Evolution of Balloon Angioplasty
From POBA to newer technologies

NCVH
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Overview

• 1. Physics of balloon angioplasty
• 2. Focused force angioplasty (FFA) concept
• 3. Development of focused force balloons
• 4. Chocolate balloons
• 5. Drug coated balloons
**Balloon Angioplasty**

Concept and Physics

**Goal:** Plaque fracture and effective lumen enlargement

**Problem:** plaque morphology and composition is extremely variable

*Nissen S E, Yock P* Circulation 2001;103:604-616
Balloon Angioplasty

DILATING FORCE applied to the plaque by conventional balloon designs is unpredictable - depends primarily on **plaque morphology**

How could we achieve plaque fracture and lumen enlargement with minimal vascular trauma?
Physical Principles of Balloon Dilation

Pascal’s principle

The pressure exerted on a confined liquid is transmitted equally in all directions
Physical Principles of Balloon Dilation

Dilating Force / Tension: \( T = PR/W \)

The **DILATING FORCE or TENSION** (\( T \)) exerted on the wall of the inflated balloon is directly proportional to the **PRESSURE** (\( P \)) within the balloon and the **RADIUS** (\( R \)) of the balloon

\[ T = PR \]
Physical Principles of Balloon Dilation

Pascal’s principle and Laplace’s law
Physical Principles of Balloon Dilation

Pascal’s principle and Laplace’s law
Challenges with POBA

Longitudinal / Torsion Stress

PRE-INFLATION

DURING INFLATION

END OF INFLATION

PRE-INFLATION

DURING INFLATION
Balloon Angioplasty

Scoring Technology

Plaque Modification Technology
Early-stage “Focused Force Angioplasty”

“buddy wire technique”

place a balloon along a guidewire

balloon inflation is “focused” along the guidewire

• 3X increase in the longitudinal dilating force
• Much lower SRP (stenosis resolution pressure)
• Fewer spiral dissections
• Lower residual stenosis

Khurana et al. J Invasive Cardiol 1995
Advanced Focused Force Balloons

Cutting Balloon  VascuTrak

Angiosculpt
Advanced Focused Force Balloons

Cutting Balloons

Balloon affixed with longitudinally mounted microsurgical blades - AHEROTOMES
Advanced Focused Force Balloons

Cutting Balloons

Irregular tears and micro-dissections after conventional angioplasty

“Pie-shaped” incision of an atherotome with minimal trauma to the media
## Peripheral Cutting Balloons

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Recommended Guidewire</th>
<th>Minimum Introducer Sheath (F)</th>
<th>OTW</th>
<th>Monorail® Catheter</th>
<th>Catheter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>15</td>
<td>0.014”</td>
<td>6</td>
<td>✔</td>
<td>✔</td>
<td>140</td>
</tr>
<tr>
<td>2.5</td>
<td>15</td>
<td>0.014”</td>
<td>6</td>
<td>✔</td>
<td>✔</td>
<td>140</td>
</tr>
<tr>
<td>3.0</td>
<td>15</td>
<td>0.014”</td>
<td>6</td>
<td>✔</td>
<td>✔</td>
<td>140</td>
</tr>
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<td>6</td>
<td>✔</td>
<td>✔</td>
<td>140</td>
</tr>
<tr>
<td>4.0</td>
<td>15</td>
<td>0.014”</td>
<td>6</td>
<td>✔</td>
<td>✔</td>
<td>140</td>
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<tr>
<td>5.0</td>
<td>20</td>
<td>0.018”</td>
<td>6</td>
<td>✔</td>
<td></td>
<td>50, 90, 135</td>
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</tr>
<tr>
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<td>0.018”</td>
<td>7</td>
<td>✔</td>
<td></td>
<td>50, 90, 135</td>
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</table>
Advanced Focused Force Balloons

VascuTrak

Semi-compliant balloon with 2 external wires
2.0-7.0 mm diameter
20-300 mm length
Advanced Focused Force Balloons

AngioSculpt® PTA Scoring Balloon

Two main components:

1. Angioplasty balloon catheter:
   - semi-compliant nylon balloon,
   - coaxial nylon shaft,
   - 2 radiopaque markerbands

2. Scoring element
   - laser-cut Nitinol hypotube
   - helical configuration
Advanced Focused Force Balloons

*AngioSculpt® PTA Scoring Balloon*

PTA Technical Considerations

**Sizing**
- 2.0 - 3.5mm diameter balloons, size the AngioSculpt < 1.0 x RVD
- 4.0 - 6.0mm diameter balloons, size the AngioSculpt a minimum of 0.5mm LESS than the RVD

**Inflation Technique**
- Increase pressure by 2atm every 10-15 seconds until full inflation
- Do not exceed the RBP
Advanced Focused Force Balloons

Advantages over Conventional Balloon Angioplasty

PRECISION

LARGER LUMINAL GAIN

SAFETY
Precision

• Rectangular edges of the scoring element “lock” the device in place

• Minimal device slippage

Larger Luminal Gain
Cutting Balloons

Percent change in lumen diameter

Cutting Balloon (CB)

Versus

High-pressure balloon (HPB)

Larger Luminal Gain

Scoring Force

The leading edges are designed to drive outward expansion with up to 15-25 times the force of a conventional balloon.

15-25 x dilating force of conventional balloons

The helical nitinol element creates a large initial luminal expansion*
Stent expansion (IVUS-measured minimum stent diameter [MSD] divided by manufacturer’s predicted MSD) as a function of IVUS plaque morphology.

Pretreatment with the AngioSculpt balloon significantly improved final stent expansion.
Safety

Minimal trauma to the media
Low dissection rate $^{1,2}$
Low rate of adjunctive stenting $^{1,2}$

1 Kiesz RS, Scheinert D, Peeters PJ et al. Results from the international registry of the AngioSculpt Scoring Balloon Catheter for the treatment of infrapopliteal disease. *J Am Coll Cardiol*. 2008;51(10(suppl B)):76.

Safety

Diseased EIA / CFA

Fem-Fem Bypass
The **CHOCOLATE® PTA Catheter** with **Nitinol Pressure Shield**

Designed to provide protection from torsional, radial and longitudinal stresses that can lead to vessel trauma.

**Key Features**
- Nitinol Pressure Shield*
- Uniform Dilatation Pillows
- Plaque-Channeling Grooves

**Designed to Provide:**
- Controlled, Predictable, Uniform Inflation
- Reduced “Dog-Boning”
- Concentric Secondary Profile
To Be Aware:

At least 1:1 Balloon Sizing – Do Not Undersize!
Ensure to take balloon to nominal pressure (not below).
**CHOCOLATE® PTA Balloon Catheter**

### Product Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform</td>
<td>0.014” or 0.018”</td>
</tr>
<tr>
<td>Diameters</td>
<td>2.5 – 6.0 mm</td>
</tr>
<tr>
<td>Balloon</td>
<td>Nylon, Semi-compliant</td>
</tr>
<tr>
<td>Constraining Structure</td>
<td>Nitinol</td>
</tr>
<tr>
<td>Catheter Lengths</td>
<td>120 cm, 135 cm, 150 cm</td>
</tr>
<tr>
<td>Balloon Lengths</td>
<td>40 mm, 80 mm, 120 mm</td>
</tr>
<tr>
<td>Sheath Fits</td>
<td>5F or 6F (depends on balloon size)</td>
</tr>
<tr>
<td>RBP</td>
<td>12 - 14 atm</td>
</tr>
<tr>
<td>Catalog #’s</td>
<td>CB: Non-hydrophilic coating</td>
</tr>
<tr>
<td></td>
<td>CF: Hydrophilic coating</td>
</tr>
</tbody>
</table>

![Diagram of CHOCOLATE® PTA Balloon Catheter](image-url)
## CHOCOLATE® PTA Balloon Catheter

### The CHOCOLATE® BAR Study (n=354)

<table>
<thead>
<tr>
<th>Patient Populations</th>
<th>ATK N=180</th>
<th>BTK N=174</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Age</td>
<td>71</td>
<td>72</td>
</tr>
<tr>
<td>Male</td>
<td>63.9%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Diabetes</td>
<td>54.4%</td>
<td>54.0%</td>
</tr>
<tr>
<td>CLI</td>
<td>24.6%</td>
<td>53.8%</td>
</tr>
<tr>
<td>Rutherford 5</td>
<td>17.9%</td>
<td>28.9%</td>
</tr>
<tr>
<td>Rutherford 6</td>
<td>0%</td>
<td>4.6%</td>
</tr>
<tr>
<td>CTO</td>
<td>16.1%</td>
<td>30.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calcification</th>
<th>ATK N=180</th>
<th>BTK N=174</th>
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</thead>
<tbody>
<tr>
<td>Severe</td>
<td>34.6%</td>
<td>31.6%</td>
</tr>
<tr>
<td>Moderate</td>
<td>29.6%</td>
<td>29.9%</td>
</tr>
<tr>
<td>Mild</td>
<td>27.4%</td>
<td>27.0%</td>
</tr>
<tr>
<td>None</td>
<td>8.4%</td>
<td>11.5%</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Lesion Length</th>
<th>ATK N=180</th>
<th>BTK N=174</th>
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<tbody>
<tr>
<td>Average</td>
<td>93.2 mm</td>
<td>88.5 mm</td>
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<tr>
<td>Range</td>
<td>10 mm–380 mm</td>
<td>5 mm–380 mm</td>
</tr>
</tbody>
</table>

The CHOCOLATE® BAR Study

(n=354)

<table>
<thead>
<tr>
<th>Procedural Success†</th>
<th>ATK N=180</th>
<th>BTK N=174</th>
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</thead>
<tbody>
<tr>
<td>Freedom from Flow-Limiting Dissection</td>
<td>98.3%</td>
<td>99.4%</td>
</tr>
<tr>
<td>Achieved &lt;30% Diameter Stenosis*</td>
<td>89.9%</td>
<td>93.6%</td>
</tr>
<tr>
<td>Freedom from Bail-Out Stenting</td>
<td>94.4%</td>
<td>96.6%</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Clinical Outcomes†</th>
<th>ATK N=56</th>
<th>BTK N=113</th>
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</thead>
<tbody>
<tr>
<td>Freedom from MAE</td>
<td>89.3%</td>
<td>90.3%</td>
</tr>
<tr>
<td>Freedom from TLR</td>
<td>89.3%</td>
<td>92.9%</td>
</tr>
<tr>
<td>Amputation Free Survival</td>
<td>96.4%</td>
<td>97.3%</td>
</tr>
</tbody>
</table>

* By visual assessment
Drug Coating Balloons
Structure and Mechanism of Action


Paclitaxel: Hydrophobic / Lipophilic properties
Excipient: Controls drug release
IN.PACT Admiral Balloons

**Platform**
- Admiral PTA balloon
- 4mm – 7mm diameters
- 20, 40, 60, 80, 120, 150mm lengths

**Drug**
- Paclitaxel
- Hydrophobic, lipophilic, proven anti-proliferative drug, 3.5 µg/mm²

**Excipient**
- Urea
- Hydrophilic, naturally occurring, nontoxic

**Coating process**
- Medtronic
- Uniformity + stability + release
- Controlled and scalable

**IN.PACT balloon matrix**
- Paclitaxel
- Urea

**DCB inflation:**
- Paclitaxel
- Urea

**Paclitaxel penetration:**
- Paclitaxel
MOXY Balloons

- Proprietary 2 μg/mm² paclitaxel coating with hydrophilic non-polymeric carrier
- Formulation balances drug retention during transit and uptake upon inflation
- Drug delivered during single 30 second inflation
- Robust, uniform coating
## Drug Coated Balloon – US Trials

<table>
<thead>
<tr>
<th>Trial Name</th>
<th>Target</th>
<th>Lesion</th>
<th>Rutherford Category</th>
<th>Outflow</th>
<th>Exclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEVANT 2</td>
<td>• Femoropopliteal artery&lt;br&gt;• 4–6 mm in diameter</td>
<td>• De novo or nonstented restenotic&lt;br&gt;• ≤ 15 cm</td>
<td>2–4</td>
<td>One patent native outflow artery</td>
<td>• Severe calcium&lt;br&gt;• Renal failure or CKD&lt;br&gt;• No adjunctive treatment modality</td>
</tr>
<tr>
<td>IN.PACT</td>
<td>• SFA&lt;br&gt;• 4–7 mm in diameter</td>
<td>• De novo or nonstented restenotic lesions&lt;br&gt;• 70%–99% stenosis ≥ 4 cm and ≤ 18 cm&lt;br&gt;• 100% ≤ 10 cm</td>
<td>2–4</td>
<td>Adequate outflow</td>
<td>• Severe calcium&lt;br&gt;• CKD&lt;br&gt;• No adjunctive treatment modality</td>
</tr>
<tr>
<td>Lutonix ISR</td>
<td>• Femoropopliteal artery&lt;br&gt;• 4–6 mm in diameter</td>
<td>• ≥ 50% bare-metal stent restenosis&lt;br&gt;• 4–18 cm</td>
<td>2–4</td>
<td>One patent native outflow artery</td>
<td>• Grade 4–5 stent fracture&lt;br&gt;• No adjunctive treatment modality</td>
</tr>
<tr>
<td>Lutonix BTK</td>
<td>• Above-the-ankle tibial lesions&lt;br&gt;• 2–4 mm in diameter</td>
<td>De novo or nonstented restenotic</td>
<td>4–5</td>
<td>NA</td>
<td>CKD</td>
</tr>
</tbody>
</table>

### IN.PACT SFA vs. Levant 2

<table>
<thead>
<tr>
<th></th>
<th>IN.PACT SFA</th>
<th>Levant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean lesion length</td>
<td>89 mm</td>
<td>63 mm</td>
</tr>
<tr>
<td>Total occlusions</td>
<td>25.8 %</td>
<td>21 %</td>
</tr>
<tr>
<td>1-year primary patency control group</td>
<td>52.45 %</td>
<td>52.6 %</td>
</tr>
<tr>
<td>1-year primary patency DCB group</td>
<td>82.2 %</td>
<td>65.2 %</td>
</tr>
<tr>
<td>1-year freedom from TLR</td>
<td>79.4 %</td>
<td>83.2 %</td>
</tr>
</tbody>
</table>

*DCB drug-coated balloon, TLR target lesion revascularization*
Novel Drug Coated Technology

Inhibition of neo-intimal hyperplasia in porcine coronary arteries utilizing a novel paclitaxel-coated scoring balloon catheter

Angiographic and histologic examples of (A) uncoated and (B) coated scoring balloons (D10, 3 µg mm$^{-2}$) at baseline and 30 days

D-10 Angiosculpt

Cremers B et al. Catheter Cardiov Interv 2014
Minimal Vessel Injury Protocol

FIBROUS / MILDLY CALCIFIED PLAQUES

Lumen Enlargement with FFA or Chocolate

Inhibition of restenosis with DCB
Minimal Vessel Injury Protocol

CALCIFIED PLAQUE

Plaque modification with Orbital Atherectomy

Lumen Enlargement with FFA or Chocolate

Inhibition of restenosis with DCB
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