>
</tr>
<tr>
<td>Bone</td>
<td>2 x 10^-8</td>
</tr>
<tr>
<td>Oil</td>
<td>1 x 10^-8</td>
</tr>
<tr>
<td>Water</td>
<td>1 x 10^-8</td>
</tr>
<tr>
<td>Fat</td>
<td>1 x 10^-8</td>
</tr>
</tbody>
</table>

Side Bar: Gray Scale/Dynamic Range

The Gray Scale Map and Dynamic Range can be adjusted using Front Panel Controls and Optimized for each application.
Sound Waves in Tissue: Attenuation

Controls that help address Attenuation

Frequency
- (uro, speed, PRF)
- Power
- Gain
- TGC

Resolution vs. Penetration

Beam Focusing

Optimize Focus

Side Bar: Frame Rate

The Frame Rate can be adjusted to optimize performance for the application.

The faster the target is moving, the higher the frame rate required to accurately place/follow the target.

Maximum frame rate is dependent on depth, PRF, # focal zones, window size, etc.

*Not to be confused with Persistence (frame averaging) which also affects motion depiction.
B-mode Ultrasound
- “Direct” test
- “Real Time”
- Provides anatomical information
  - Spatial relationships
  - Vessel identification
  - Atherosclerotic plaque
  - Provides roadmap for Doppler sampling
  - Allows visualization of source of Sx, events

Advantages of B-Mode
- Very good at differentiating between adjacent tissues of different acoustic impedance (density)
- Real Time
- Multiplanar
- Safe (no ionizing radiation)
  - Serial follow up
- Inexpensive

B-mode Terminology – “Echogenicity”
- Strong (echo rich) = “hyperechoic”
  - dense fibrotic plaques
  - calcification
- Weak (echo lacking) = “hypoechoic” or “anechoic”
  - fluid collections, blood
  - lipid collections
- Mid level echoes = “echoic” or “isoechoic”
  - muscle, liver, loose stroma, organized thrombus, fatty plaques, neovascularization

Side Bar: Acoustic Impedance

B-mode Terminology (Patterns of Echogenicity)
Homogeneous
- echoes are predominantly of similar echogenicity

Heterogeneous
- echoes are of mixed areas echogenicity (“hyper” and “hypo”)
  *especially when these areas are immediately adjacent

Mixed

B-Mode Plaque Morphology
Hyperechoic areas within plaques have been shown to be associated with:
- dense fibrous plaques
- varying amounts of calcification
B-Mode Plaque Morphology

Anechoic or hypoechoic areas within plaques have been shown to be associated with:
- hemmorhage
  - outside in?
  - inside out?
- soft (fresh) thrombus
- lipid core(s)
- ulceration, fracture, fissure

Reilly et al. (1983)

B-Mode Plaque Morphology

• Echoic or isoechoic areas have been shown to be associated with:
  - Smooth muscle
  - Loose stroma
  - Fibro-collagenous plaque
  - Neovascularization

Describing the “Hypoechoic” Area

• The size or proportion of the hypoechoic area
• Proximity to cap (lumen)

Plaque Surface Characteristics

- Smooth uninterrupted, smooth surface
- Irregular irregular surface without obvious interruption of cap
- Possible obvious interruption of cap continuous with hypoechoic area within plaque, crater, tunnel
  * Attempt to document in at least 2 views
  * Color or Power Doppler can be helpful

Plaque Surface Characteristics

- Smooth uninterrupted, smooth surface
- Irregular irregular surface without obvious interruption of cap
- Possible obvious interruption of cap continuous with hypoechoic area within plaque, crater, tunnel
  * Attempt to document in at least 2 views
  * Color or Power Doppler can be helpful
Plaque Surface Characteristics

- Smooth: uninterrupted, smooth surface
- Irregular: irregular surface without obvious interruption of cap
- Possible Ulceration or Fracture: obvious interruption of cap continuous with hypoechoic area within plaque, crater, tunnel

* Attempt to document in at least 2 views
* Color or Power Doppler can be helpful

Limitations of B-mode

- Not validated in clinical trials
- 2 Dimensional (3-D available)
- Interobserver variability
- Highly operator dependent
- Variability in equipment performance
- Variability in patients (body habitus, U/S)
- No "standardized" accepted classification system
- Inconsistency of reference standard
  - Symptoms, events
  - CEA specimens

User Influence on B-mode

- Optimize Transducer Selection & Settings
- Optimize Focus
- Low Persistence
- High Frame Rate
- Maximum Dynamic Range (Gray Scale)
- Optimize TGC
- Optimize Overall Gain
- Beam perpendicular to artery or plaque surface
- Plaque occupies significant portion of image

Frequently Overlooked

- Monitor Settings (Sonographer & Reader)
  - Contrast
  - Brightness
  - Adjusted for background light

Additional Recommendations

- Correlate with Hx, Sx
- Correlate with CEA Specimens
  - Go to the OR (or Pathology)
- Correlate with other imaging modalities
- Continuing Education
  - Physicians
  - Sonographers
- Commit to Certification
- Commit to Accreditation

Suggestion:

Hire the best Sonographer/Technologist you can afford!

Communicate Regularly!
Etiology of Embolic Stroke

Specific plaque features are associated with neurologic events

Reilly, Lusby, et al. (1982)
Johnson et al. (1985)
Carr et al. (1996)
AbuRhama et al. (1999)

Key morphologic features of vulnerable plaques include:

- A thin or interrupted cap
- A significant hypoechoic component
- Active inflammation
- Severe stenosis
- Serial rapid progression of stenosis or plaque
- A combination of these

Ulcerated Plaques

- Increased risk for Sx
  - High grade stenosis = even greater risk
- More frequently reported by CT & Angio
- Can also be demonstrated by B-mode
  - Highly operator dependent

AbuRhama et al (J Endovasc Surg 1999)
AbuRhama et al (Stroke 2002)

<table>
<thead>
<tr>
<th>Stenosis Classification (N)</th>
<th>Symptomatic</th>
<th>Asymptomatic</th>
<th>Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous Plaques, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50%</td>
<td>794</td>
<td>127 (16)</td>
<td>8.9 (5.8–13.7)</td>
</tr>
<tr>
<td>≥50–60%</td>
<td>564</td>
<td>78 (21)</td>
<td>11.9 (7.7–18.5)</td>
</tr>
<tr>
<td>≥60%–&lt;70%</td>
<td>487</td>
<td>43 (23)</td>
<td>12.6 (7.9–20)</td>
</tr>
<tr>
<td>≥70%–99%</td>
<td>615</td>
<td>37 (31)</td>
<td>13.7 (8.4–22.4)</td>
</tr>
<tr>
<td>Total</td>
<td>2460</td>
<td>285</td>
<td>14.9 (12.3–18.3)</td>
</tr>
</tbody>
</table>

P values are for symptomatic homogeneous vs heterogeneous plaques within stenosis classification.

* TIA/stroke.

Plaque Fracture?

Hypoechoic Component Near Surface

3 Little Pigs

Hypoechoic Area in Plaque Near Surface in Case of Recent CVA

2 Plaque classification Schemes
Smooth Plaque

Irregular Plaque w/o Obvious Ulceration

Suggestive for Ulceration

Longitudinal View

Transverse View

Angio

Color & CEU Can Be Helpful to Confirm Presence of Ulceration
Plaque Remodeling?

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