What is the best way to do single stenting of coronary bifurcation?

Y. Louvard, ICPS, Massy, Générale de santé, Ramsay, France

Bulgarian Bifurcation and Complex Coronary Interventions Course
22-23 January 2016
Tokuda Hospital, Sofia
Coronary anatomy and function
Coronary artery tree: pseudo-fractal object

Finet et al. Eurointervention 2007; 490-8
Benoit Mandelbrot (1924-2010): fractals
Structure-function scaling laws of vascular trees

Murray’s law
\[ D_{13}^* = D_{23}^* + D_{33}^* \]

Finet’s formula
\[ D_1 = (D_2 + D_3) \times 0.678 \]

Adapted from G. Kassab
Mathematical model of coronary arterial tree

From G. Kassab
Anatomy of Bifurcations

- Murray's law: Minimum Work
  \[ D_{m3} = D_{d13} + D_{d23} \]
  \( \frac{1}{1.26} \)

- HK: Huo-Kassab, Minimum Energy
  \[ D_{m7/3} = D_{d17/3} + D_{d27/3} \]
  \( \frac{1}{1.35} \)

- Flow conservation
  \[ Q_m = Q_{d1} + Q_{d2} \]
  \[ D_{m2} = D_{d12} + D_{d22} \]
  \( \frac{1}{1.4} \)

- Finet, Measurement
  \[ D_{m} = 0.678 \left( D_{d1} + D_{d2} \right) \]
  \( \frac{1}{1.36} \)

The larger the SB, the larger the change in MV diameter throughout the bifurcation.

Courtesy of N Foin
Choose the stent from the distal MB diameter
Pseudo fractal geometry and dedicated QCA

The bigger the SB the larger the overestimation of DM stenosis

Systematic underestimation of PM stenosis

Murray’s law
\[ D_{13} = D_{23} + D_{33} \]

Finet’s law
\[ D_1 = 0.67(D_2 + D_3) \]

Huo Kassab law
\[ D_{2.3} = D_{2.3} + D_{2.3} \]

Systematic overestimation of SB ostial stenosis

Modified from PIE medical
Why so many bifurcation stenosis?
Flow Patterns and Spatial Distribution of Atherosclerotic Lesions in Human Coronary Arteries

High wall shear stress = antiatherogenic

Flow Patterns and Spatial Distribution of Atherosclerotic Lesions in Human Coronary Arteries

Low wall shear stress = proatherogenic

Flow Patterns and Spatial Distribution of Atherosclerotic Lesions in Human Coronary Arteries

The low WSS values distribution is in accordance with the frequent localization of atherosclerosis lesion.

Soulis et al. J of Biomechanics 2006;39:742
Low wall shear stress and atheroma in bifurcation

Virmani, Chatzizisis
Stenting, bifurcation anatomy and wall stress
Best solution ?
Restauration of initial flow (+ stent turbulences)

WSS < 0.5 Pa = risk of restenosis

Flow mediated NIH and neo-atheroma

Ku 1997, Malek et al. 1999

Virmani, Mintz …
Pathological Findings at Bifurcation Lesions: Impact of Flow Distribution on Atherosclerosis and Arterial Healing After Stent Implantation

<table>
<thead>
<tr>
<th></th>
<th>DES (12 Lesions, 17 Stents)</th>
<th>BMS (14 Lesions, 18 Stents)</th>
<th>p Value for DES vs. BMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow Divider</td>
<td>Lateral</td>
<td>Flow Divider</td>
</tr>
<tr>
<td>Neointimal thickness (mm)</td>
<td>0.07 (0.03–0.15)</td>
<td>0.17 (0.09–0.23)</td>
<td>0.26 (0.16–0.73)</td>
</tr>
<tr>
<td>Fibrin deposition (% struts)</td>
<td>60 (21–67)</td>
<td>17 (0–55)</td>
<td>8 (0–33)</td>
</tr>
<tr>
<td>Uncovered struts (% struts)</td>
<td>40 (16–76)</td>
<td>0 (0–15)</td>
<td>0 (0–21)</td>
</tr>
</tbody>
</table>
Percentage of Patients With Atherosclerotic Changes in DES Versus BMS in Relation to Duration of Implant at Autopsy

Nakazawa et al. J Am Coll Cardiol Img 2009;2:625-8
Evaluation of Local Flow Conditions in Jailed Side Branch Lesions Using Computational Fluid Dynamics

Area of low WSS (<4 Pa) in 8-computational bifurcation models

A 1.8%  B 26.6%  C 24.8%

D 27.8%  E 23.2%  F 8.6%

G 12.4%  H 20.5%
Impact of stent mis-sizing and mis-positioning on coronary fluid wall shear and intramural stress

Effects of radial geographical miss or stent oversizing: 10% oversizing (A) and 20% oversizing (B)

C

Max. Wall Stress (MPa)

Correct Sizing 10% Oversizing 20% Oversizing

0 1 2 3 4

D

% Plaque Area > 1 MPa

Correct Sizing 10% Oversizing 20% Oversizing

0 20 40 60 80

Simulation of the microscopic process during initiation of stent thrombosis

Streamlines (left panels) and shear stress contours (right panels) for different strut heights, including 50 (top panels), 100 (middle panels), and 200 mm (bottom panels).
Excess of Metal
Clinical datas about non-Left-Main bifurcation stenting
Simple or Complex Stenting for Bifurcation Coronary Lesions: A Patient-Level Pooled-Analysis of Nordic 1 and BBC

Kaplan-Meier freedom from the composite event

Lower total death rate at 5 years in simple stenting group!
Simple or Complex Stenting for Bifurcation Coronary Lesions: A Patient-Level Pooled-Analysis of Nordic 1 and BBC

Primary outcome for individual subgroups

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Odds ratio and 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>True bifurcations (657)</td>
<td>1.90 (1.22-2.94)</td>
</tr>
<tr>
<td>Angle&gt;60-70° (217)</td>
<td>1.67 (0.78-3.62)</td>
</tr>
<tr>
<td>SB diameter≥2.75mm (281)</td>
<td>2.42 (1.22-4.80)</td>
</tr>
<tr>
<td>SB lesion&gt;5mm (464)</td>
<td>1.71 (1.05-2.77)</td>
</tr>
<tr>
<td>SB diameter≥2.75mm/lesion&gt;5mm (137)</td>
<td>1.84 (0.68-4.97)</td>
</tr>
<tr>
<td>Equivalence (108)</td>
<td>1.35 (0.48-3.70)</td>
</tr>
<tr>
<td>Total (913)</td>
<td>1.84 (1.28-2.66)</td>
</tr>
</tbody>
</table>
Randomized study comparing Double Kissing Crush with Provisional Stenting for treatment of coronary bifurcation lesions: DK-CRUSH-II

Comparison of Survival Rate Free From TLR Between DK Crush and PS Groups
Randomized study comparing Double Kissing Crush with Provisional Stenting for treatment of coronary bifurcation lesions: DK-CRUSH-II

Clinical outcome (2)

<table>
<thead>
<tr>
<th></th>
<th>DK Group (n = 185)</th>
<th>PS Group (n = 185)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedural success</td>
<td>179 (96.8)</td>
<td>173 (93.5)</td>
<td>0.217</td>
</tr>
<tr>
<td>At 6-month</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac death</td>
<td>1 (0.5)</td>
<td>2 (1.1)</td>
<td>1.000</td>
</tr>
<tr>
<td>MI</td>
<td>6 (3.2)</td>
<td>4 (2.2)</td>
<td>0.751</td>
</tr>
<tr>
<td>CABG</td>
<td>0 (0)</td>
<td>1 (0.5)</td>
<td>0.500</td>
</tr>
<tr>
<td>TLR</td>
<td>2 (1.1)</td>
<td>6 (3.2)</td>
<td>0.284</td>
</tr>
<tr>
<td>TVR</td>
<td>3 (1.6)</td>
<td>8 (4.3)</td>
<td>0.220</td>
</tr>
<tr>
<td>MACE</td>
<td>6 (3.2)</td>
<td>11 (5.9)</td>
<td>0.321</td>
</tr>
<tr>
<td>Stent thrombosis definite</td>
<td>4 (2.2)</td>
<td>1 (0.5)</td>
<td>0.372</td>
</tr>
<tr>
<td>At 12-month</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac death</td>
<td>2 (1.1)</td>
<td>2 (1.1)</td>
<td>1.000</td>
</tr>
<tr>
<td>MI</td>
<td>6 (3.2)</td>
<td>4 (2.2)</td>
<td>0.751</td>
</tr>
<tr>
<td>CABG</td>
<td>0 (0)</td>
<td>1 (0.5)</td>
<td>0.500</td>
</tr>
<tr>
<td>TLR</td>
<td>8 (4.3)</td>
<td>24 (13.0)</td>
<td>0.005</td>
</tr>
<tr>
<td>TVR</td>
<td>12 (6.5)</td>
<td>27 (14.6)</td>
<td>0.017</td>
</tr>
<tr>
<td>MACE</td>
<td>19 (10.3)</td>
<td>32 (17.3)</td>
<td>0.070</td>
</tr>
<tr>
<td>Stent thrombosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definite</td>
<td>5 (2.7)</td>
<td>2 (1.1)</td>
<td>0.449</td>
</tr>
<tr>
<td>Possible</td>
<td>4 (2.2)</td>
<td>1 (0.5)</td>
<td>0.372</td>
</tr>
</tbody>
</table>

Follow-up coronary angiography at 8 months
Bifurcation lesion treatment principles

1. Limit the number of stents (carena)
2. Apposition (no overlapping ?)
3. Respect the original anatomy (speculative)
Provisional SB stenting strategy
Provisional Side Branch Stenting
Patient’s specific simulation
## Predictors and Outcomes of SB Occlusion After Main Vessel Stenting in Coronary Bifurcation Lesions Results From the COBIS II Registry

### Independent Predictors of SB Occlusion

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio (95% CI) (range)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-procedural %DS of the SB $\geq 50%$</td>
<td>2.34 (1.59–3.43)</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Pre-procedural %DS of the proximal MV $\geq 50%$</td>
<td>2.34 (1.57–3.50)</td>
<td>0.03</td>
</tr>
<tr>
<td>SB lesion length</td>
<td>1.03 (1.003–1.06)</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Acute coronary syndrome</td>
<td>1.53 (1.06–2.19)</td>
<td>0.02</td>
</tr>
<tr>
<td>Left main lesions (vs. non-left main lesions)</td>
<td>0.34 (0.16–0.72)</td>
<td>0.005</td>
</tr>
</tbody>
</table>
IVUS findings of Carina shift vs. Plaque shift

Before MB stent

After MB stent

* : A 0.014 inch coronary wire

Both plaque shift and carina shift ➔ Aggravation of SB luminal narrowing after MB stent implantation from Bon Kwon Koo, EBC
SB salvage technique
SB salvage technique
SB salvage technique
SB salvage technique
SB salvage technique
SB salvage technique
SB salvage technique
Why the POT?

- To give to the cross-over stent the 2 diameters of the 2 covered segment (respect the anatomy/function)

- To exchange safely the wires for kissing (no exchange outside the undeployed proximal part of the stent)

- Open the stent cells in front of the SB ostium (better access for balloon/stent)
<table>
<thead>
<tr>
<th>Balloon Max. size</th>
<th>Element</th>
<th>Xience</th>
<th>Taxus</th>
<th>Integrity</th>
<th>BioMatrix</th>
<th>Cypher</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>2.25 Very Small WH (2 cells) max exp.: 3.0mm</td>
<td>Medium Workhorse (6 crowns, 3 cells) max expansion: 4.4mm</td>
<td>Small workhorse (6 crowns, 2 cells) max expansion: 3.4mm</td>
<td>Small workhorse (7 crowns, 2 cells*) max expansion: 4.9mm *1.5 cell in Resolute</td>
<td>Medium workhorse (6 crowns, 2 cells) max expansion: 4.6mm</td>
<td>Medium workhorse (6 crowns, 6 cells) max expansion: 4.7mm</td>
</tr>
<tr>
<td>2.50</td>
<td>Small workhorse (8 crowns, 2 cells) max expansion: 3.8mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.75</td>
<td>Medium Workhorse (8 crowns, 2 cells) max expansion: 4.4mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>Medium Workhorse (8 crowns, 2 cells) max expansion: 4.4mm</td>
<td>Large workhorse: (9 crowns, 3 cells) max expansion: 5.6mm</td>
<td></td>
<td></td>
<td>Large workhorse (9 crowns, 3 cells) max expansion: 5.4mm</td>
<td></td>
</tr>
<tr>
<td>3.50</td>
<td>Large workhorse (10 crowns, 2 cells) max expansion: 5.7mm</td>
<td></td>
<td>Large workhorse (9 crowns, 3 cells) max expansion: 5.6mm</td>
<td>Large workhorse (9 crowns, 3 cells) max expansion: 5.9mm</td>
<td>Large workhorse (7 crowns, 7 cells) max expansion: 5.8mm</td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Minimal stent LD excluding struts
- Limited to 6.0 mm SC balloon at 14 ATM

Stent MLD (inner lumen) achieved after stepwise overexpansion and 2x final post-dilatation
Wire exchange

MB wire: long shape!
Wire exchange

MB wire: long shape!
Wire exchange

SB wire: short loop!
Proximal vs distal recrossing toward side branch

OCT atlas, Alegria-Barrero et al. Eurointervention 2012: 8: 205
POT + Kissing balloon inflation
Long-term Clinical outcomes of final KB in coronary bifurcation lesions treated with the 1-stent technique: results from the COBIS II registry

Clinical Outcomes in FKB Group Compared With Non-FKB Group in Propensity-Matched Population During FU Period

<table>
<thead>
<tr>
<th></th>
<th>FKB (n = 545)</th>
<th>Non-FKB (n = 545)</th>
<th>Unadjusted HR (95% CI)</th>
<th>p Value</th>
<th>Adjusted HR* (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause death</td>
<td>17 (3.1)</td>
<td>20 (3.7)</td>
<td>0.67 (0.30-1.48)</td>
<td>0.32</td>
<td>0.68 (0.28-1.63)</td>
<td>0.39</td>
</tr>
<tr>
<td>Cardiac death</td>
<td>3 (0.6)</td>
<td>8 (1.5)</td>
<td>0.43 (0.11-1.66)</td>
<td>0.22</td>
<td>0.50 (0.11-2.29)</td>
<td>0.37</td>
</tr>
<tr>
<td>MI</td>
<td>4 (0.7)</td>
<td>5 (0.9)</td>
<td>0.50 (0.09-2.73)</td>
<td>0.42</td>
<td>0.18 (0.01-20.36)</td>
<td>0.48</td>
</tr>
<tr>
<td>Stent thrombosis†</td>
<td>3 (0.6)</td>
<td>4 (0.7)</td>
<td>0.72 (0.16-3.23)</td>
<td>0.67</td>
<td>0.77 (0.17-3.45)</td>
<td>0.73</td>
</tr>
<tr>
<td>Target lesion revascularization</td>
<td>32 (5.9)</td>
<td>43 (7.9)</td>
<td>0.53 (0.30-0.94)</td>
<td>0.03</td>
<td>0.51 (0.28-0.91)</td>
<td>0.02</td>
</tr>
<tr>
<td>Main vessel</td>
<td>31 (5.7)</td>
<td>40 (7.3)</td>
<td>0.53 (0.30-0.96)</td>
<td>0.04</td>
<td>0.51 (0.28-0.93)</td>
<td>0.03</td>
</tr>
<tr>
<td>Side branch</td>
<td>12 (2.2)</td>
<td>18 (3.3)</td>
<td>0.57 (0.24-1.36)</td>
<td>0.21</td>
<td>0.57 (0.24-1.37)</td>
<td>0.21</td>
</tr>
<tr>
<td>Both vessels</td>
<td>23 (4.2)</td>
<td>38 (7.0)</td>
<td>0.47 (0.25-0.88)</td>
<td>0.02</td>
<td>0.47 (0.25-0.90)</td>
<td>0.02</td>
</tr>
<tr>
<td>MACE†</td>
<td>37 (6.8)</td>
<td>53 (9.7)</td>
<td>0.54 (0.32-0.89)</td>
<td>0.02</td>
<td>0.50 (0.30-0.85)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Adjusted covariates include hypertension, history of coronary artery bypass graft, and distal RD of SB
Non compliant balloons for kissing

Semi-Compliant Balloon (Ryujin Plus, Terumo)

Non-Compliant Balloon (Hiryu, Terumo)
(re)-Proximal Optimizing Technique in provisional coronary bifurcation stenting

The full version...

Gérard Finet MD PhD


Department of Cardiology and Interventional Cardiology
Cardiovascular Hospital - Hospices Civils de Lyon
INSERM Research Unit 1060 CarMeN
Claude Bernard University Lyon 1
Lyon - France

gerard.finet@univ-lyon1.fr
The rePOT sequence

Balloon positioning for the POT

1. Implantation of a stent with the main-branch reference diameter
2. Initial POT with the MoV reference diameter
3. SB wiring (distal cell)
4. SB inflation with the SB reference diameter
5. Final POT with the MoV reference diameter (re-POT)
RESULTS

Comparison of ellipticity index, global malapposed strut ratio (%), and strut obstruction ratio in side branch ostium (SBO) (%)

A

Ellipticity Index

B

Malapposed struts (%)

C

% Strut obstruction in SBO

- KBI only (12/12 atm)
- POT + KBI asyn (4/12 atm)
- POT + SBI
- POT + SBI + POT

Promus premier™
Ultimaster™

* †
Significant Post Stenting SB Stenosis: QCA vs FFR

(jailed side branch lesions, n=94)


Functionally significant stenosis:

$r = -0.464$

$p < 0.001$

38% of lesions
SB Ostial Lesions Are Overestimated

Koo et al. EBC 2006
T or TAP?

SB recrossing

Post kissing

TAP

T
T or TAP? (stent boost)
ACS ST-, ulcerated LAD1, LAD1, Diag1 bifurcation 1,0,1
Ulcerated LAD1,LAD1,Diag1 bifurcation 1,0,1
2 BMW wires
Predilatation with 2.5 X 20 mm (length)
Nobori 3x24 mm from LAD to Diagonal
Post stenting
POT with a 3.5X9 mm balloon
Post POT
Post kissing
Final result
Conclusion

- Good knowledge of anatomy / fonction of a coronary bifurcation is useful for classification, quantification and treatment of coronary bifurcation stenosis

- In the majority of situations a bifurcation stenosis can be treated with 1 (or even 2 stents) using the Provisional SB stenting strategy

- Choice of an adapted stent with a diameter of the DM segment is followed by a POT using a short balloon adapted to PM segment diameter, final kissing balloon inflation is useful when the SB is big (alternative: POT, Side, POT ?)

- When the access to SB is very difficult, SB may be stented first (mini DK crush)

- Clinical validation of informations coming from patient specific simulation is necessary

- Treatment principles: **limit stent number, apposition, respect initial anatomy**