Mechanism of Lumen Enlargement During Intracoronary Stent Implantation
An Intravascular Ultrasound Study

Javed M. Ahmed, MD; Gary S. Mintz, MD; Neil J. Weissman, MD; Alexandra J. Lansky, MD; Augusto D. Pichard, MD; Lowell F. Satler, MD; Kenneth M. Kent, MD, PhD

Background—Intravascular ultrasound analysis has assessed mechanisms of lumen enlargement after nonstent interventions, but not after stenting.

Methods and Results—Preintervention and postintervention intravascular ultrasound was used to study 25 de novo native coronary lesions treated with single MultiLink stents without preatheroablation. External elastic membrane, lumen, and plaque and media (P&M) areas were measured every 1 mm to include the lesion and reference segments that were 5 mm proximal and distal to it. Lesion mean lumen area increased from 4.0±1.0 mm² before the intervention to 8.8±2.0 mm² after the intervention (P<0.0001) as a result of an increase in mean external elastic membrane area (14.2±2.7 to 16.1±3.0 mm², P<0.0001) and a decrease in mean P&M area (10.2±2.2 to 7.2±1.8 mm², P<0.0001). The decrease in lesion P&M was accompanied by an increase in both proximal reference mean P&M (7.0±1.9 to 8.4±2.0 mm², P<0.0001) and distal reference mean P&M (5.8±2.1 to 7.2±2.1 mm², P<0.0001). Volumetric analysis showed an axial redistribution of plaque away from the center of the lesion toward the reference segments to increase the plaque burden in both the proximal and distal reference segments. Total (lesion plus reference) mean P&M decreased from 8.6±2.1 to 7.5±1.8 mm² (P<0.0001).

Conclusions—The mechanisms of lumen enlargement after stenting involved (1) significant axial redistribution of plaque from the lesion into the reference segments, (2) vessel expansion, and (3) either plaque embolization or compression. (Circulation. 2000;102:7-10.)

Key Words: stents ■ ultrasonics ■ imaging

Intravascular ultrasound (IVUS) has been used to study the mechanisms of lumen enlargement with balloon and most new angioplasty devices.1-7 However, the design of first-generation stents, especially the Palmaz-Schatz stent, precluded consistent imaging of peri-stent arterial structures. Thus, despite the fact that stent implantation is the dominant current catheter-based intervention, the mechanism of lumen enlargement after stenting has not been studied in detail. The design of second-generation stents, especially the MultiLink stent, permits routine measurements of external elastic membrane (EEM) and plaque and media (P&M) cross-sectional areas (CSAs). The aim of the current study was to use sequential IVUS imaging before and after MultiLink stent implantation to determine the mechanisms of lumen enlargement after intracoronary stenting.

Methods

Patient and Lesion Population
We studied 25 consecutive patients (16 men and 9 women with a mean age of 61±12 years) with 25 nonostial, noncalcified, de novo native coronary lesions treated with a single ACS MultiLink DUET stent without preatheroablation (Guidant Corporation). Lesion locations included the left anterior descending artery (n=8), the left circumflex artery (n=5), and the right coronary artery (n=12). An 8-mm-long stent was used in 5 patients, a 13-mm-long stent in 11 patients, and an 18-mm-long stent in 9 patients.

Stent Deployment and IVUS Imaging
All stents were implanted using inflations of 12 to 16 atm. Optimal deployment (a minimum stent CSA of 80% of the average reference lumen area or a minimum stent CSA of 7.5 mm² with complete stent-vessel apposition) was achieved using interactive IVUS.

All IVUS studies were performed after the administration of 200 µg of intracoronary nitroglycerine. Preintervention IVUS was performed before predilation. Postintervention IVUS was done as the final step in the procedure. The commercially available sector scanner (Boston Scientific Corporation) used in this study incorporated a single-element 30 or 40 MHz beveled transducer mounted on the tip of a flexible shaft rotated at 1800 rpm within a 3.2 or 2.6 French short monorail imaging sheath. The IVUS catheter was advanced ~10 mm distal to the lesion. The entire artery was imaged retrograde to the aorto-ostial junction using motorized transducer pullback at 0.5 mm/s.

Angiographic Analysis
Quantitative coronary angiography was performed using computer-assisted automated edge-detection (CMS, MEDIS). With the external

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Coronary Angiography and IVUS Measurements

<table>
<thead>
<tr>
<th></th>
<th>Preintervention</th>
<th>Postintervention</th>
<th>Change (Pre vs Post)</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td><strong>QCA</strong></td>
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<tr>
<td>Proximal reference</td>
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<tr>
<td>Distal reference</td>
<td></td>
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<tr>
<td>Minimal lumen diameter</td>
<td>1.18±0.48</td>
<td>2.72±0.50</td>
<td>-1.54±0.52</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Diameter stenosis, %</td>
<td>60.0±0.16</td>
<td>10.0±0.07</td>
<td>-50.0±0.16</td>
<td>&lt;0.0001</td>
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<tr>
<td><strong>IVUS</strong></td>
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<tr>
<td>Proximal reference</td>
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<tr>
<td>Mean EEM CSA, mm²</td>
<td>15.6±3.3</td>
<td>15.9±3.3</td>
<td>0.3±0.6</td>
<td>0.0008</td>
</tr>
<tr>
<td>Mean lumen CSA, mm²</td>
<td>8.5±2.1</td>
<td>7.5±2.0</td>
<td>-1.0±0.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean P&amp;M CSA, mm²</td>
<td>7.0±1.9</td>
<td>8.4±2.0</td>
<td>1.4±0.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Plaque burden, %</td>
<td>45±8</td>
<td>53±8</td>
<td>8±8</td>
<td>&lt;0.0001</td>
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<tr>
<td><strong>Lesion</strong></td>
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<tr>
<td>Mean EEM CSA, mm²</td>
<td>14.2±2.7</td>
<td>16.1±3.0</td>
<td>1.9±1.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean lumen CSA, mm²</td>
<td>4.0±1.0</td>
<td>8.8±2.0</td>
<td>4.8±2.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean P&amp;M CSA, mm²</td>
<td>10.2±2.2</td>
<td>7.2±1.8</td>
<td>-3.0±2.3</td>
<td>&lt;0.0001</td>
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<tr>
<td>Distal reference</td>
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<tr>
<td>Mean EEM CSA, mm²</td>
<td>13.4±3.2</td>
<td>13.7±3.1</td>
<td>0.3±0.4</td>
<td>&lt;0.0001</td>
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<tr>
<td>Mean lumen CSA, mm²</td>
<td>7.5±1.7</td>
<td>6.5±1.6</td>
<td>-1.0±0.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean P&amp;M CSA, mm²</td>
<td>5.8±2.1</td>
<td>7.2±2.1</td>
<td>1.4±0.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Plaque burden, %</td>
<td>43±8</td>
<td>52±7</td>
<td>9±7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total mean P&amp;M CSA, mm²</td>
<td>8.6±2.1</td>
<td>7.5±1.8</td>
<td>-1.1±1.3</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Values are mean±SD. QCA indicates quantitative coronary angiography. *P<0.05 vs proximal reference.

IVUS Analysis
With the use of reproducible axial landmarks (side branches, aorto-ostial junction, and perivascular markings) and a known pullback speed (0.5 mm/s), identical cross-sectional image slices 1 mm apart were identified and measured before and after the intervention using computerized planimetry (TapeMeasure, Indec Systems). The arterial segment included 5 mm of distal reference, the lesion, and 5 mm of proximal reference. Pre- and postintervention EEM, lumen, and P&M (EEM minus lumen) CSAs and plaque burden (P&M divided by EEM) were averaged within the distal reference segment, the lesion site, and the proximal reference segment. Validation of IVUS area and longitudinal measurements has been reported.8–12

Statistical Analysis
Statistical analysis was performed using StatView 4.5 (SAS Institute). Continuous variables (presented as mean±1SD) were compared using a paired Student’s t test, regression analysis, or factorial ANOVA (with the Bonferroni correction for multiple comparisons). P<0.05 was considered significant.

Results
Quantitative coronary angiography results are shown in the Table. Lesion length was 9.20±2.79 mm.

Planar IVUS results before and after the intervention are shown in the Table. After the intervention, an increase in mean lesion lumen CSA resulted from an increase in mean lesion EEM CSA and a decrease in mean lesion P&M CSA. The P&M CSA reduction contributed more toward lumen enlargement than did the EEM increase (58±22% versus 42±22%, P=0.065).

The decrease in lesion P&M was accompanied by an increase in proximal and distal reference segment P&Ms and a decrease in proximal and distal reference lumen dimensions (Table). Only a minimal increase occurred in the proximal and distal reference EEMs; this was significantly less than the increase in lesion EEM (P<0.0001 for both comparisons). No differences existed in the proximal versus distal reference segment changes in EEM, lumen, and P&M CSAs.

Figure 1 shows IVUS measurements for the 18-mm MultiLink stents. The increase in lumen CSA was greatest in the center of the lesion (P<0.0001 by ANOVA). Plaque was redistributed axially, away from the center of the lesion, toward the ends of the lesion, and into the proximal and distal reference segments (P<0.0001 by ANOVA). Postintervention EEM, lumen, and P&M CSAs did not vary over the length of the stent (P>0.9 by ANOVA for all comparisons). There was a greater increase in proximal and distal reference P&Ms and a greater decrease in proximal and distal reference lumens in the slices closest to the edges of the stent (P<0.01 by ANOVA). These findings were similar for the 13-mm and 8-mm stents.

The total (lesion plus reference) mean P&M CSA decreased significantly (Table). The postintervention total P&M correlated with the preintervention P&M (r=0.919, P<0.0001, Figure 2A). The decrease in total P&M correlated with the preintervention P&M (r=0.525, P=0.0071, Figure 2B).
Discussion

IVUS studies of the mechanisms of lumen enlargement after catheter-based interventions have shown plaque reduction (ablation, removal, embolization, or compression), plaque redistribution, vessel expansion, and dissection, depending on the device and plaque composition.1–7 In the current study, lumen enlargement after stenting was a combination of plaque redistribution (within the lesion), plaque extrusion (into contiguous reference segments), vessel expansion, and plaque compression/embolization. These mechanisms are similar to those after balloon angioplasty2 except, presumably, the stent tended to keep the redistributed plaque components “in place,” preventing recoil.

Plaque Redistribution/Extrusion

Postintervention EEM CSAs did not vary over the length of the stent, which suggests that plaque redistribution occurred because stent-related vessel expansion reached its limit. Otherwise, the poststent EEM CSA would be largest at the location of the maximum preintervention P&M CSA. Thus, plaque redistribution/extrusion may prevent vessel rupture during aggressive stent implantation.

Stent implantation changes the distribution of atherosclerotic plaque. Poststent plaque burden is a predictor of neointimal hyperplasia13; thus, plaque “shifting” may contribute to the pattern of neointimal hyperplasia accumulation. In the porcine model, neointimal thickness correlates with vessel injury, which is determined by the depth of stent wire penetration.14 Plaque redistribution may contribute to stent-wire medial disruption by decreasing P&M thickness.

Increased reference segment plaque burden and decreased reference segment lumen dimensions may contribute to edge restenosis15 and to the “step-up/step-down” angiographic appearance after stent implantation.

Plaque Compression/Embolization

Plaque compression cannot be distinguished from embolization. Macroparticle embolization and creatine kinase-MB elevation after intervention have driven the development of distal protection devices. In the current study, the decrease in P&M CSA (evidence of distal embolization) correlated with preintervention P&M CSA (Figure 2B); previously, we showed that preintervention plaque burden is a predictor of creatine kinase-MB elevation.16

Limitations

No lesion was calcified. Mechanisms of lumen enlargement may vary with plaque composition. However, calcified lesions are often heterogenous, and extrusion of noncalcified elements could still occur. We only studied one type of stent using a uniform implantation strategy. Mechanisms of lumen enlargement may be stent design–specific and related to the aggressiveness of the implantation technique.17 One previous study showed plaque redistribution during adjunct PTCA (Yasuhiro Honda, MD, unpublished observations, March 1997). We only measured 5-mm-long reference segments. The increase in reference segment plaque may extend beyond...
5 mm; this may have affected the measured decrease in total P&M. Only a small number (n = 25) of lesions were studied.

References

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