FFR and IVUS Guided DES Implantation in Long Diffuse Lesions

Can We Reach Optimal DES Expansion With Conventional Stent Delivery System in Long Diffuse Lesion?

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Suwon, Korea
Angioplasty Summit 2007-TCT Asia Pacific

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The Convention Center of Sheraton Grand Walkerhill Hotel, Seoul, Korea
Are Drug-Eluting Stents Changing Your Daily Practice?

After 24 months of DES for all patients, the point of no return has been reached and we will not come back to bare stent.

Thank you
DES Penetration in Ajou University Medical Center

Ajou University Database

Angioplasty Summit 2007
DES changes our pattern of PCI

We are getting more aggressive..
Complex Lesions
Long Diffuse Lesions
Small Vessels
Diabetic Patients
DES Mania .. Metal Jacket ..
Do we have optimal stent expansion in every stent?
Evaluation of Stent Expansion in Long Diffuse Lesion

No expert can be perfect with visual assessment...
Optimal DES expansion and apposition is important..

- Optimal expansion and uniform apposition facilitates drug delivery \(^2,3,4,5\)
- Incomplete apposition may contribute to stent thrombosis\(^1\)
- Stent underexpansion may increase risk for restenosis and TLR \(^6,7\)

4. Leon, M. *The basic “tips and tricks” for DES implantation*; TCT 2003 presentation
5. The TAXUS Stent Directions for Use
Predictors of Restenosis and Target Vessel Revascularization after SES Implantation

Clinical variables
  Diabetes

Angiographic variables
  Small reference vessel diameter
  Ostial location
  Non–left anterior descending artery lesion
  In-stent restenosis

Procedural variables
  Long stent length
  Small stent diameter or minimal stent area (MSA) by IVUS
### Predictors of Drug-Eluting Stent Thrombosis

<table>
<thead>
<tr>
<th>Clinical variables</th>
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<tbody>
<tr>
<td>Diabetes</td>
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<tr>
<td>Renal failure</td>
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<td>Low ejection fraction</td>
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<table>
<thead>
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<td>Bifurcation lesions</td>
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<table>
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<th>Procedural variables</th>
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<tr>
<td>Use of multiple stents</td>
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<tr>
<td>Use of long stents</td>
</tr>
<tr>
<td>Small final stent area (MSA) by IVUS</td>
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<tr>
<td>Stent underexpansion</td>
</tr>
<tr>
<td>Residual reference segment stenosis</td>
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<table>
<thead>
<tr>
<th>Postprocedural variables</th>
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<tbody>
<tr>
<td>Premature discontinuation of antiplatelet therapy</td>
</tr>
</tbody>
</table>
Predictors of angiographic restenosis in 550 patients with 670 native artery lesions in patients treated with Cypher Stents

(Hong et al. Euro Heart J 2006;27:1305-10)
Post-dilatation with non-compliant balloons double the rate of optimum stent deployment.

Optimal stent deployment* is only achieved in 29% of patients with current stent delivery systems; usually due to inability of stent delivery balloon to expand fully the stent to nominal size.

*MSD ≥ 90% of average reference lumen diameter
The DES achieved only 75% of predicted MSD and 66% of predicted MSA.

This was similar form SES and PES.

24%-28% of DES did not achieve a final MSA of 5.0 mm².

<table>
<thead>
<tr>
<th>Minimal stent diameter (mm)</th>
<th>3.2 ± 0.3</th>
<th>3.1 ± 0.4</th>
<th>.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal stent cross-sectional area (mm²)</td>
<td>6.1 ± 1.6</td>
<td>6.2 ± 1.9</td>
<td>.5</td>
</tr>
<tr>
<td>IVUS/manufacturer’s predicted stent diameter (%)</td>
<td>75.6 ± 10.3</td>
<td>74.6 ± 11.0</td>
<td>.5</td>
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<tr>
<td>IVUS/manufacturer’s predicted stent cross-sectional area (%)</td>
<td>66.0 ± 16.2</td>
<td>65.4 ± 18.1</td>
<td>.4</td>
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</table>
### Table 3
Comparison of postintervention IVUS parameters at different delivery pressures

<table>
<thead>
<tr>
<th>Variable</th>
<th>SES (n=46)</th>
<th>PES (n=41)</th>
<th>P value</th>
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<tbody>
<tr>
<td><strong>14 atm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min stent CSA (mm²)</td>
<td>5.0±1.4</td>
<td>5.6±2.1</td>
<td>.15</td>
</tr>
<tr>
<td>Max stent CSA (mm²)</td>
<td>6.9±1.9</td>
<td>8.0±2.4</td>
<td>.007</td>
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<tr>
<td>Min stent diameter (mm)</td>
<td>2.34±0.33</td>
<td>2.40±0.50</td>
<td>.46</td>
</tr>
<tr>
<td>Max stent diameter (mm)</td>
<td>2.93±0.37</td>
<td>3.35±0.50</td>
<td>&lt;.0001</td>
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<tr>
<td>Axial stent symmetry</td>
<td>0.73±0.11</td>
<td>0.69±0.13</td>
<td>.08</td>
</tr>
<tr>
<td>Radial stent symmetry</td>
<td>0.80±0.09</td>
<td>0.72±0.09</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Underexpansion</td>
<td>37/46 (80.4%)</td>
<td>26/41 (63.4%)</td>
<td>.08</td>
</tr>
<tr>
<td><strong>20 atm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min stent CSA (mm²)</td>
<td>6.4±1.7</td>
<td>6.0±2.0</td>
<td>.30</td>
</tr>
<tr>
<td>Max stent CSA (mm²)</td>
<td>8.0±1.9</td>
<td>8.4±2.3</td>
<td>.44</td>
</tr>
<tr>
<td>Min stent diameter (mm)</td>
<td>2.64±0.34</td>
<td>2.51±0.44</td>
<td>.16</td>
</tr>
<tr>
<td>Max stent diameter (mm)</td>
<td>3.20±0.38</td>
<td>3.45±0.48</td>
<td>.01</td>
</tr>
<tr>
<td>Axial stent symmetry</td>
<td>0.82±0.11</td>
<td>0.70±0.10</td>
<td>.0004</td>
</tr>
<tr>
<td>Radial stent symmetry</td>
<td>0.83±0.08</td>
<td>0.73±0.08</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Underexpansion</td>
<td>22/46 (47.8%)</td>
<td>9/26 (34.6%)</td>
<td>.28</td>
</tr>
</tbody>
</table>

* Stent Underexpansion by MUSIC criteria
Mechanism of Suboptimal Stent Expansion
Balloon compliance and dilation force

Compliant/Semi-Compliant

Non Compliant

High dilation force
More vessel injury

Low dilation force and
Stent Underexpansion

\[
F = \frac{\text{Pressure} \times \text{Diameter}}{2 \times \text{Wall Thickness}}
\]
Mechanism of Suboptimal Stent Expansion
Inflation pressure and dilatation force

Inflation pressure = 10 atm

Dilation force varies from

\[ 10 \times \frac{3}{2} \times 0.5 = 30 \text{ atm} \]

to

\[ 10 \times \frac{1}{2} \times 1.5 = 3.3 \text{ atm} \]
Compliance of current DES delivery system

![Graph showing compliance of DES delivery system](image)

- **DES1**: Red line
- **DES2**: Blue line
- **HPB**: Green line

**Axes:**
- **Inflation Pressure (atm)**
- **Balloon Diameter (mm)**

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**Angioplasty Summit 2007**

**Affiliation:** Ajou University Medical Center
Long Diffuse Lesion
FFR and IVUS-guided DES Implantation

- PCI with current semi-compliant stent delivery system (SDS) in long diffuse lesion may result in stretching of the balloon around the lesion rather than concentrating the force at the lesion and cannot achieve optimal stent expansion at culprit site.

- Visual angiographic estimation of stenosis may poorly correlate with anatomic and physiologic significance.

Long Diffuse Lesion
FFR and IVUS-guided DES Implantation

• Evaluate the incidence of suboptimal stent expansion with current drug SDS in long diffuse lesion.

• Evaluate effectiveness of post-stent adjuvant high-pressure non-compliant balloon dilatation.

• Identify the factors which was related with the suboptimal stent expansion.

Long Diffuse Lesion  
FFR and IVUS-guided DES Implantation

• **Inclusion Criteria**
  – 41 consecutive angina patients, 47 de novo lesions  
  – % DS on QCA >50% with evidence of myocardial ischemia  
  – Stent length > 32mm  
  – Informed consents for IVUS and FFR measurement.

• **Exclusion Criteria**
  – Restenotic lesion  
  – Acute myocardial infarction or prior myocardial infarction  
  – LV dysfunction: LVEF < 55%  
  – Left main disease  
  – Significant cardiac arrhythmia hampering physiologic study

Long Diffuse Lesion
FFR and IVUS-guided DES Implantation

Pre PCI  Stenting with SDS  Adjunctive High Pressure
(at RBP: 16-18 atm)  (Quantum at 20-22 atm)

if Post Stent FFR<0.95

IVUS  IVUS  IVUS
FFR  FFR  FFR

Pressure measurement: RADI Medical System, Uppsala, Sweden
IVUS: 40MHz Atlantis™ SR Pro, Galaxy 2 Ultrasound Imaging System, Boston Scientific Corporation, Natick, MA, USA

63 y-o Male, Unstable Angina

MLD 0.72 mm  MLA 1.15 mm²
DS 77.0%  %AS 87.6%
Lesion length 38 mm  Plaque Burden 89.3%

EY Park

Ajeon University Medical Center

Angioplasty Summit 2007
Angioplasty Summit 2007

EY Park

MLA: 4.70 mm²

MLA: 6.55 mm²
**69 y-o Male Stable Angina**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLD</td>
<td>0.58 mm</td>
</tr>
<tr>
<td>DS</td>
<td>81.0%</td>
</tr>
<tr>
<td>Lesion length</td>
<td>61 mm</td>
</tr>
<tr>
<td>MLA</td>
<td>0.94 mm²</td>
</tr>
<tr>
<td>%AS</td>
<td>87.7%</td>
</tr>
<tr>
<td>Plaque Burden</td>
<td>90.3%</td>
</tr>
</tbody>
</table>

SH Han

*Ajou University Medical Center*

Angioplasty Summit 2007
72 y-o Stable Angina

MLD 0.70 mm  MLA 2.15 mm²
DS 77.0%  %AS 72.7%
Lesion length 40 mm  Plaque Burden 80.5%

HJ Lee
Angioplasty Summit 2007
Results

47 Lesions

Stenting with Current SDS at RBP

FFR ≥ 0.95

9 Lesions (19.1%)

- MLA: 7.2 ± 1.4 mm²
- %DS: 13.7 ± 12.1%

MLA < 5.5 mm²: (2) *

38 Lesions (80.9%)

- MLA: 5.5 ± 1.5 mm²
- %DS: 26.3 ± 12.5%

FFR < 0.95

Adjunctive High Pressure

FFR ≥ 0.95 (n=16)

25 Lesions (53.2%)

- MLA: 7.1 ± 1.3 mm²
- %DS: 5.9 ± 2.2%

MLA < 5.5 mm²: (3)**

22 Lesions (47.8%)

- MLA: 5.8 ± 1.5 mm²
- %DS: 9.7 ± 6.1%

MLA < 5.5 mm²: (10)**

* 24/47 (52.7%) lesions could not reach MLA>5.5mm² on IVIS with SDS at RBP

** 13/47 (27.7%) lesions could not reach MLA>5.5mm² on IVIS after HP dilatation
<table>
<thead>
<tr>
<th></th>
<th>Post Stent</th>
<th>Post HP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FFR &gt; 0.95</strong></td>
<td>9 (19.1%)</td>
<td>25 (53.2%)</td>
</tr>
<tr>
<td><strong>IVUS MSA &gt; 5.5mm²</strong></td>
<td>23 (47.3%)</td>
<td>38 (72.3%)</td>
</tr>
<tr>
<td><strong>IVUS MUSIC</strong></td>
<td>12 (25.5%)</td>
<td>14 (29.8%)</td>
</tr>
</tbody>
</table>

* Final lumen CSA > 80% of the reference (or > 90% if minimal lumen CSA was < 9 mm²)
Late Loss and “Headroom” to Restenosis in Patients $\text{FFR} \geq 0.95$

Vessel Size 3.2 mm
Minimal Stent Diameter 3.0 mm

Headroom to Restenosis
1.5 mm after Post PCI

1.3 mm
1.1 mm
0.9 mm

0.5 mm in BMS
RV Size 3.0 mm

MLD < 1.5 mm = Restenosis

DES1  MLL 0.2 mm
DES 2  MLL 0.4 mm
DES3  MLL 0.6 mm
Late Loss and “Headroom” to Restenosis in Patients FFR<0.95

Vessel Size 3.2 mm
Minimal Stent Diameter 2.3 mm

Headroom to Restenosis
0.7 mm after Post PCI
0.5 mm
0.3 mm
0.1 mm
-0.3 mm in BMS
RV Size 3.0 mm

Smallest Acceptable
MSD 2.65 mm
MSA 5.5 mm²
Mean Late Loss and Risk of Restenosis

- **Mean RVD 2.79, Minimal SD 2.67, Headroom 1.275**
- **Mean RVD 3.20, Minimal SD 2.32, Headroom 0.720, - 0.55**

Mauri L, Orav JE, Kuntz RE. Circulation 2005; 111: 3435-3442
### Angiographic and Procedural Findings

<table>
<thead>
<tr>
<th></th>
<th>Group A (FFR(\geq)0.95, n=9)</th>
<th>Group B (FFR&lt;0.95, n=38)</th>
<th>p Value</th>
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</thead>
<tbody>
<tr>
<td><strong>Pre-Stent</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLD (mm)</td>
<td>0.57 ± 0.11</td>
<td>0.59 ± 0.19</td>
<td>0.921</td>
</tr>
<tr>
<td>DS (%)</td>
<td>81.1 ± 4.5</td>
<td>81.5 ± 5.4</td>
<td>0.872</td>
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<tr>
<td><strong>Post-Stent</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MLD (mm)</td>
<td>3.09 ± 0.23</td>
<td>2.32 ± 0.46</td>
<td>0.012</td>
</tr>
<tr>
<td>DS (%)</td>
<td>13.8 ± 12.1</td>
<td>26.3 ± 12.5</td>
<td>0.014</td>
</tr>
<tr>
<td><strong>Reference Diameter (mm)</strong></td>
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<tr>
<td>Proximal</td>
<td>3.40 ± 0.17</td>
<td>3.42 ± 0.25</td>
<td>0.776</td>
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<tr>
<td>Distal</td>
<td>2.95 ± 0.14</td>
<td>3.0 ± 0.29</td>
<td>0.641</td>
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<tr>
<td><strong>Lesion length (mm)</strong></td>
<td>42.8 ± 10.4</td>
<td>52.3 ± 12.2</td>
<td>0.049</td>
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<tr>
<td>Stent number</td>
<td>1.64 ± 0.50</td>
<td>1.95 ± 0.55</td>
<td>0.096</td>
</tr>
<tr>
<td>Stent length (mm)</td>
<td>46.4 ± 13.9</td>
<td>56.9 ± 15.3</td>
<td>0.047</td>
</tr>
</tbody>
</table>

## IVUS Findings

<table>
<thead>
<tr>
<th></th>
<th>Group A (FFR≥0.95, n=9)</th>
<th>Group B (FFR&lt;0.95, n=38)</th>
<th>p Value</th>
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<tr>
<td><strong>Pre-stent</strong></td>
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<tr>
<td>MLA (mm²)</td>
<td>2.65 ± 0.68</td>
<td>1.75 ± 0.69</td>
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<tr>
<td>AS (%)</td>
<td>71.3 ± 9.8</td>
<td>80.0 ± 10.6</td>
<td>0.030</td>
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<tr>
<td><strong>Post-stent</strong></td>
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<tr>
<td>MLA (mm²)</td>
<td>7.16 ± 1.64</td>
<td>5.57 ± 1.57</td>
<td>0.005</td>
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<tr>
<td>AS (%)</td>
<td>23.3 ± 12.3</td>
<td>36.2 ± 19.7</td>
<td>0.059</td>
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<tr>
<td>Ref Lumen Area (mm²)</td>
<td>10.0 ± 3.4</td>
<td>8.9 ± 1.9</td>
<td>0.176</td>
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<tr>
<td>VA at Lesion (mm²)</td>
<td>13.0 ± 4.2</td>
<td>10.8 ± 2.5</td>
<td>0.041</td>
</tr>
<tr>
<td>Plaque Burden</td>
<td>78.7 ± 6.3</td>
<td>83.7 ± 6.5</td>
<td>0.042</td>
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<tr>
<td>Ref Vessel Area (mm²)</td>
<td>14.6 ± 4.4</td>
<td>13.3 ± 2.9</td>
<td>0.284</td>
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<tr>
<td>Remodeling Index</td>
<td>0.92 ± 0.22</td>
<td>0.82 ± 0.16</td>
<td>0.140</td>
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</table>

Independent Predictor for Suboptimal Stent Expansion (FFR<0.95 or FFR≥0.95)

Variables in the Equation

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable(s) entered on step 1: PLAQ_C, REMOD_IX, ECCENT, MINLA, ST_LENGT.</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>PLAQ_C, REMOD_IX, ECCENT, MINLA, ST_LENGT.</td>
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<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
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<tr>
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<td>.502</td>
<td>1.116</td>
<td>.202</td>
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<td>.653</td>
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<td>REMOD_IX</td>
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<td>.002</td>
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<td></td>
<td>ECCENT</td>
<td>-3.706</td>
<td>2.720</td>
<td>1.857</td>
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<td></td>
<td>MINLA</td>
<td>-1.482</td>
<td>.685</td>
<td>4.682</td>
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<td></td>
<td>ST_LENGT</td>
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<td>.041</td>
<td>.213</td>
<td>1</td>
<td>.645</td>
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<td></td>
<td>Constant</td>
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<td>3.453</td>
<td>1.380</td>
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</table>

By Multiple binary logistic regression analysis

Independent Predictor for Suboptimal Stent Expansion (correlation with post-stent FFR)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>.933</td>
<td>.041</td>
<td>-.154</td>
<td>22.891</td>
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<td>PLAQ_C</td>
<td>-.012</td>
<td>.012</td>
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<tr>
<td>REMOD_JX</td>
<td>.001</td>
<td>.032</td>
<td>.005</td>
<td>.036</td>
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<tr>
<td>ECCENT</td>
<td>.024</td>
<td>.033</td>
<td>.095</td>
<td>.725</td>
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<tr>
<td>MINLA</td>
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<td>.008</td>
<td>.328</td>
<td>2.120</td>
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<td>ST_LENGT</td>
<td>-.001</td>
<td>.000</td>
<td>-.351</td>
<td>-2.364</td>
</tr>
</tbody>
</table>

a. Dependent Variable: FFR_STEN

By Multiple linear regression analysis

FFR vs. IVUS Minimal Stent Area

$\text{r} = 0.501, p < 0.001$
The Relation between Final FFR and MSA (BCV of FFR for MSA ≥5.5 mm²)

Final FFR

100
90
80
70
60
50
40
30
20
10
0

Sensitivity

0 20 40 60 80 100

100-Specificity

BCV : 0.94
Sensitivity : 72%
Specificity : 79%
AUC: 0.78 (0.64-0.91)

Effect of HP Dilatation on Headroom to Restenosis
QCA Analysis

Reference Vessel Diameter

Head Room to Restenosis before HP

Head Room to Restenosis after HP

FFR<0.95
FFR>0.95
FFR and IVUS Criteria Reached were Inadequate with current SDS

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th>Post HP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR&gt;0.95</td>
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<td>25 (53.2%)</td>
<td></td>
</tr>
<tr>
<td>IVUS MSA &gt;5.5mm²</td>
<td>23 (47.3%)</td>
<td></td>
<td>38 (72.3%)</td>
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<tr>
<td>IVUS MUSIC*</td>
<td>12 (25.5%)</td>
<td></td>
<td>14 (29.8%)</td>
<td></td>
</tr>
</tbody>
</table>

* Final lumen CSA > 80% of the reference (or > 90% if minimal lumen CSA was < 9 mm²)

- Independent IVUS predictors for suboptimal stent expansion was minimal lumen area and lesion length.

- Best cut-off value of FFR for MSA>5.5mm² was 0.94
Conclusion

- Routine adjunctive high-pressure ballooning of DES might be required to achieve optimal functional and anatomic stent expansion, in number of long diffuse coronary stenoses.

- FFR and IVUS-guided PCI could potentially improve the procedural precision and decrease the rate of target vessel failure in DES era. However, the role of physiologic and IVUS study in DES era needs more randomized trials.
DES Implantation in Long Diffuse Lesion

- Appropriate lesion preparation
- Adjunctive High Pressure Dilatation

Do not forget old lessons even in DES era.

- Do not believe your visual estimation
- Please do not avoid modern facilities of convenience