Fundamentals of PCI--Balloons and Stents

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DISCLOSURES:

- None relevant to the content of this presentation
Outline

- Coronary Angioplasty Balloons
  - Angioplasty Balloons of Historical Interest
  - Balloon Design Considerations
  - Specialty Balloons

- Intracoronary Stents
  - Coronary Stents of Historical Interest
  - Bare Metal Stents
  - Drug Eluting Stents
  - Covered Stents
  - Bioresorbable Scaffolds

- Conclusions
Early Coronary Angioplasty Balloons

- Fixed Wire Balloons
- Perfusion Balloons
Design Characteristics of Contemporary Coronary Balloons

- **Rapid Exchange (RX)**
  - Most commonly used system
  - 190 cm guidewire used

- **Over-the-wire (OTW)**
  - 145-155 cm working length
  - 300 cm guidewire used
Rapid Exchange Balloons

Advantages

• Allows for single operator
• Quicker exchanges over a short guidewire
• Less fluoroscopy time
• Can use for kissing balloon applications with most 6F systems

Disadvantages

• Pushability can be reduced by short wire lumen
• Cannot reshape or exchange wire without loss of position
• More difficult to use balloon for support in crossing lesions or advancing wire
Over The Wire Balloons

**Advantages**

- Ability to change wires through catheters
- Better pushability due to wire running entire course of balloon

**Disadvantages**

- Need for two operators
- Longer fluoroscopy times needed for exchanges
- Slightly larger profile/shaft sizes
  - Especially for kissing balloon angioplasty
Balloon Construction and Function

- Polyolefin copolymer (POC)
- Pebax (polyether block amide)
- Polyethylene (PE)
- Nylon
- Polyethylene terephthalate (PET)

More Compliant

Less Compliant

Nominal Pressure: Pressure at which the balloon is at listed size (outside the body)

Rated Burst Pressure: Highest pressure at which 99.5% of balloons will not rupture
## Balloon Selection

<table>
<thead>
<tr>
<th>Compliant and Semi-Compliant Balloons</th>
<th>Non-Compliant Balloons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-dilation</td>
<td>Post-dilation of stents</td>
</tr>
<tr>
<td>Ballooning through side struts</td>
<td>Resistant lesions</td>
</tr>
<tr>
<td>Very tight lesions</td>
<td>Heavy calcification</td>
</tr>
<tr>
<td>Tortuous anatomy</td>
<td>Non-dilatable lesions</td>
</tr>
<tr>
<td>Re-crossing stents</td>
<td>Aorto-ostial lesions</td>
</tr>
<tr>
<td>Side branch access</td>
<td></td>
</tr>
</tbody>
</table>
Compliance and Wall Stress
Balloon Tip Taper

Longer taper increases crossability

Shorter shoulders decrease edge effects
# Current Balloon Options*

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Compliant</th>
<th>Non-Compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbott Vascular</td>
<td>Trek (2.25-5.0 mm)</td>
<td>NC Trek (1.5 mm – 5.0 mm)</td>
</tr>
<tr>
<td></td>
<td>MiniTrek (1.20 and 1.5-2.0 mm)</td>
<td></td>
</tr>
<tr>
<td>Boston Scientific</td>
<td>Emerge Flex (1.2-4.0 mm)</td>
<td>NC Emerge (2.0-6.0 mm)</td>
</tr>
<tr>
<td></td>
<td>Emerge Push (1.2 and 1.5 mm)</td>
<td>NC Quantum Apex (2.0-5.0 mm)</td>
</tr>
<tr>
<td>Medtronic</td>
<td>Euphora (1.5-4.0 mm)</td>
<td>NC Euphora (2.0-5.0 mm)</td>
</tr>
<tr>
<td></td>
<td>Sprinter Legend (1.25-4.0 mm)</td>
<td>NC Sprinter (2.0-5.0 mm)</td>
</tr>
</tbody>
</table>

*FDA Approved

Crossing profiles:

- **Compliant Balloons (0.021-0.026”)**
- **Non-compliant balloons (0.024-0.031”)**
Cutting/Scoring Balloons

Flextome Cutting Balloon—Boston Scientific

Angiosculpt Scoring Balloon—AngioScore, Inc

Pressure
- Nominal: 6 atm
- RBP: 12 atm

Diameters: 2 mm - 4 mm (0.25 mm increments)
Lengths: 6 mm, 10 mm, 15 mm

Pressure
- Nominal: 8 atm
- RBP: 16-20 atm

Diameters 2 mm-3.5 mm (0.5 increments)
Lengths: 6 mm, 10 mm, 15 mm
Cutting/Scoring Balloons

Pros:
- “Controlled” dissection
- Less slippage
- Non-compliant balloons

Cons:
- Expensive
- Higher profile
- Stiffer balloons so difficult to navigate tortuosity

Acting Mechanisms of Regular and Cutting Balloons

- **Regular balloon**
  - Entire balloon surface contact the vessel wall - arterial wall damage
  - Multiple rips and tears in media
  - Endothelium is completely disrupted, large hematoma has formed due to trauma

- **Cutting balloon**
  - Injury localized to the scoring sites - reduced trauma
  - Media with no visible disruption
  - Endothelial layer remains intact
Early Coronary Stent Designs

Stent Design Type

- Coiled Wire
- Slotted Tube
- Modular ring
- Multicellular

Stent Types:

- Gianturco-Roubin (GR-1)
- Gianturco-Roubin II
- Palmaz-Schatz (J and J)
- Driver--Medtronic
- Bx Velocity
Stent Design

- Open-cell design
  - More space between struts
  - More flexible/conformable
  - More tissue prolapse
Stent Design

- Closed-cell design
  - Smaller area per cell
  - Higher metal to artery ratio
  - Improved scaffolding
  - ? Smaller side branch access

Cypher Stent (Bx Velocity Platform)  Cordis Co.
Stent Attributes

- Trackability
- Flexibility
- Deliverability
- Radial strength
- Lesion/vessel coverage
- Radiologic visibility
Progress in Stent Strut Thickness and Composition

<table>
<thead>
<tr>
<th>1st Generation</th>
<th>2nd Generation</th>
<th>3rd Generation</th>
<th>4th Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypher® Stent</td>
<td>TAXUS® Express® Stent</td>
<td>Xience V® and Xience Prime® Stents</td>
<td>SYNERGY™ Stent</td>
</tr>
<tr>
<td>TAXUS® Liberte® Stent</td>
<td>Endeavor® Stent</td>
<td>ION™ / TAXUS® Element™ Stent</td>
<td></td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>Cobalt Alloys</td>
<td>Platinum Chromium</td>
<td></td>
</tr>
</tbody>
</table>

Current benchmark for lowest strut thickness:

- PROMUS Element™ Stent
- Xience V® Stent
- Xience Prime™ Stent
- Endeavor™ Stent
- Resolute Integrity™ Stent
Stent Design—Balloon Overhang

- **TAXUS® Liberté® Stent**
  - Total: 0.88mm

- **TAXUS® Express® Stent**
  - Total: 0.89mm

- **XIENCE/PROMUS™ Stent**
  - Total: 0.95mm

- **Endeavor® Stent**
  - Total: 1.38mm

- **Cypher® Stent**
  - Total: 1.61mm

Mineral Balloon Overhang to help minimize vessel trauma or damage outside the stent.
Longitudinal Stent Deformation

Multivariable Predictors of Stent Deformation from 1800 patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promus Element stent</td>
<td>5.53 (1.54 – 19.85)</td>
<td>0.0088</td>
</tr>
<tr>
<td>Multiple stents</td>
<td>2.06 (1.45 – 2.90)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Guideliner</td>
<td>22.09 (4.73 – 103.04)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Postdilation balloon</td>
<td>5.47 (1.31 – 22.81)</td>
<td>0.0197</td>
</tr>
</tbody>
</table>

Biomatrix Flex, Resolute Integrity, Promus Element, and Xience V stents

Original Stent Shape

Ormiston et al. JACC: Cardiovascular Intervention, 2011.
## Current Bare Metal Stent Options

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Stent</th>
<th>Sizes</th>
<th>Lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbott Vascular</td>
<td>Vision (CoCr)</td>
<td>2.75-4.00 mm</td>
<td>8-28 mm</td>
</tr>
<tr>
<td></td>
<td>Mini-Vision (CoCr)</td>
<td>2.00-2.50 mm</td>
<td>8-28 mm</td>
</tr>
<tr>
<td>Boston Scientific</td>
<td>VeriFLEX (316L SS)</td>
<td>2.75-5.00 mm</td>
<td>8-32 mm</td>
</tr>
<tr>
<td></td>
<td>Rebel (PtCr)</td>
<td>2.25-4.50 mm</td>
<td>8-32 mm</td>
</tr>
<tr>
<td>Medtronic</td>
<td>Integrity (CoCr)</td>
<td>2.25-4.00 mm</td>
<td>8-30 mm</td>
</tr>
</tbody>
</table>
Evolution of DES

Easter Island (Rapa Nui)

Pacific Yew Tree
Currently available DES are characterized by three principal components:

- The drug
  - antiproliferative agents that reduce neointimal hyperplasia.
- The polymer
  - durable or bioabsorbable polymers that represent the vehicle for drug delivery and can be modulated to alter the dosage and timing of drug release
  - Polymer-free DES have been developed
- The platform
  - durable or bioresorbable stent scaffolds.
Polymers control the dosage and duration of antiproliferative drug release.

Durable polymers identified as a potential trigger for hypersensitivity reactions associated with chronic inflammation and delayed arterial healing, which may increase the risk of VLST and delayed restenosis.

Biodegradable polymers may provide the safety benefit of BMS after polymer breakdown and has been associated with a reduced rate of VLST.

- Each has a specific biocompatibility profile and degradation time.
- Must resist mechanical stress of balloon inflation and the configuration change during stent expansion.

Polymer-free drug carrier systems have been developed and are under investigation.
Drug-eluting Stents: 1st Generation

**TAXUS**
- **Drug**: Paclitaxel
- **Polymer**: Polyolefin derivative
- **Stent**: Liberté

**Cypher**
- **Drug**: Sirolimus
- **Polymer**: PEVA + PBMA blend
- **Stent**: BX Velocity
Stent Design Can Influence Drug Elution

**Open Cell**
- Gap – low drug concentration

**Closed Cell**
- Pinch – high drug concentration
- More uniform drug concentration
Drug Eluting Stents-- 2nd Generation

Everolimus concentration: 100 ug/cm²
Polymer: PBMA & PVDF-ss)

**XIENCE V / PROMUS (CoCr-EES)**

**PROMUS Element (PtCr-EES)**

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PBMA=poly (n-butyl methacrylate) (primer layer);
PVDF-HFP=poly (vinylidene fluoride-co-hexafluoropropylene) (drug matrix layer)
Drug-eluting Stents: 2nd Generation

Endeavor
- Zotarolimus Drug
- Phosphorylcholine Polymer
- Hydrophilic Hydrophobic
- Resolute
- Zotarolimus
- BioLinx
- Driver

Driver
- BioLinx
# Drug Eluting Stent Timeline

<table>
<thead>
<tr>
<th>First Generation</th>
<th>Date Approved</th>
<th>Manufacturer</th>
<th>Stent Alloy</th>
<th>Drug</th>
<th>Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypher</td>
<td>2003</td>
<td>Cordis</td>
<td>Stainless steel</td>
<td>Sirolimus</td>
<td>Durable</td>
</tr>
<tr>
<td>Taxus</td>
<td>2004</td>
<td>Boston Scientific</td>
<td>Stainless steel</td>
<td>Paclitaxel</td>
<td>Durable</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Second Generation</th>
<th>Date Approved</th>
<th>Manufacturer</th>
<th>Stent Alloy</th>
<th>Drug</th>
<th>Polymer</th>
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</thead>
<tbody>
<tr>
<td>Xience V</td>
<td>2007</td>
<td>Abbott Vascular</td>
<td>Cobalt chromium</td>
<td>Everolimus</td>
<td>Durable</td>
</tr>
<tr>
<td>Promus</td>
<td>2008</td>
<td>Boston Scientific</td>
<td>Cobalt chromium</td>
<td>Everolimus</td>
<td>Durable</td>
</tr>
<tr>
<td>Endeavor</td>
<td>2008</td>
<td>Medtronic</td>
<td>Cobalt chromium</td>
<td>Zotarolimus</td>
<td>Durable</td>
</tr>
<tr>
<td>Xience Prime</td>
<td>2011</td>
<td>Abbott Vascular</td>
<td>Cobalt chromium</td>
<td>Everolimus</td>
<td>Durable</td>
</tr>
<tr>
<td>Promus Element</td>
<td>2011</td>
<td>Boston Scientific</td>
<td>Platinum chromium</td>
<td>Everolimus</td>
<td>Durable</td>
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<tr>
<td>Taxus Ion</td>
<td>2011</td>
<td>Boston Scientific</td>
<td>Platinum chromium</td>
<td>Paclitaxel</td>
<td>Durable</td>
</tr>
<tr>
<td>Resolute</td>
<td>2012</td>
<td>Medtronic</td>
<td>Cobalt chromium</td>
<td>Zotarolimus</td>
<td>Durable</td>
</tr>
</tbody>
</table>
Revascularization vs. Medical Rx: SIHD
Impact of new DES

100 trials in 93,553 pts with 262,090 pt-yrs follow-up

Death or MI (88 trials, 89,373 pts)

Windecker S et al. BMJ. 2014; 348: g3859
Revascularization vs. Medical Rx: SIHD
Impact of new DES

100 trials in 93,553 pts with 262,090 pt-yrs follow-up

Revascularization (94 trials, 90,282 pts)

CABG v medical treatment 0.16 (0.13 to 0.20)
PTCA v medical treatment 0.97 (0.82 to 1.16)
BMS v medical treatment 0.69 (0.59 to 0.82)
PES v medical treatment 0.44 (0.35 to 0.55)
SES v medical treatment 0.29 (0.24 to 0.36)
E-ZES v medical treatment 0.38 (0.29 to 0.51)
R-ZES v medical treatment 0.26 (0.17 to 0.40)
EES v medical treatment 0.27 (0.21 to 0.35)

Favors revascularization Favors medical treatment

Windecker S et al. BMJ. 2014; 348: g3859
**Abluminal Bioabsorbable Polymer**

**BSC Synergy stent**

- Bioabsorbable polymer (PLGA) • gone in 4 months
- Applied only to the abluminal surface
- Thin strut (0.0028”) PtCr Stent

**PLGA Bioabsorbable Polymer** + Everolimus on Abluminal Side of Stent (Elutes in 3 months)

**Current Durable Polymer**

**Durable Permanent Polymer** + Drug 360° Around Stent
# Current Drug Eluting Stent Options--

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Stent</th>
<th>Drug</th>
<th>Polymer</th>
<th>Size</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbott Vascular</td>
<td>Xience V and Xience Nano</td>
<td>Everolimus</td>
<td>Durable</td>
<td>2.25-4.00 mm</td>
<td>8-38 mm</td>
</tr>
<tr>
<td></td>
<td>Xience Prime (CoCr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Xience Xpedition (CoCr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Xience Alpine (CoCr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boston Scientific</td>
<td>Ion (PtCr)</td>
<td>Paclitaxel</td>
<td>Durable</td>
<td>2.25-4.00 mm</td>
<td>8-38 mm</td>
</tr>
<tr>
<td></td>
<td>Promus Element Plus (PtCr)</td>
<td>Everolimus</td>
<td></td>
<td>2.25-4.00 mm</td>
<td>8-38 mm</td>
</tr>
<tr>
<td></td>
<td>Promus Premier (PtCr)</td>
<td>Everolimus</td>
<td>Bioabsorbable</td>
<td>2.25-4.00 mm</td>
<td>8-38 mm</td>
</tr>
<tr>
<td></td>
<td>Synergy (PtCr)</td>
<td>Everolimus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medtronic</td>
<td>Resolute Integrity</td>
<td>Zotarolimus</td>
<td>Durable</td>
<td>2.25-4.00 mm</td>
<td>8-30 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34, 38 in</td>
<td>3.0-4.0</td>
</tr>
</tbody>
</table>

FDA Approved
Covered Stents

- Graftmaster Rx Stent (Abbott Labs)
  - Previously known as Jostent

- Two 316L stainless steel stents with PTFE membrane between them

- FDA approved under humanitarian device exemption (HDE) for the treatment of free perforations of native coronary arteries or saphenous vein grafts

- IRB approval required for use (particularly for off-label use)

- Requires mandatory paperwork for submission to Abbott prior to re-ordering

- Needed in every cath lab, but hopefully not used!
# Covered Stents—Considerations

- **Guide Catheter Size Needs to Be Considered**
- **Need to Size to Outer Diameter**

<table>
<thead>
<tr>
<th>GRAFTMASTER® Diameter</th>
<th>2.8 – 4.0 mm</th>
<th>4.5 – 4.8 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stent Material</strong></td>
<td>Stainless Steel 316L</td>
<td>Stainless Steel 316L</td>
</tr>
<tr>
<td><strong>Graft Material</strong></td>
<td>Expandable Polytetrafluoroethylene (ePTFE) sandwiched between two identical stents</td>
<td>Expandable Polytetrafluoroethylene (ePTFE) sandwiched between two identical stents</td>
</tr>
<tr>
<td><strong>Double Wall Thickness (mm)</strong></td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td><strong>Balloon Material</strong></td>
<td>Semi Compliant</td>
<td>Semi Compliant</td>
</tr>
<tr>
<td><strong>Shaft Size (F)</strong></td>
<td>2.0 – 2.7</td>
<td>2.0 – 2.7</td>
</tr>
<tr>
<td><strong>Minimum Deployment Pressure (ATM)</strong></td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td><strong>Rated Burst Pressure (ATM)</strong></td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td><strong>Minimum Guide Wire (in)</strong></td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td><strong>Usable Length (cm)</strong></td>
<td>143</td>
<td>143</td>
</tr>
<tr>
<td><strong>Maximum Stent graft Expansion (mm)</strong></td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Minimum Guide Catheter (in) / F</strong></td>
<td>0.068 / ≥ 6</td>
<td>0.074 / ≥ 7</td>
</tr>
<tr>
<td><strong>Crimped Stent Profile (in)</strong></td>
<td>0.064</td>
<td>0.068</td>
</tr>
<tr>
<td><strong>Tip Entry Profile (in)</strong></td>
<td>0.024</td>
<td>0.024</td>
</tr>
<tr>
<td><strong>Average Crossing Profile (in)</strong></td>
<td>0.064</td>
<td>0.068</td>
</tr>
</tbody>
</table>

**Long term patency is not well studied**
Fully Bioreabsorbable Stents (Scaffolds)

- **Igaki-Tamai**
  - PLA

- **BVS**
  - PLA (everolimus coat)

- **REVA**
  - Iodinated tyrosine-polycarbonate (with PTX)

- **BTI**
  - PAE-salicylate (with sirolimus)

- **Biotronik**
  - Magnesium
Bioresorbable Vascular Scaffold (BVS) System (Abbott Vascular, Santa Clara, CA)

- balloon-expandable with two platinum markers at each end
- poly-l-lactic acid (PLLA) scaffold (average strut thickness 150 μm)
- bioresorbable poly-d,l-lactic acid (PDLLA) coating (~7 μm thick)
- Everolimus, (100 mcg/cm2), 80% eluted in 30 days
- The PLLA scaffold is composed of circumferentially oriented sinusoidal rings connected by linear links similar to MultiLink stent design

ABSORB III—US Pivotal Trial
Primary Endpoint: Target Lesion Failure

Target Lesion Failure = cardiac death, target-vessel MI, or ischemia-driven target-lesion revascularization

Conclusions

- Balloon construction determines the clinical role for specific balloons in patients undergoing PCI
  - Specialty balloons may have a role in specific clinical scenarios
- Stent design has markedly improved over the last 22 years since the first BMS was FDA approved
  - While there were differences in early stent design and performance, current BMS and DES are all quite good
  - Specific clinical scenarios require specific stents…ensure you are familiar with what is on your shelf!
- Drug eluting stent design is rapidly advancing with a goal to have polymers that are bioresorbable or drug delivery systems that don’t require polymers
- Bioresorbable scaffolds are promising but we have much to learn (re-learn) about their use