Relationship between plaque development and local hemodynamics in coronary arteries


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Background

- Coronary atherosclerosis major cause of death in industrialized nations
- Mechanisms of arterial plaque accumulation need to be understood
- Improvement of diagnostic methods
- Improvement of treatment (interventions)
Plaque Progression / Intervention
Background

Vessel Geometry

Accurate Model?

Plaque Development

Hemodynamics
Angiography

- Lumen

Intravascular Ultrasound

- Plaque + Wall
3-D Model
Fusion Methods

- Combines advantages of both modalities
  - Cross-sectional accuracy from IVUS
  - 3-D Geometrical accuracy from angiography

- Detailed talk on IVUS segmentation
  [5747-51, Wed. 1:20pm]
Curvature vs. Plaque Thickness

- No immediate correlation between wall shear stress and plaque thickness
- Curvature less distorted by plaque progression than shear stress
- Wall shear stress expected to be lower on *inner* bend of a curved vessel
  - *Q*: is there a direct correlation between vessel curvature and plaque distribution?
Plaque Thickness

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 RAO 120 CRAN</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>30 RAO 60 CRAN</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>30 RAO 0 CRAN</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>30 RAO 60 CAUD</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>30 RAO 120 CAUD</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Curvature Index

- Scalar value specifying:
  - Curvature magnitude
  - *inner* and *outer* curvature

- Differential geometry
  - Frenet frame
Curvature Index

(tangent)

(normal)

(curvature vectors)
## Classification Regions

<table>
<thead>
<tr>
<th>Inner curv.</th>
<th>Outer curv.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Above average.</strong></td>
<td>$R_{ai}$</td>
</tr>
<tr>
<td><strong>Below average.</strong></td>
<td>$R_{bi}$</td>
</tr>
</tbody>
</table>
Classification Regions \(^{(1)}\)

\[
r_{PC} = \frac{\| R_{ai} + R_{bo} \|}{\| R_{ai} + R_{bo} + R_{ao} + R_{bi} \|}
\]

Hypothesis test: \( r_{PC} > 0.5 \)
Results — Curvature/Plaque

$R_{PC}$

$n = 53$

Curvature Threshold ($T$) [°/cm]
Classification Regions \(^{(2)}\)

\[ r_{PW} = \frac{\| R_{al} + R_{bh} \|}{\| R_{al} + R_{bh} + R_{ah} + R_{bl} \|} \]

Hypothesis test: ?
Wall Shear Stress vs. Plaque

- Correlation should be found in segments of “early disease”
  - *Q:* how to be defined?

- Glagov *et al.* found compensatory enlargement at <40% area stenosis
  - *Q:* correlation better than in >40%?
Grouping by Disease Severity

Legend:

- <10%
- <40%
- >40%

(area stenosis)

Calc. Excl.
Grouping by Disease Severity

1. exclude: branches, stents, calcifications
Grouping by Disease Severity

2.

Example Vessel A

Example Vessel B

Set #2

exclude: >40% area stenosis

Set #2a
Grouping by Disease Severity

Example Vessel A

Set #2
exclude: >40% area stenosis

Example Vessel B

Set #2α

3. exclude: vessels for which <35% of segments have <40% area stenosis
Grouping by Disease Severity

Example Vessel A

Set #3
exclude: >40% area stenosis

Example Vessel B

Vessel excluded

Set #3a
Vessel excluded
Classification Regions \((2.1)\)

\[
r_{PW} = \frac{\| R_{al} + R_{bh} \|}{\| R_{al} + R_{bh} + R_{ah} + R_{bl} \|}
\]

Hypothesis: \[
\frac{r_{PW}}{0-100\% \text{ area-stenosis}} > 1
\]
Results Sets #2 vs. #2a

\[ y = 1.0677x - 0.0502 \]

\[ R^2 = 0.2811 \]

\[ p > 0.4 \]

\[ n = 39 \]
Results Sets #2 vs. #2a

- Equation: $y = 1.0677x - 0.0502$
- Coefficient of determination: $R^2 = 0.2811$
- p-value: $p > 0.4$
- Sample size: $n = 39$
$y = 1.1659x - 0.0568$

$R^2 = 0.86$

$p < 0.005$

$n = 24$
## Results – Summary

<table>
<thead>
<tr>
<th>$r_{PW}$</th>
<th>Increase</th>
<th>Same</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2 / #2a</td>
<td>59% (23)</td>
<td>5% (2)</td>
<td>36% (14)</td>
</tr>
<tr>
<td>#3 / #3a</td>
<td>75% (18)</td>
<td>8% (2)</td>
<td>17% (4)</td>
</tr>
</tbody>
</table>
Conclusions

- Direct plaque-thickness/curvature correlation in majority of vessels
- No direct plaque/wall-shear-stress correlation can be determined
- Plaque/wall-shear-stress correlation predominantly in vessel segments in early stages of atherosclerosis
Acknowledgments

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Acknowledgments

Thank you!

http://www.engineering.uiowa.edu/~awahle