Basics of Intravascular Ultrasound

Sang-Wook Kim, MD
Professor of Medicine
Director of Heart Research Institute
Cardiovascular-Arrhythmia Center
Chung-Ang University Medical Center
Basics of Intravascular Ultrasound

★ Physics
★ Terminology
★ Imaging Protocol
★ Basic Understanding
★ Summary
Two types of IVUS

Mechanical (rotating transducer) vs. Electronic Array

Sound Wave

Create electrical Impulse
Converted into the image

Piezoelectric Effect

Transducer Design

Reflected
Spatial Resolution

- Ability to discriminate small adjacent objects
- Resolution increases as transducer frequency increases;

**Axial resolution**
- along the ultrasound beam (or radius of the artery)
- 80-100 μm

**Circumferential resolution**
- along the circumference of the artery
- is affected by NURD

**Lateral resolution**
- along the long axis of the artery
- is affected by pullback and beam width
- 200-250 μm
**Near Field and Far Field**

<table>
<thead>
<tr>
<th></th>
<th>Near Field</th>
<th>Far Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVUS beam</td>
<td>fairly parallel for a distance</td>
<td>begins to diverge</td>
</tr>
<tr>
<td>Resolution</td>
<td>Better</td>
<td>Less</td>
</tr>
<tr>
<td>Image quality</td>
<td>Better</td>
<td>Worse</td>
</tr>
</tbody>
</table>

Length of the near field: \( L = \frac{r^2}{\lambda} \)

- \( L \); length of the near field
- \( r \); radius (aperture) of the transducer
- \( \lambda \); wavelength
Contrast Resolution (Dynamic Range)

The number of shades of grey (회색음영) that can be differentiated between the weakest and the strongest targets.

**High dynamic range**
More shades of grey and can differentiate more different tissue types and more structural elements.

**Low dynamic range**
Images appear “black and white” with only a few “in between” gray-scale levels.
Three layer appearance of normal vessel wall, with the muscular media being revealed as a low signal layer comprised between internal and external lamina.
Three Layers Appearance
EEM and Lumen

The third and outer layer is consists of the adventitia and periadventitial tissues. **External elastic membrane** is the outer layer of the vessel in IVUS measurement because the border of adventitia and periadventitial tissue is not distinct.

Intimal leading edge can be easily identified because the intima has thickened enough to be resolved as a separate layer and has sufficiently different acoustic impedance from the lumen in normal segments.
Classification of Plaque

- Grey scale IVUS -

Soft plaque

Fibrotic plaque

Calcific plaque

Mixed plaque
Soft plaque

Not as bright as the adventitia (hypoechoic) low echogenicity
Fibrotic plaque

As bright or brighter than the adventitia (hyperechoic)
High echo (brighter than the adventitia)
Obstructs the penetration of ultrasound (acoustic shadowing)
Only the leading edge is detected and thickness cannot be determined
Imaging Procedure

★ IVUS catheter was advanced 10 mm distal to the target lesion, and imaging was performed retrograde back to aorto-ostial junction pull-back speed; 0.5 mm/sec
★ Don’t forget to use heparin - avoid thrombosis
★ Remember to give intracoronary NTG prior to imaging - avoid spasm
★ Disengage guiding catheter when imaging aorto-ostial lesions - avoid confusing the guiding catheter with the ostium
★ Careful Saline flush with rotating catheter using 1 ml syringe, more than 10 ml saline flush
Confusing the guiding catheter with the ostial lesion
## Pullback Methods

<table>
<thead>
<tr>
<th>Feature</th>
<th>Motorized Pullback</th>
<th>Manual Pullback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady, slow pullback</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Skipping over pathology</td>
<td>No</td>
<td>Possible</td>
</tr>
<tr>
<td>Length measurements</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Volume measurements</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Regions of interest</td>
<td>potentially inadequate examination because transducer does not remain long</td>
<td>concentrate on specific ROI by pausing the pullback at a specific location</td>
</tr>
<tr>
<td>Reproducible image acquisition</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
CTO guiding

Hemodynamic Unstable
Tight lesion IVUS jumping
**Direct Measurements**;
Reference EEM Area = 9.90 mm$^2$
Reference Lumen Area = 6.84 mm$^2$
Lesion EEM Area = 6.49 mm$^2$
Lesion Lumen Area = 1.69 mm$^2$
Maximum Plaque thickness = 1.3 mm
Minimum Plaque thickness = 0.15 mm
Lesion Maximum Lumen Diameter = 1.58 mm
Lesion Minimum Diameter = 1.38 mm
Arc of Calcium = 40 degree
Lesion length = 12 mm

**Derived Measurements**;
Lesion Plaque Area = 4.79 mm$^2$
Lesion Plaque Burden = 73.9 %
Remodeling Index = 0.7
Lesion Lumen Eccentricity Index = 0.83
Plaque Eccentricity Index = 0.12
Basic IVUS Measurements

**Draw border (circles)**
- External elastic membrane (EEM)
- Lumen-intima border

**Measures**
- EEM area (vessel area)
- Lumen area
- Plaque area
- Plaque burden (%)

Plaque burden (%) = \( \frac{\text{EEM area} - \text{Lumen area}}{\text{EEM area}} \times 100 \)
Reference Segment can be defined

Most normal looking area  
(site with largest lumen with minimal plaque burden)

Within 10mm from the lesion site (maximum stenosis)

No intervening major side branches.

an average having 35 to 50% plaque burden on IVUS.

Most normal looking site (largest lumen with minimal plaque burden)
Within 10mm from the lesion site
No intervening major side branches

<table>
<thead>
<tr>
<th>Proximal Reference</th>
<th>Ruptured plaque</th>
<th>Minimal lumen area site</th>
<th>Diagonal Br</th>
<th>Distal Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0 mm</td>
<td></td>
<td></td>
<td></td>
<td>3.21 mm</td>
</tr>
</tbody>
</table>
COMPENSATORY ENLARGEMENT OF HUMAN ATHEROSCLEROTIC CORONARY ARTERIES

SEYMOUR GLAGOV, M.D., ELLIOT WEISENBERG, B.A., CHRISTOPHER K. ZARINS, M.D., REGINA STANKUNAVICIUS, M.P.H., AND GEORGE J. KOLETTIS, B.A.

N Engl J Med. 1987
Remodeling Index

The remodeling index is calculated as the EEM CSA at the MLA divided by the average of the proximal and distal reference EEM CSA.

\[
\frac{\text{EEM CSA at Lesion site}}{\frac{\text{proximal reference EEM CSA} + \text{distal reference EEM CSA}}{2}}
\]

| ≥1.05 | <0.95 |
| Positive remodeling | Intermediate remodeling | Negative remodeling |
Positive remodeling

Remodeling Index 1.3

Proximal reference 16.55 mm²
Lesion site 20.86 mm²
Distal reference 15.9 mm²
Negative remodeling

Proximal reference 13.12 mm²

Lesion site 9.96 mm²

Distal reference 13.57 mm²

Remodeling Index 0.7
Calcium Measurements

1. Calcium Location
   1) **Superficial Ca**
      ; the leading edge of the acoustic shadowing appears within superficial
   2) **Deep Ca**
      ; deep 50% of the atheroma thickness

2. The Arc of Calcium (in degree)
   ; can be measured by using an electronic protractor centered on the calcium.

3. The Length of the Calcified Deposit
   ; can be measured using motorized transducer pullback.
Superficial calcium

Deep calcium
Calcium Measurements

EEM area = 6.52 mm$^2$, Lumen area = 6.98 mm$^2$, plaque area = 9.54 mm$^2$

Calcium degree = 85.9 degree, 32.8 degree, total 118.7 degree
Calcium arc = 2.56 mm, 1.00 mm, total 3.56 mm
40MHz

HD-IVUS

60MHz
Five Coronary Phantoms with known Lumen Diameters of 1.51, 2.03, 3.04, 4.04, and 5.04 mm were imaged in a saline-filled tank at 37 ℃.

Honda et al, TCT 2014
Careful AIR !!
Guidewire kinking (twisted) cause a dissection/plaque rupture when remove the catheter
Extreme force to push IVUS catheter

Produce a dissection/plaque rupture, IVUS in stuck
Summary

IVUS is reliable and established imaging modality to quantify the coronary lesion with high sensitivity and specificity.

Greyscale IVUS is the basics to understand the vessel and the other imaging modalities.
행복을 유지하는 비결 6 가지

① 고마운 일을 찾아라
매일 감사 리스트를 작성

② 일하는 틈틈히 재미 [IVUS]를 찾아라
뇌신경은 재미를 느낄 때 더 큰 자극을 받아 창의력이 높아진다

③ 업무환경을 밝게 꾸며라
긍정적인 생각을 유도할 수 있는 사진이나 장식들로 책상을 꾸미기

④ 걱정노트를 만들어라
부정적인 생각을 떨쳐내고자 할 때는 이를 언어화하는 것이 효과적

⑤ 인간관계에 투자하라
하루에 한사람씩 다가가는 노력부터 시작

⑥ 쉬면서 업무 효율을 높여라
90-120분 동안 일하고 5분 쉴때 업무 효율이 극대화

Fisher, A. (2009) 6 ways to be happier at work, Fortune