SCAI 2015
Fall Fellows Courses

Fundamentals of PCI--Balloons and Stents

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DISCLOSURES:

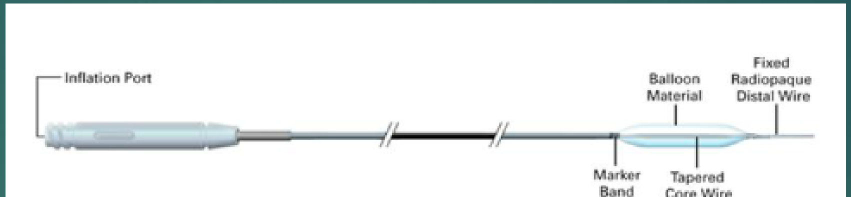
- None relevant to the content of this presentation

Outline

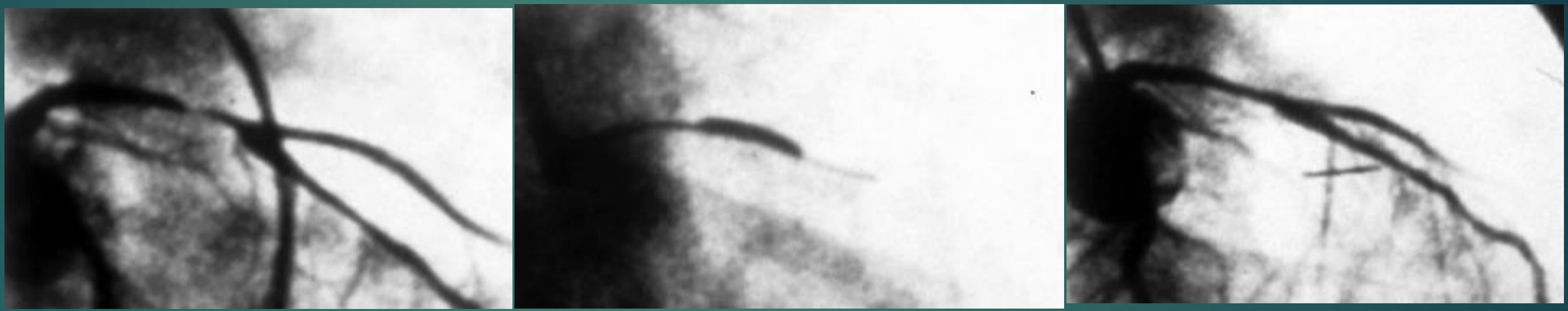
- Coronary Angioplasty Balloons
  - Angioplasty Balloons of Historical Interest
  - Balloon Design Considerations
  - Specialty Balloons
- Intracoronary Stents
  - Coronary Stents of Historical Interest
  - Bare Metal Stents
  - Drug Eluting Stents
  - Covered Stents
  - Bioresorbable Scaffolds
- Conclusions

Early Coronary Angioplasty Balloons

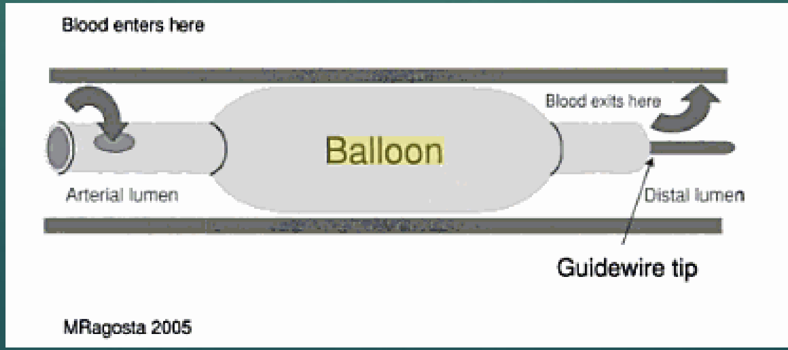
- Fixed Wire Balloons



Ace Balloon SciMed



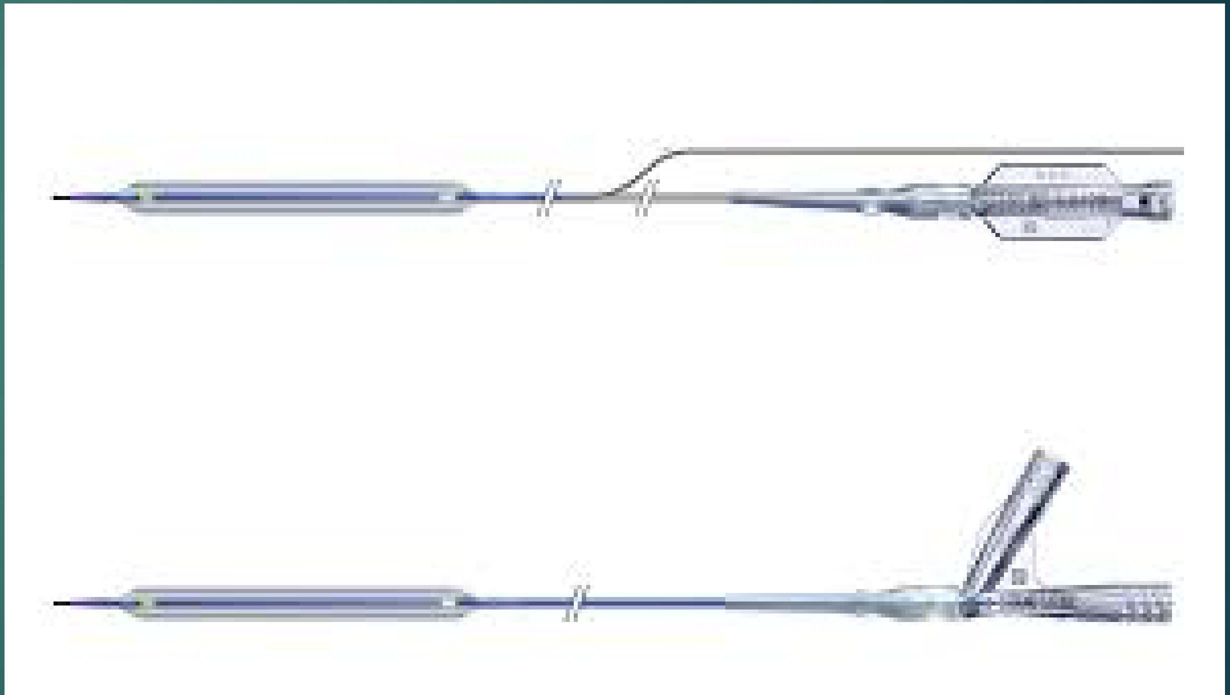
- Perfusion Balloons



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

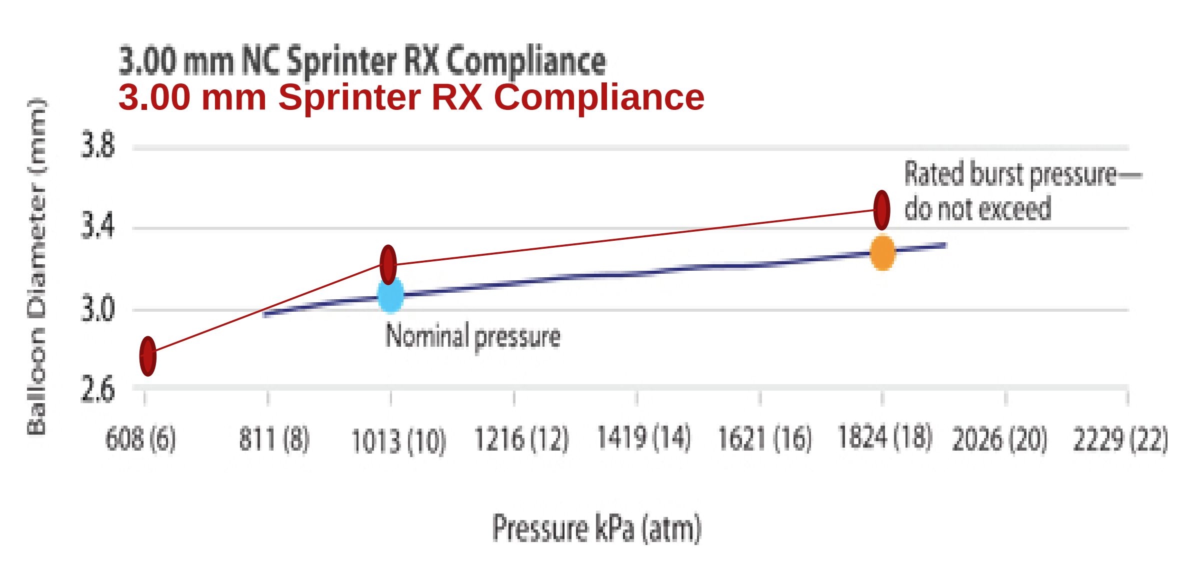
- Need for two operators
- Longer fluoroscopy times needed for exchanges
- Slightly larger profile/shaft sizes
  - Especially for kissing balloon angioplasty

Balloon Construction and Function

More Compliant

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

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 <u>will</u> not rupture

Balloon Selection

Compliant and Semi-Compliant Balloons

- Pre-dilation
- Ballooning through side struts

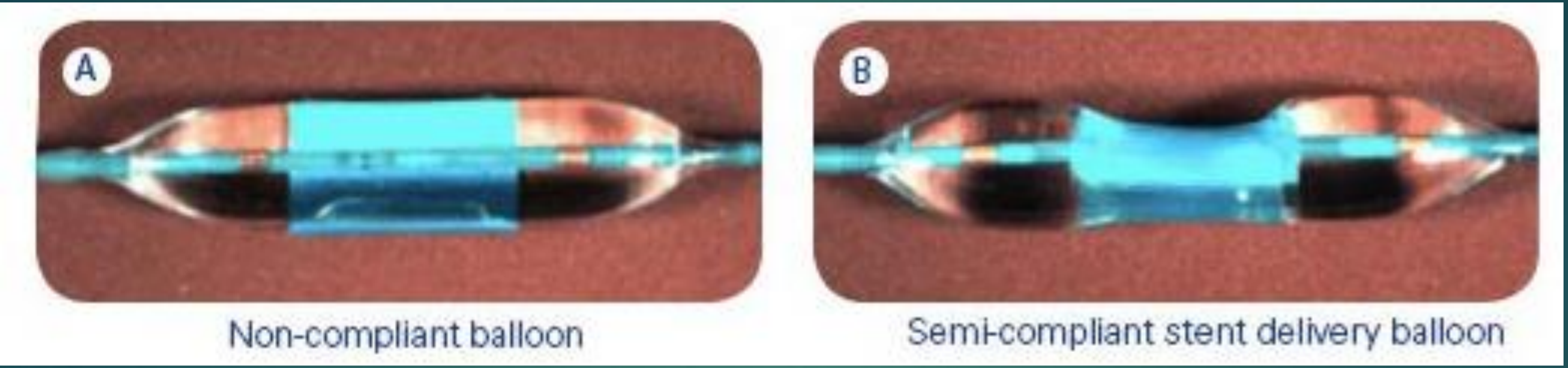
- Very tight lesions
- Tortuous anatomy
- Re-crossing stents
- Side branch access

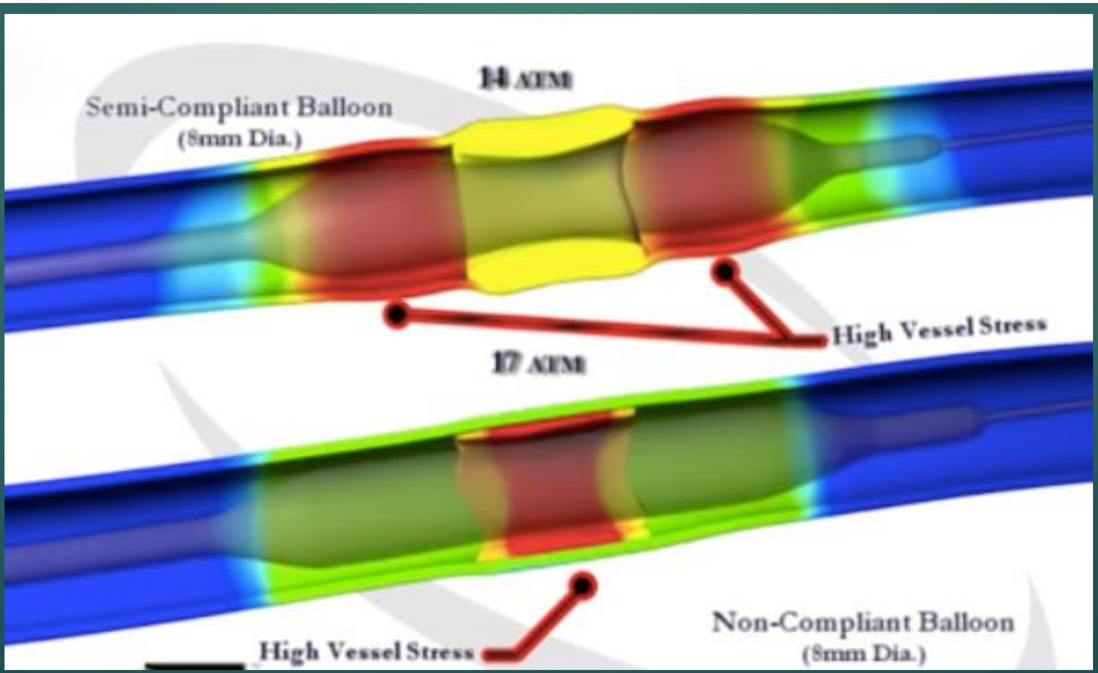
Non-Compliant Balloons

- Post-dilation of stents
- Resistant lesions

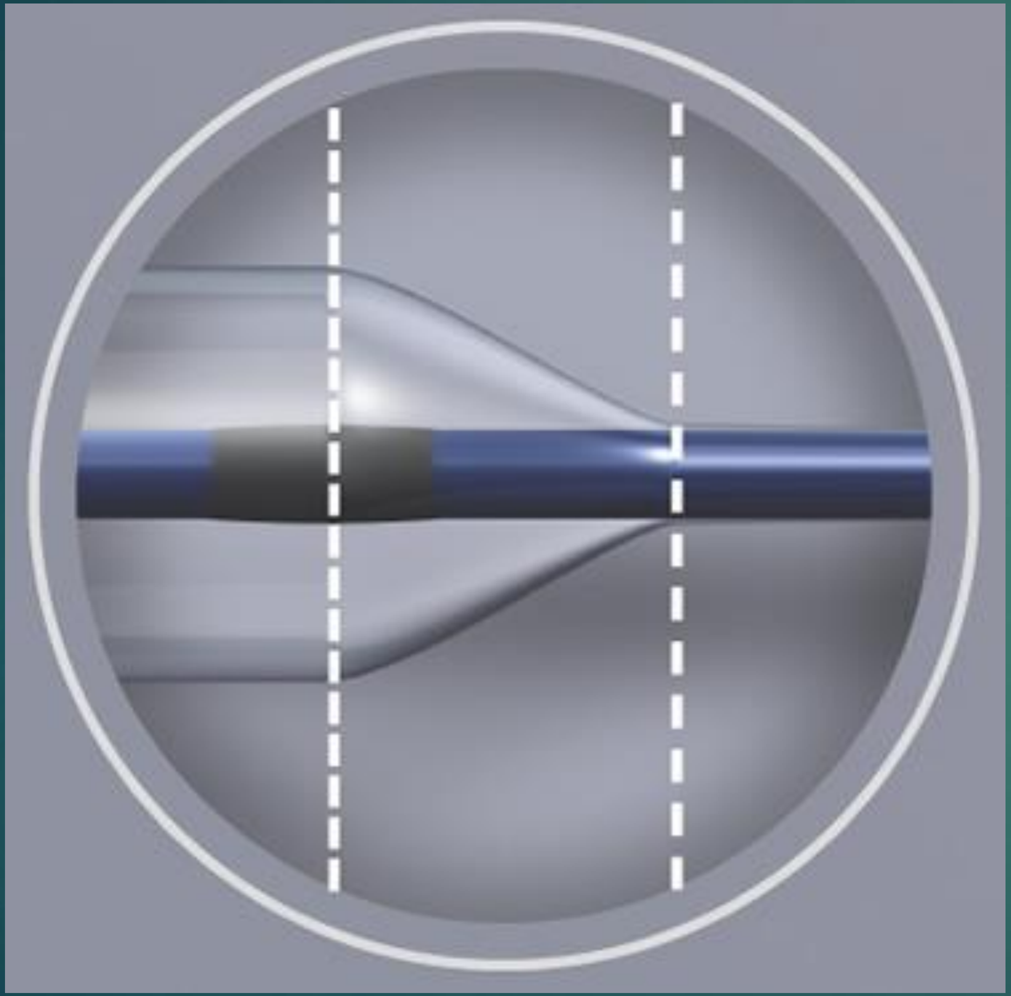
- Heavy calcification
- Non-dilatable lesions
- Aorto-ostial lesions

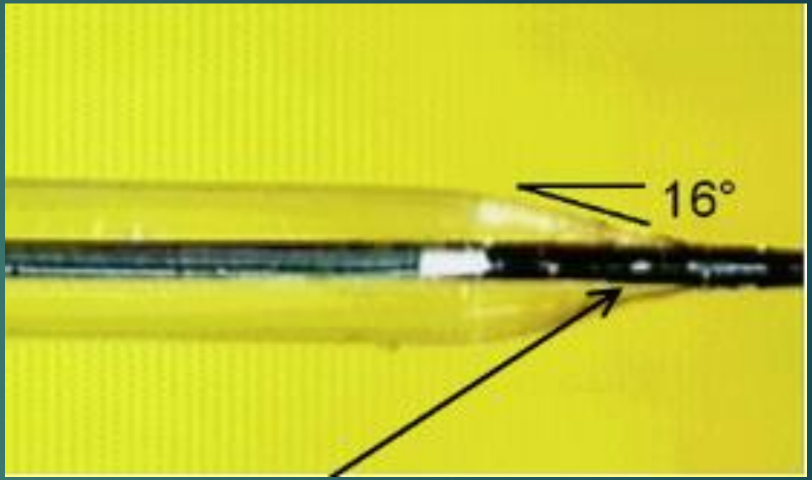
Compliance and Wall Stress



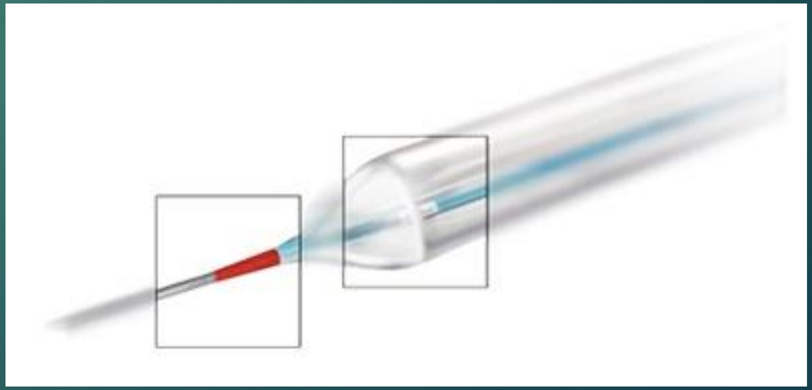


Balloon Tip Taper





Longer taper increases crossability

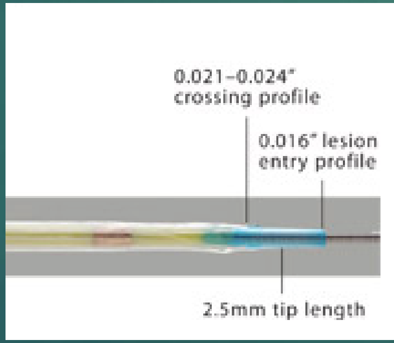


Shorter shoulders decrease edge effects

Current Balloon Options*

Vendor	Compliant	Non-Compliant
Abbott Vascular	Trek (2.25-5.0 mm) MiniTrek (1.20 and 1.5-2.0 mm)	NC Trek (1.5 mm – 5.0 mm)
Boston Scientific	Emerge Flex (1.2-4.0 mm) Emerge Push (1.2 and 1.5 mm)	NC Emerge (2.0-6.0 mm) NC Quantum Apex (2.0-5.0 mm)
Medtronic	Euphora (1.5-4.0 mm) Sprinter Legend (1.25-4.0 mm)	NC Euphora (2.0-5.0 mm) NC Sprinter (2.0-5.0 mm)

Crossing profiles:

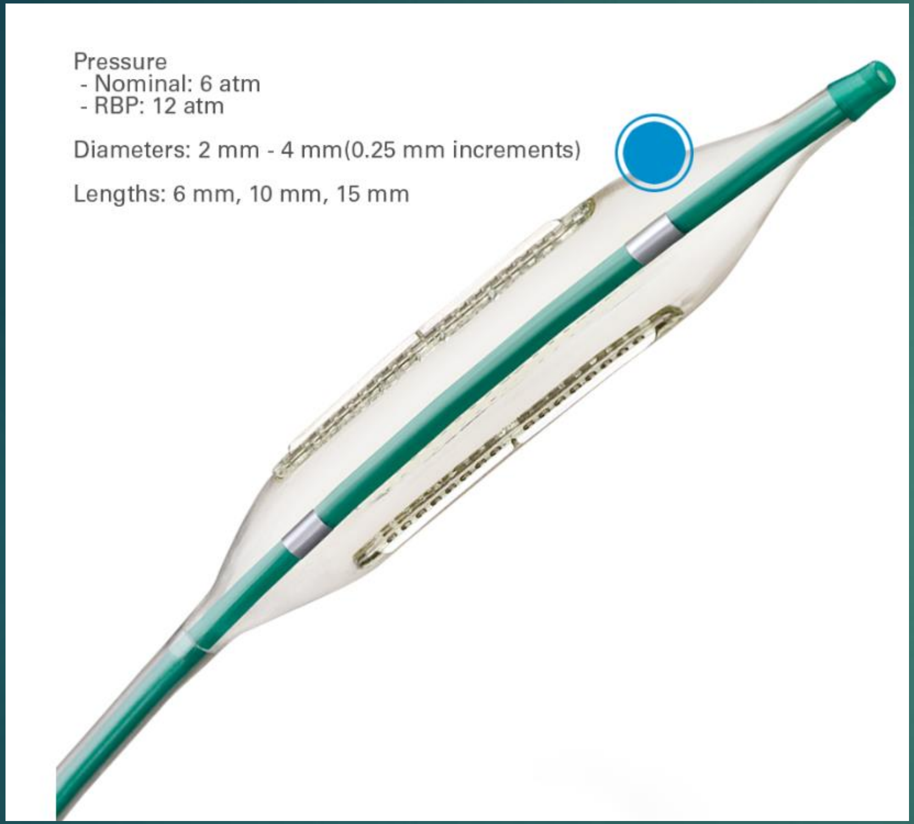


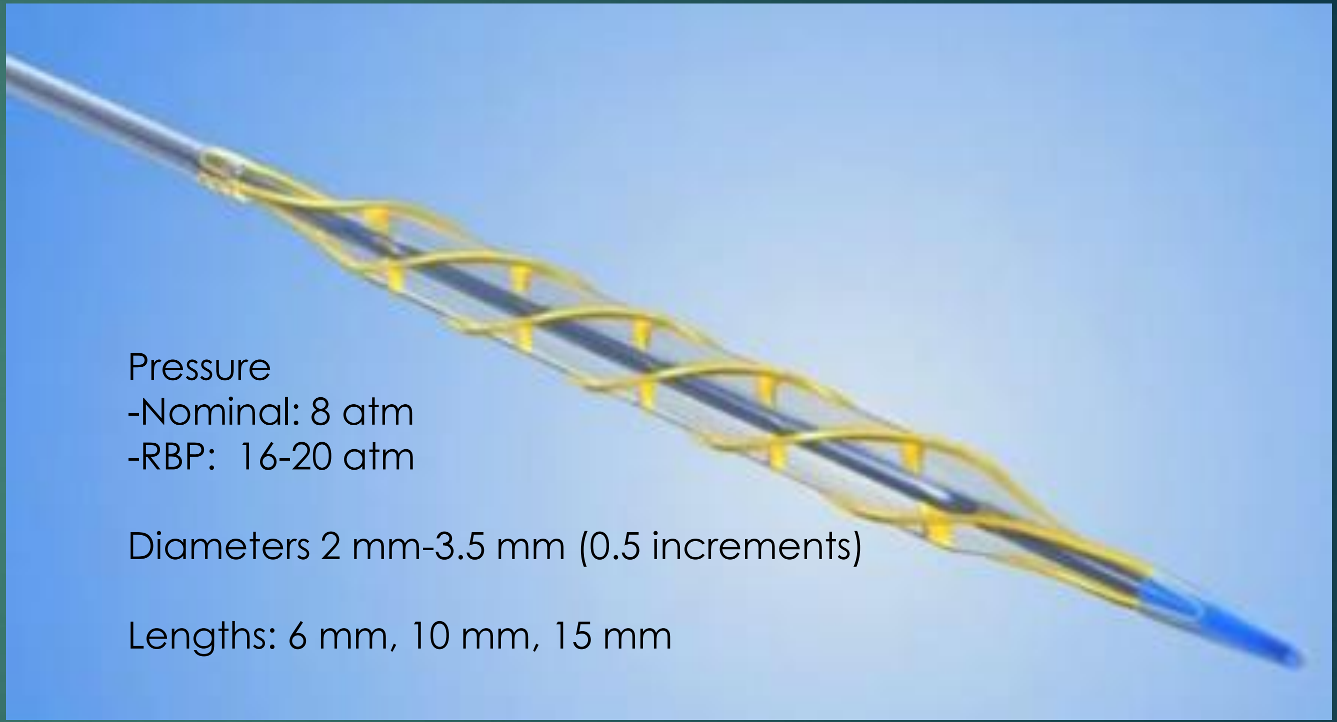
Compliant Balloons (0.021-0.026")

Non-compliant balloons (0.024-0.031")

*FDA Approved

Cutting/Scoring Balloons

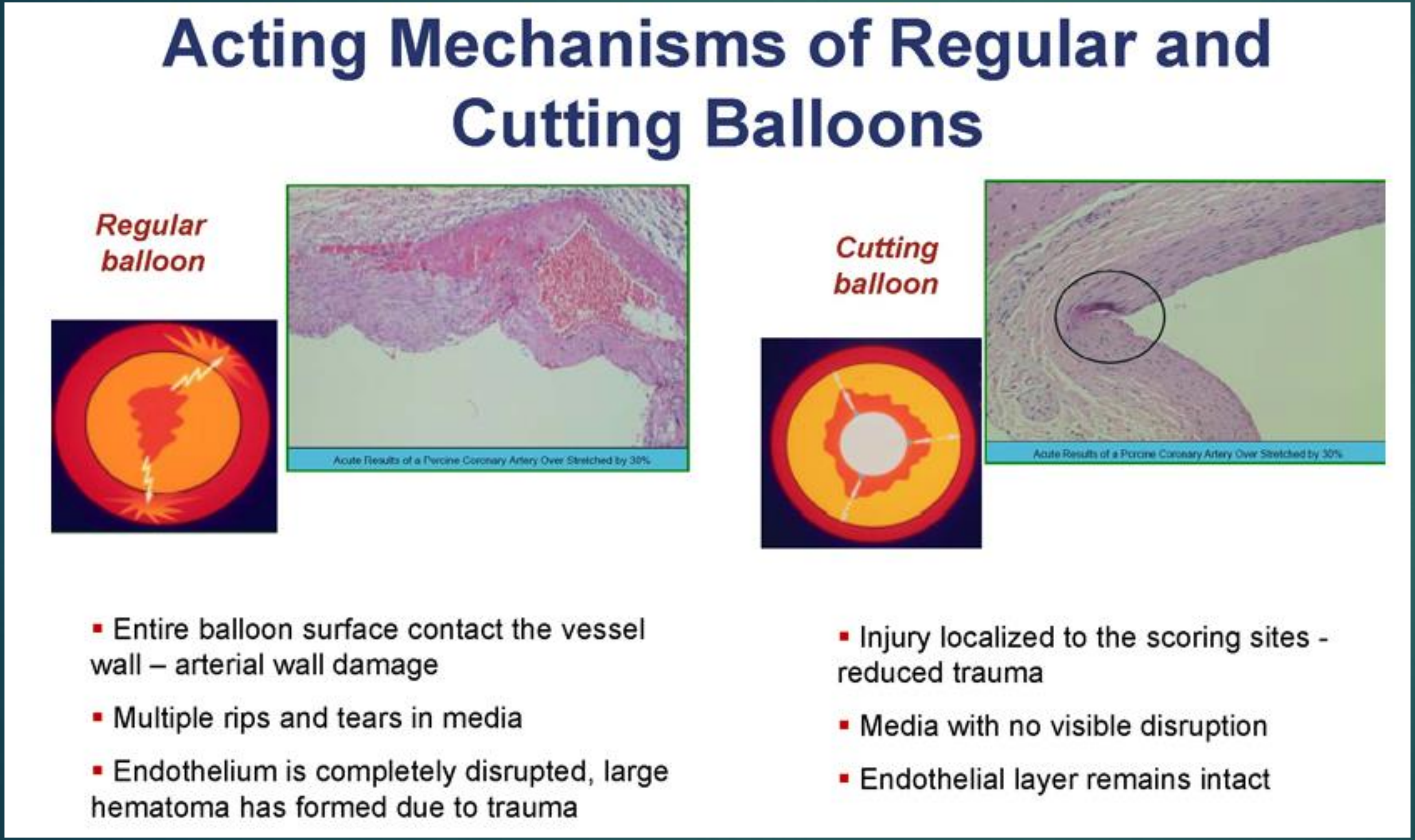




Flextome Cutting Balloon—Boston Scientific

Angiosculpt Scoring Balloon—AngioScore, Inc

Cutting/Scoring Balloons



Pros:

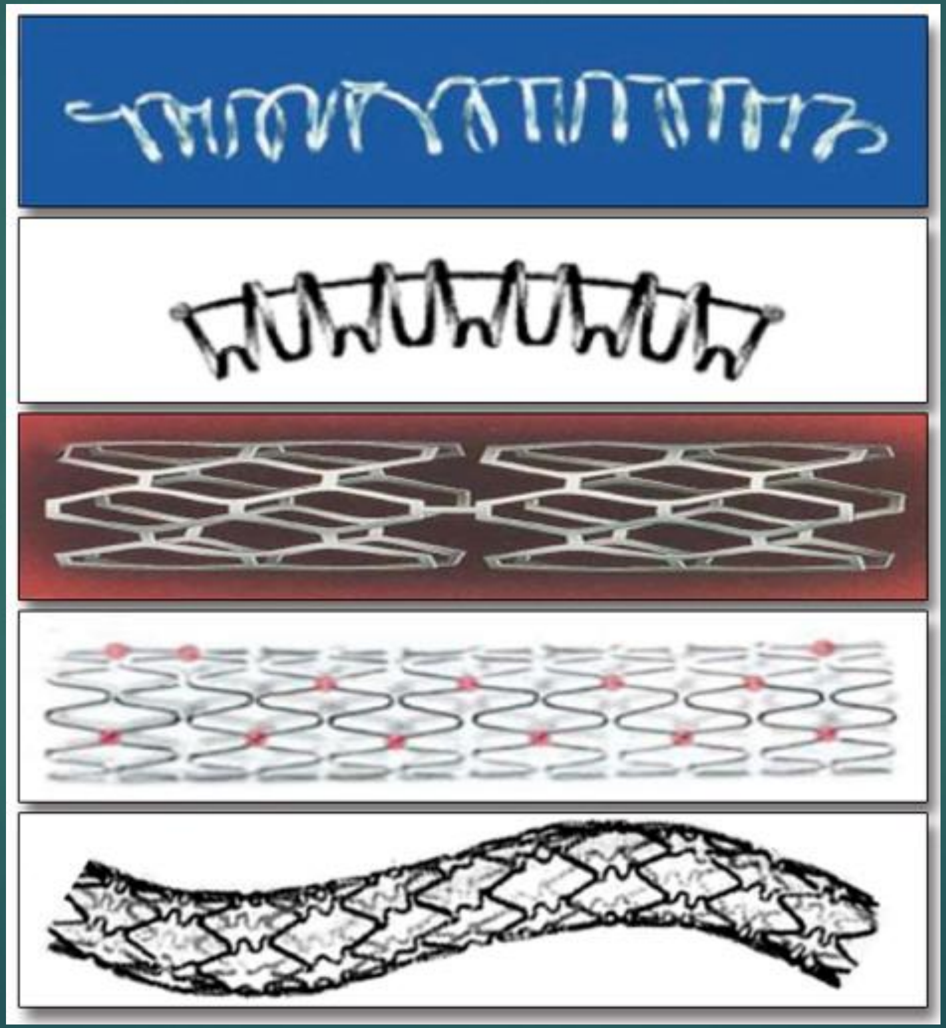
- "Controlled" dissection
- Less slippage
- Non-compliant balloons

Cons:

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

Early Coronary Stent Designs

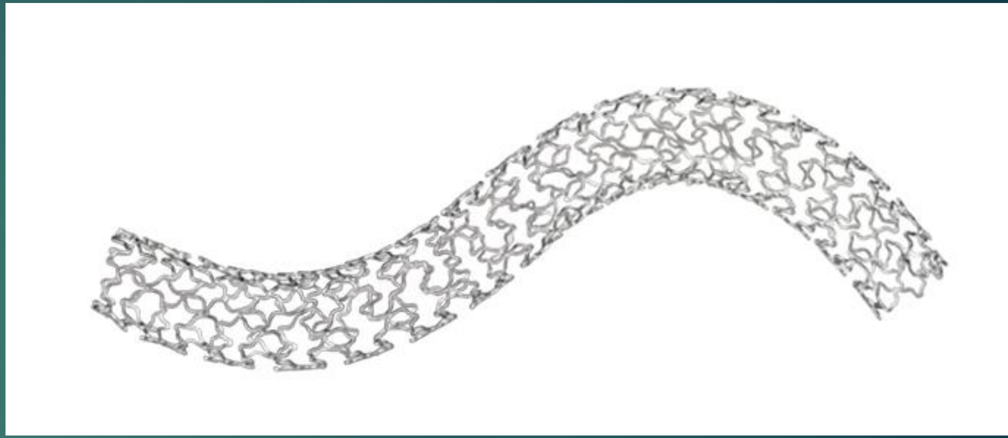
Stent Design Type



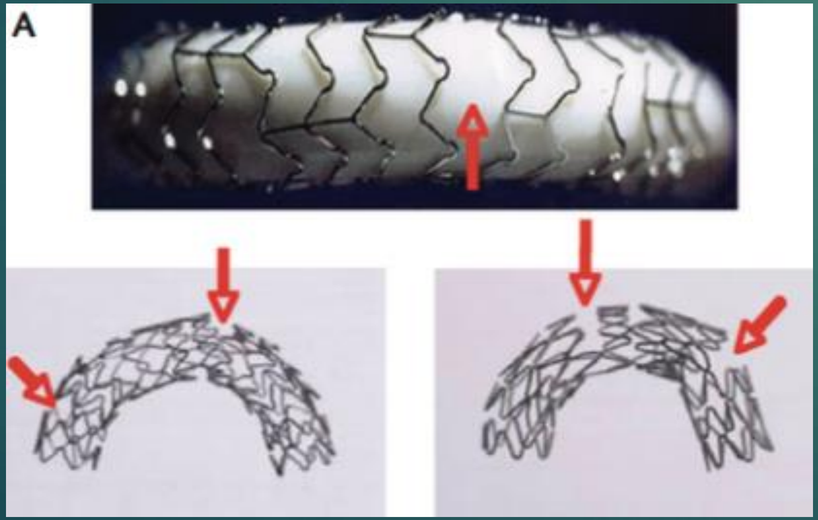
Stent Design Type	
Coiled Wire	Gianturco-Roubin (GR-1)
	Gianturco-Roubin II
Slotted Tube	Palmaz-Schatz (J and J)
Modular ring	Driver--Medtronic
Multicellular	Bx Velocity

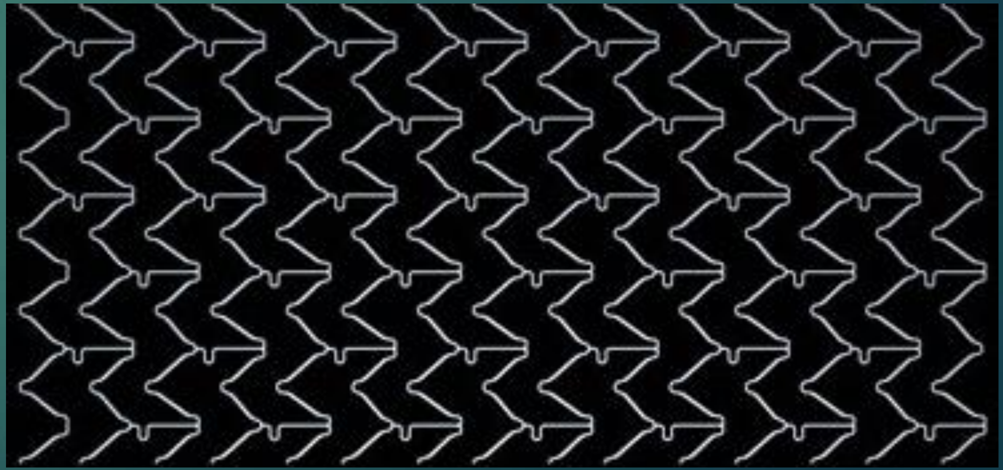
Stent Design

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



VeriFlex BMS BSCI

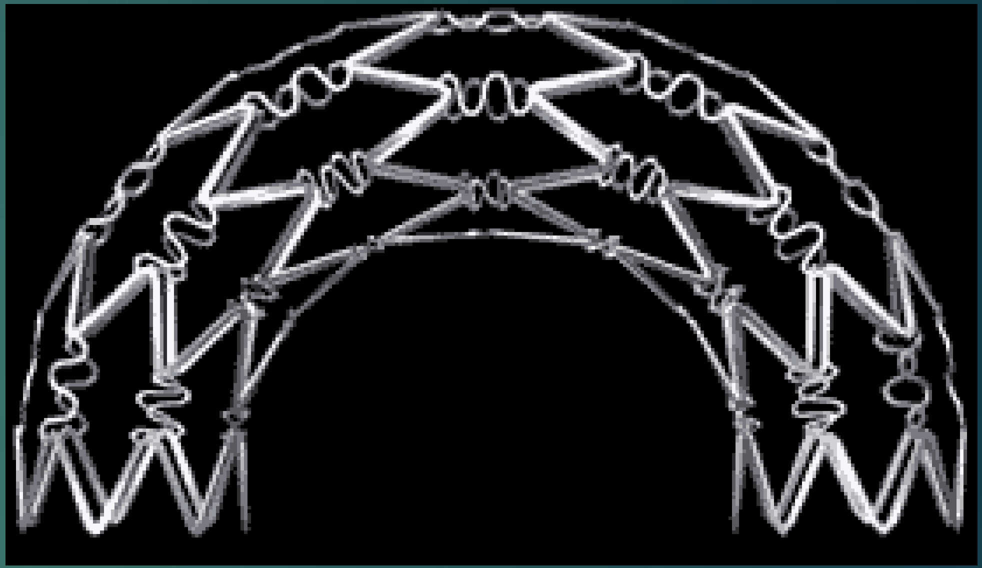




Multi-Link MiniVision Abbott

Stent Design

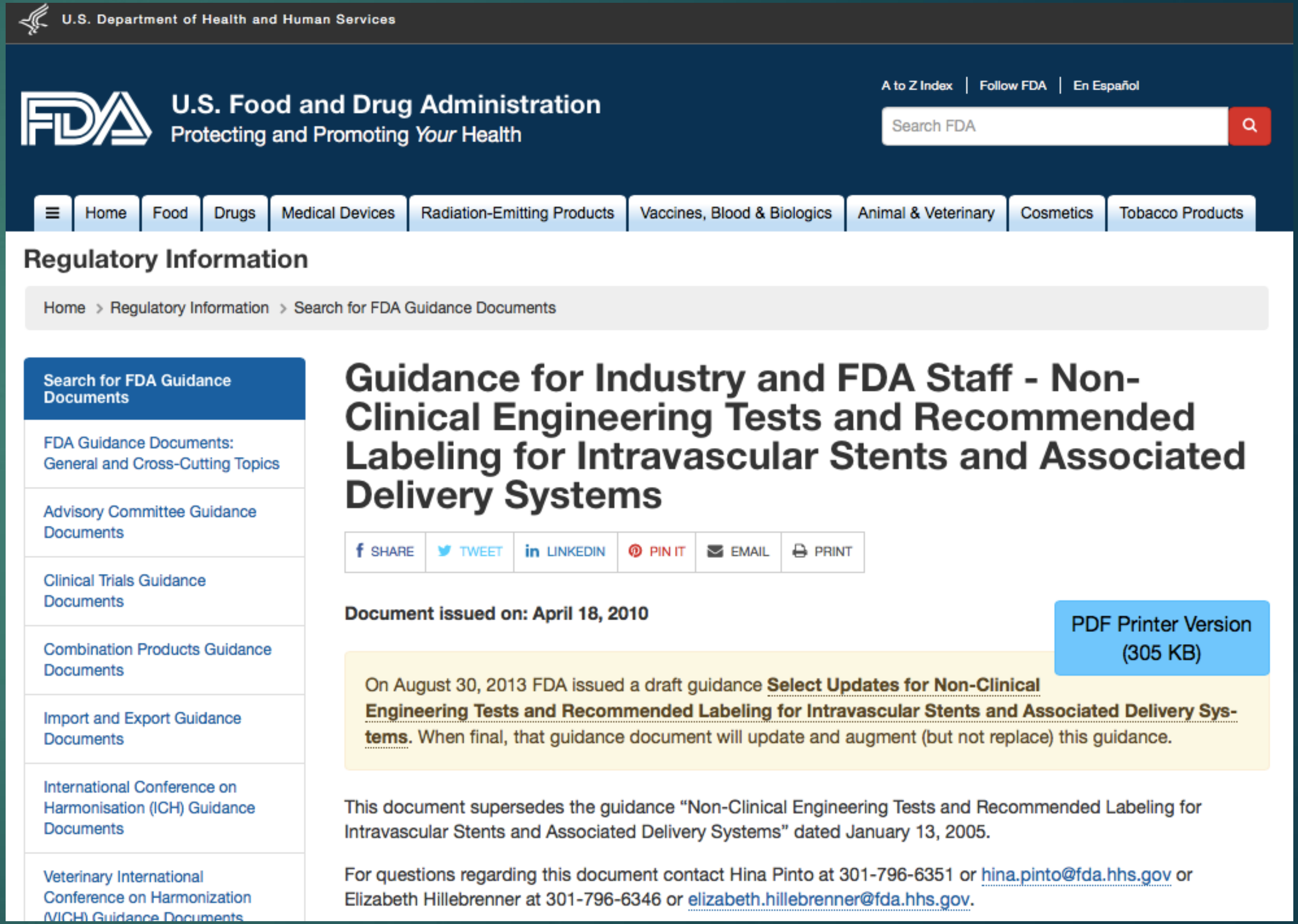
- Closed-cell design
  - Smaller area per cell
  - Higher metal to artery ratio
  - Improved scaffolding
  - ? Smaller side branch access



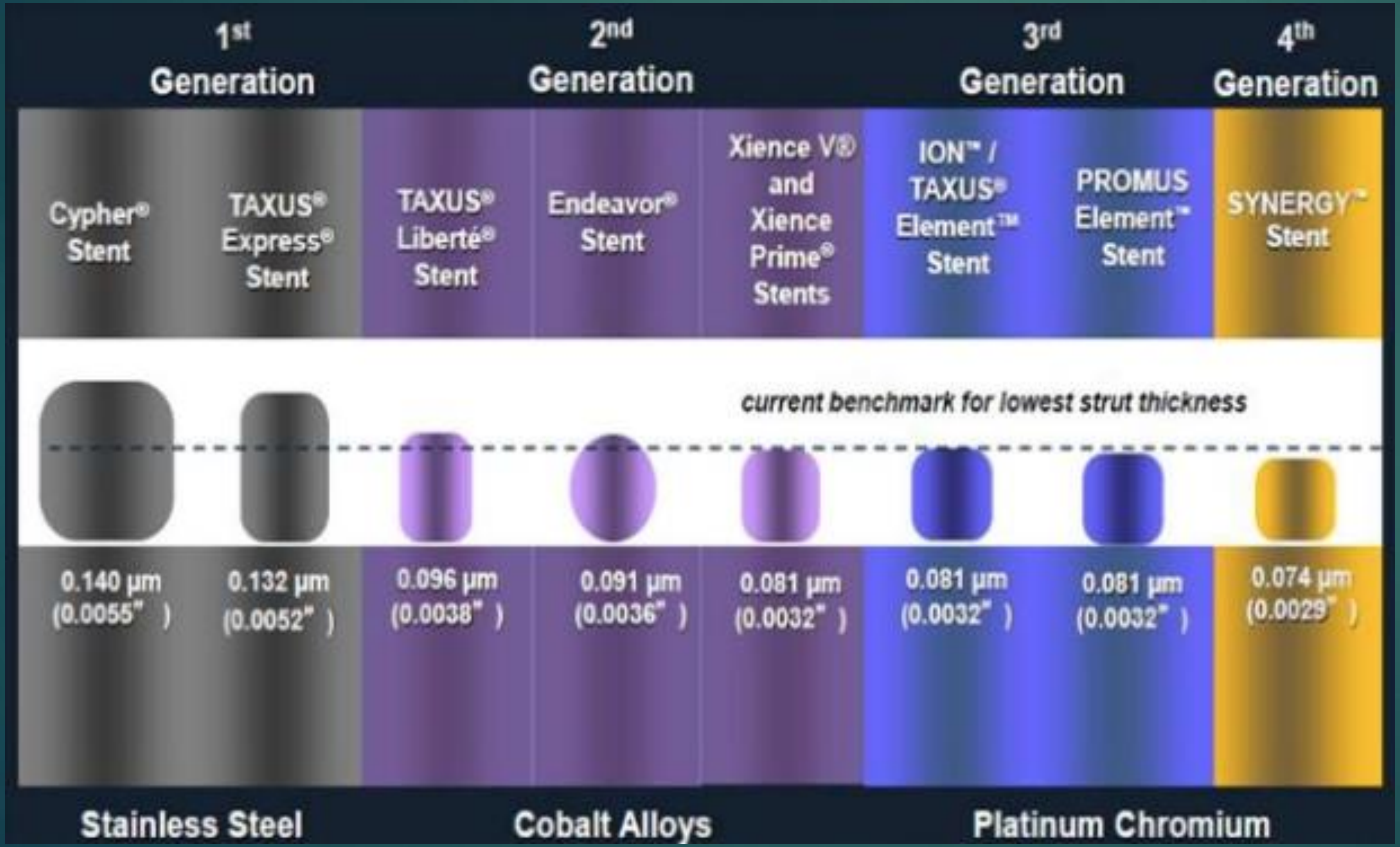
Cypher Stent (Bx Velocity Platform) Cordis Co.

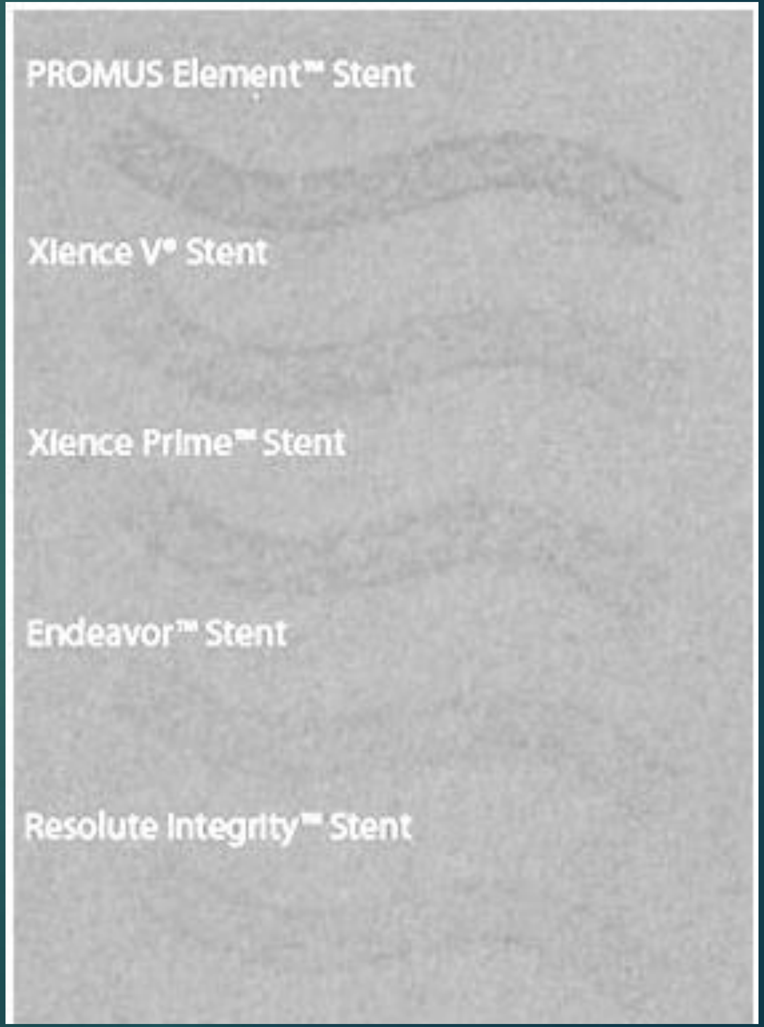
Stent Attributes

- Trackability
- Flexibility
- Deliverability
- Radial strength
- Lesion/vessel coverage
- Radiologic visibility



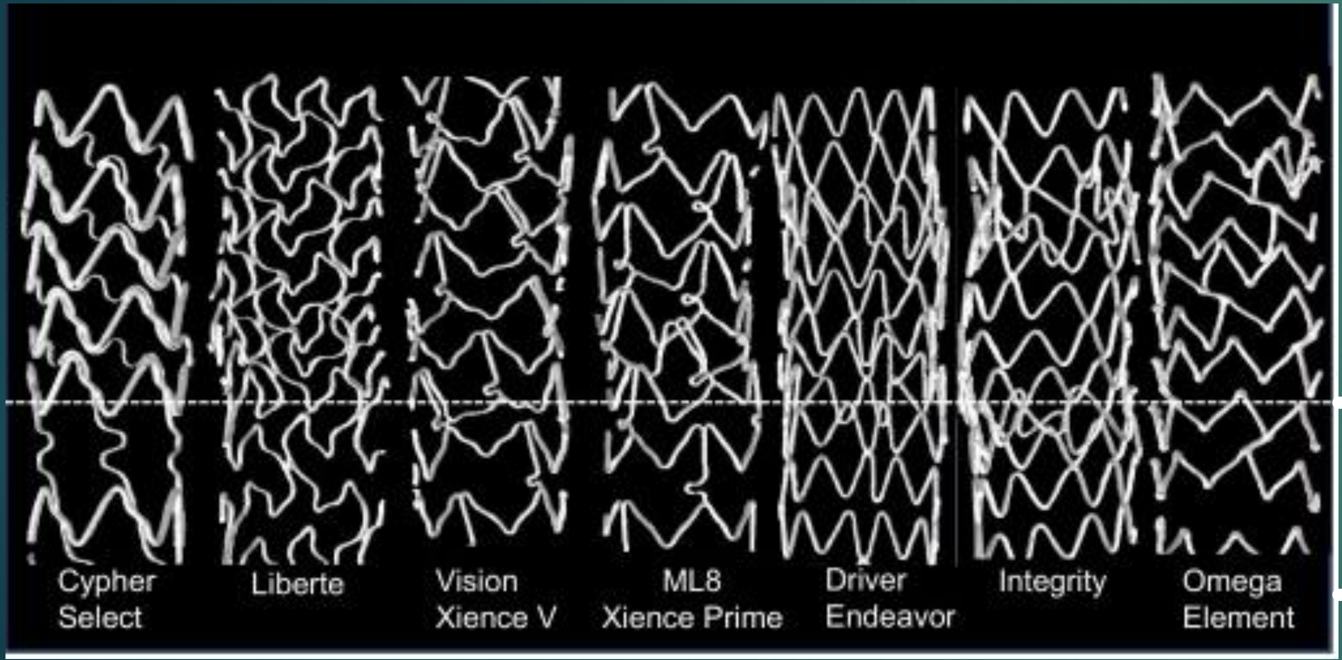
Progress in Stent Strut Thickness and Composition





Stent Design—Balloon Overhang

Longitudinal Stent Deformation



Multivariable Predictors of Stent Deformation from 1800 patients

Variable	Odds ratio (95% CI)	P-value
Promus Element stent	5.53 (1.54 – 19.85)	0.0088
Multiple stents	2.06 (1.45 – 2.90)	<0.0001
Guideliner	22.09 (4.73 – 103.04)	0.0001
Postdilation balloon	5.47 (1.31 – 22.81)	0.0197

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

Original Stent Shape

Ormiston et al. JACC: Cardiovascular Intervention, 2011.

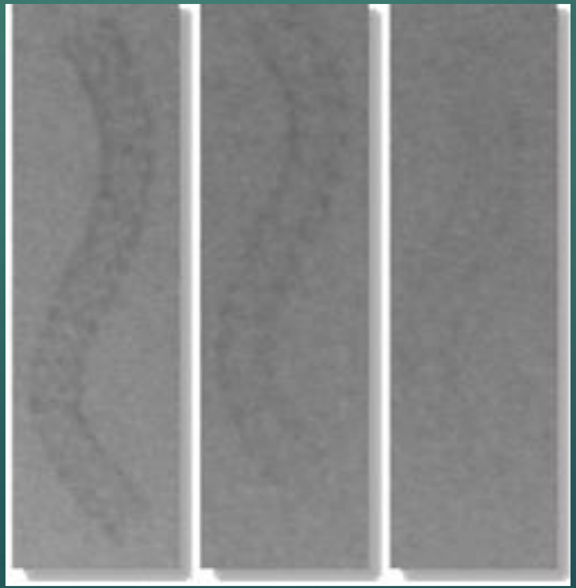
Arnous S et al . Cathet Cardiovasc Interv 86:1002–1011;2015

Current Bare Metal Stent Options--

Vendor	Stent	Sizes	Lengths
Abbott Vascular	Vision (CoCr) Mini-Vision (CoCr)	2.75-4.00 mm 2.00-2.50 mm	8-28 mm 8-28 mm
Boston Scientific	VeriFLEX (316L SS) Rebel (PtCr)	2.75-5.00 mm 2.25-4.50 mm	8-32 mm 8-32 mm
Medtronic	Integrity (CoCr)	2.25-4.00 mm	8-30 mm

Vision

Rebel



Integrity

Evolution of DES

Easter Island (Rapa Nui)

Pacific Yew Tree

Drug Eluting Stent Components

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.

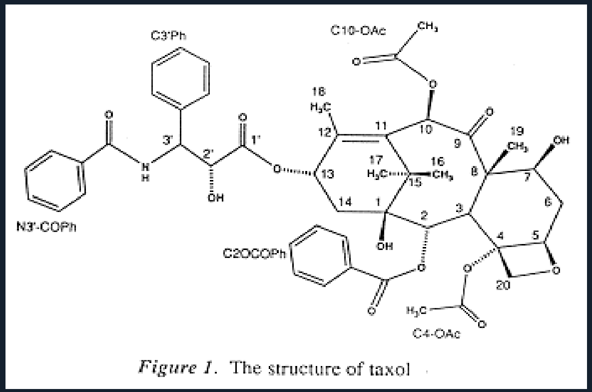
DES Polymers

Polymer Surface Coatings

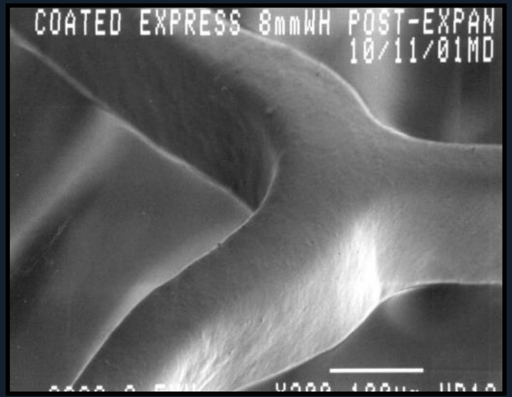
- Polymers control the dosage and duration of antiproliferative drug release
- Durable polymers Identified as a potential trigger for hypersensitivity reactions associated with chronic inflammation and delayed arterial healing
  - may increase the risk of VLST and delayed restenosis.
- Biodegradable 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

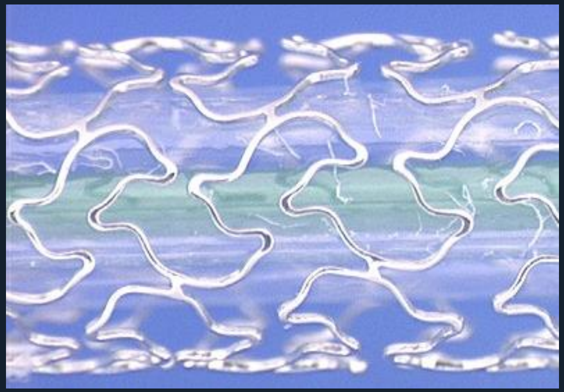
TAXUS



Paclitaxel



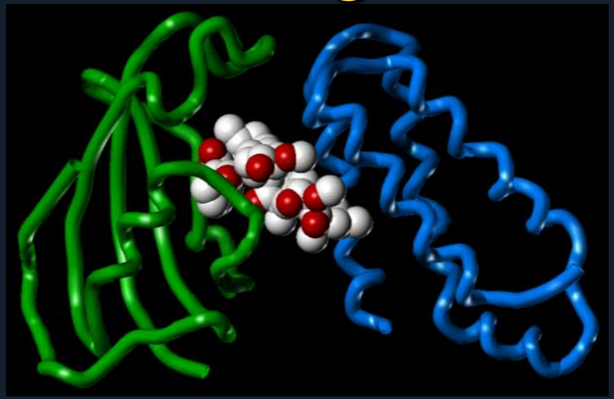
Polyolefin derivative



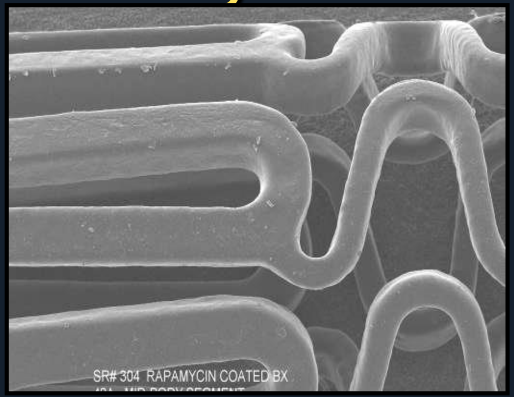
Liberté

Drug | **Polymer** | **Stent**

Cypher



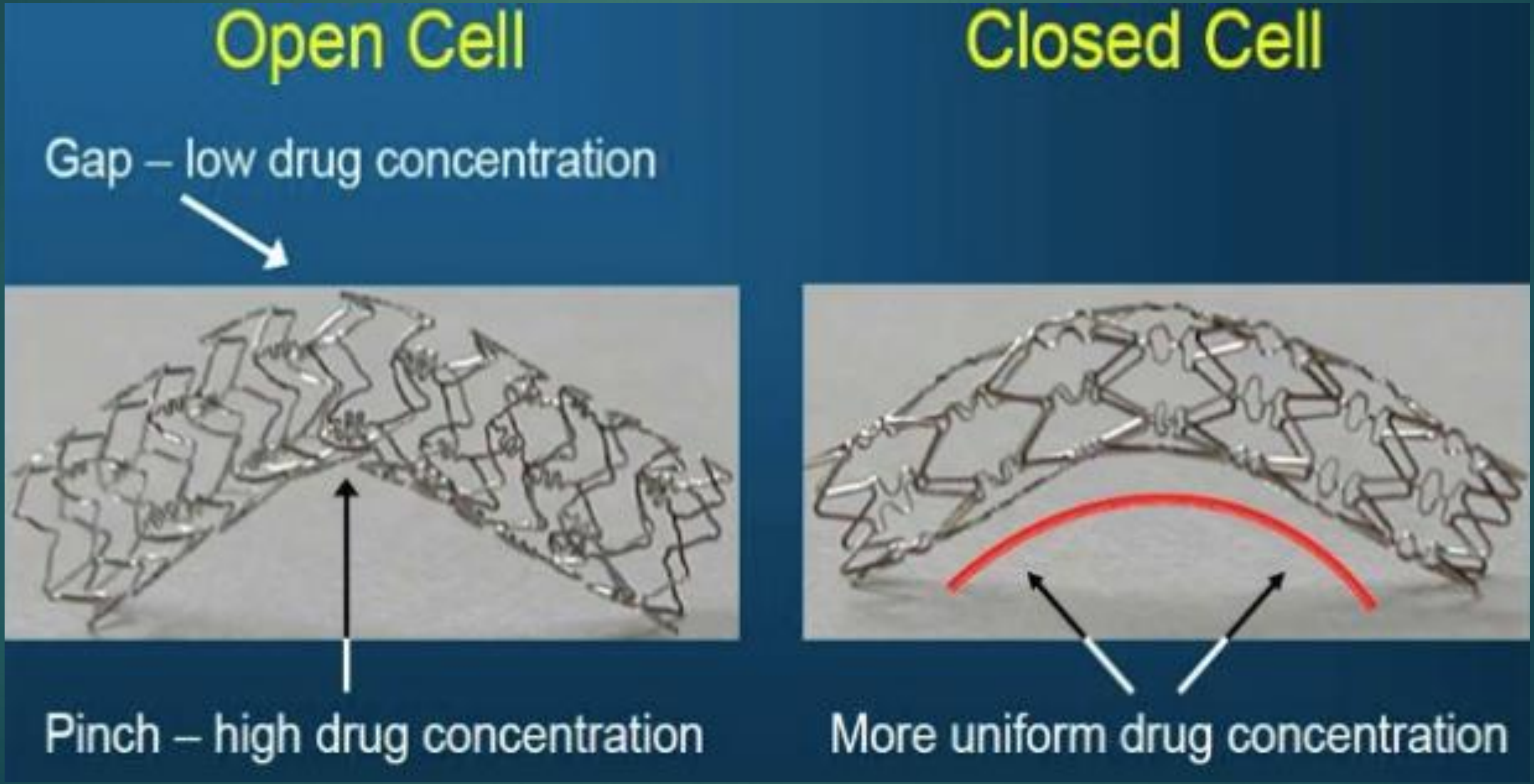
Sirolimus



PEVA + PBMA blend

BX Velocity

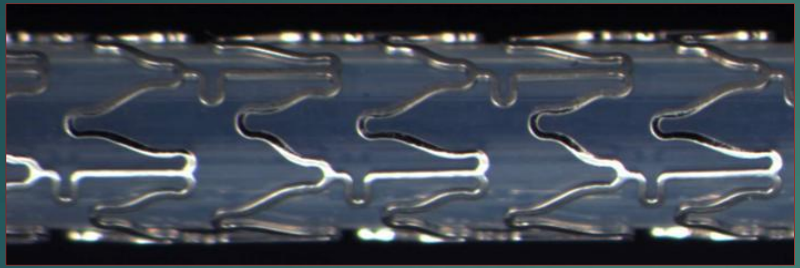
Stent Design Can Influence Drug Elution

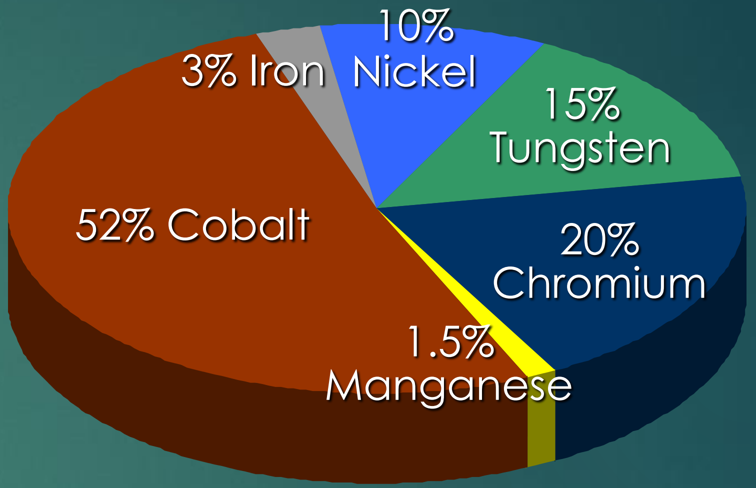


Drug Eluting Stents-- 2nd Generation

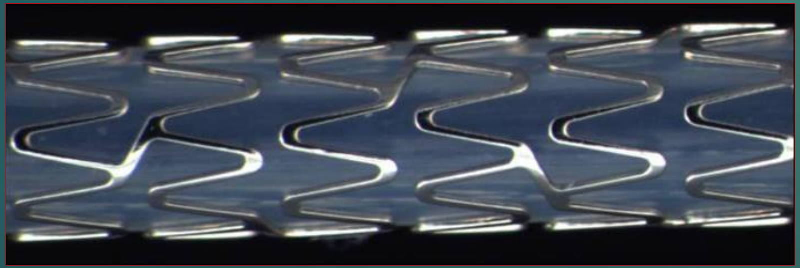
Everolimus concentration: 100 ug/cm²
Polymer: PBMA & PVDF-ss)

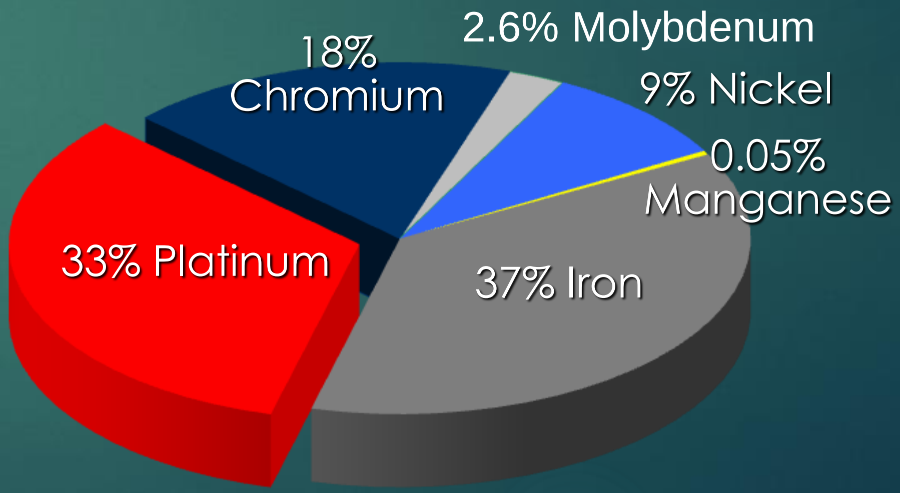
XIENCE V / PROMUS (CoCr-EES)





PROMUS Element (PtCr-EES)



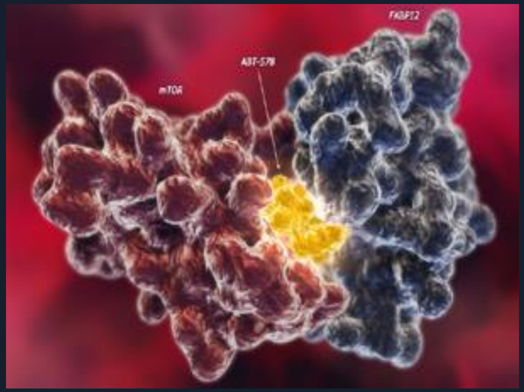


PBMA=poly (n-butyl methacrylate) (primer layer);
PVDF-HFP=poly (vinylidene fluoride-co-hexafluoropropylene) (drug matrix layer)

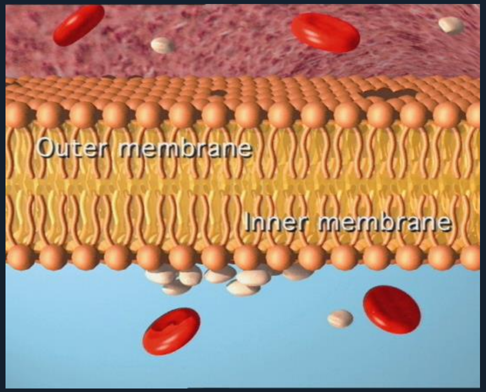
Stone GW et al. JACC 2011; 57:1700–8

Drug-eluting Stents: 2nd Generation

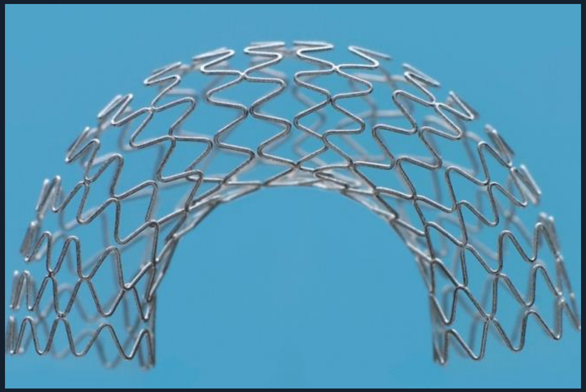
Endeavor



Zotarolimus



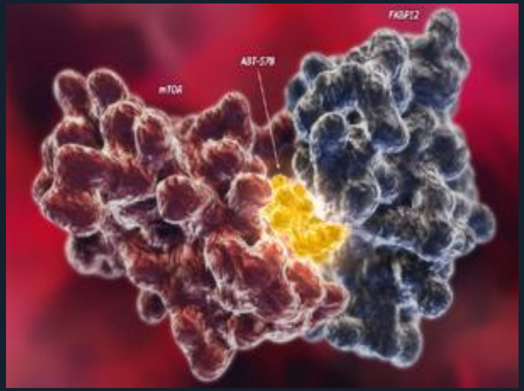
Phosphorylcholine



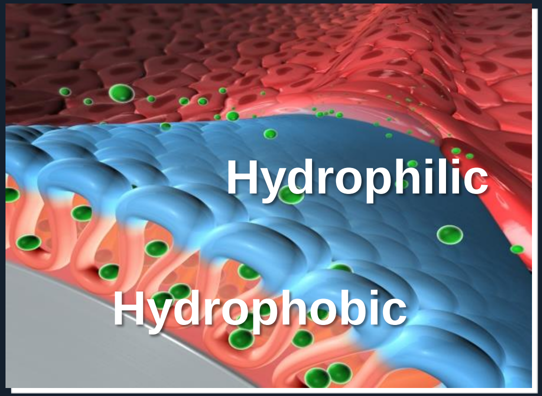
Driver

Drug | **Polymer** | **Stent**

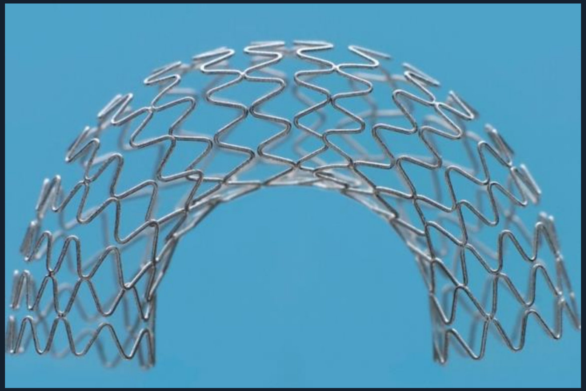
Resolute



Zotarolimus



BioLinx



Driver

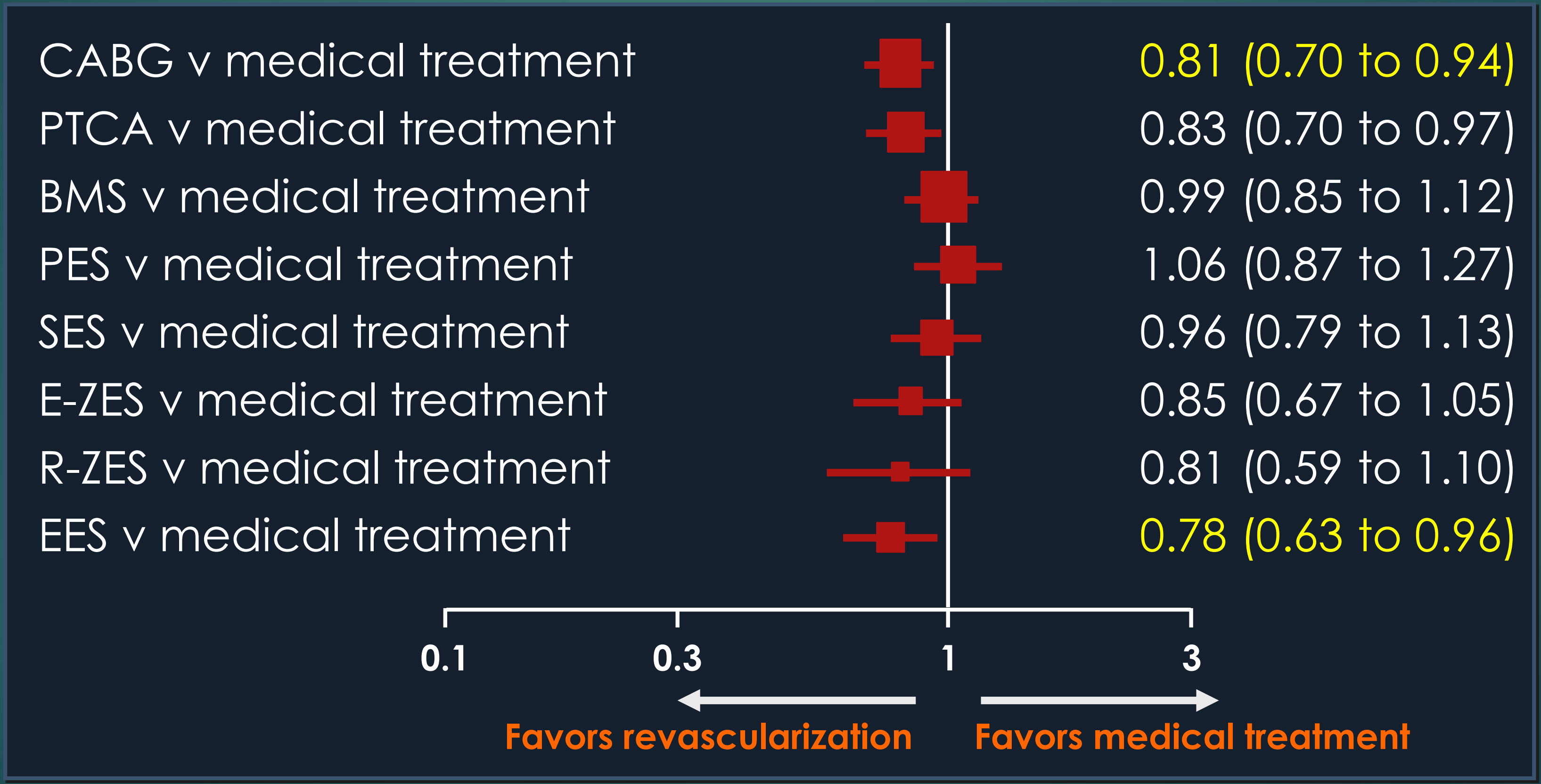
Drug Eluting Stent Timeline

	Date Approved	Manufacturer	Stent Alloy	Drug	Polymer
First Generation					
Cypher	2003	Cordis	Stainless steel	Sirolimus	Durable
Taxus	2004	Boston Scientific	Stainless steel	Paclitaxel	Durable
Second Generation					
Xience V	2007	Abbott Vascular	Cobalt chromium	Everolimus	Durable
Promus	2008	Boston Scientific	Cobalt chromium	Everolimus	Durable
Endeavor	2008	Medtronic	Cobalt chromium	Zotarolimus	Durable
Xience Prime	2011	Abbott Vascular	Cobalt chromium	Everolimus	Durable
Promus Element	2011	Boston Scientific	Platinum chromium	Everolimus	Durable
Taxus Ion	2011	Boston Scientific	Platinum chromium	Paclitaxel	Durable
Resolute	2012	Medtronic	Cobalt chromium	Zotarolimus	Durable

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)

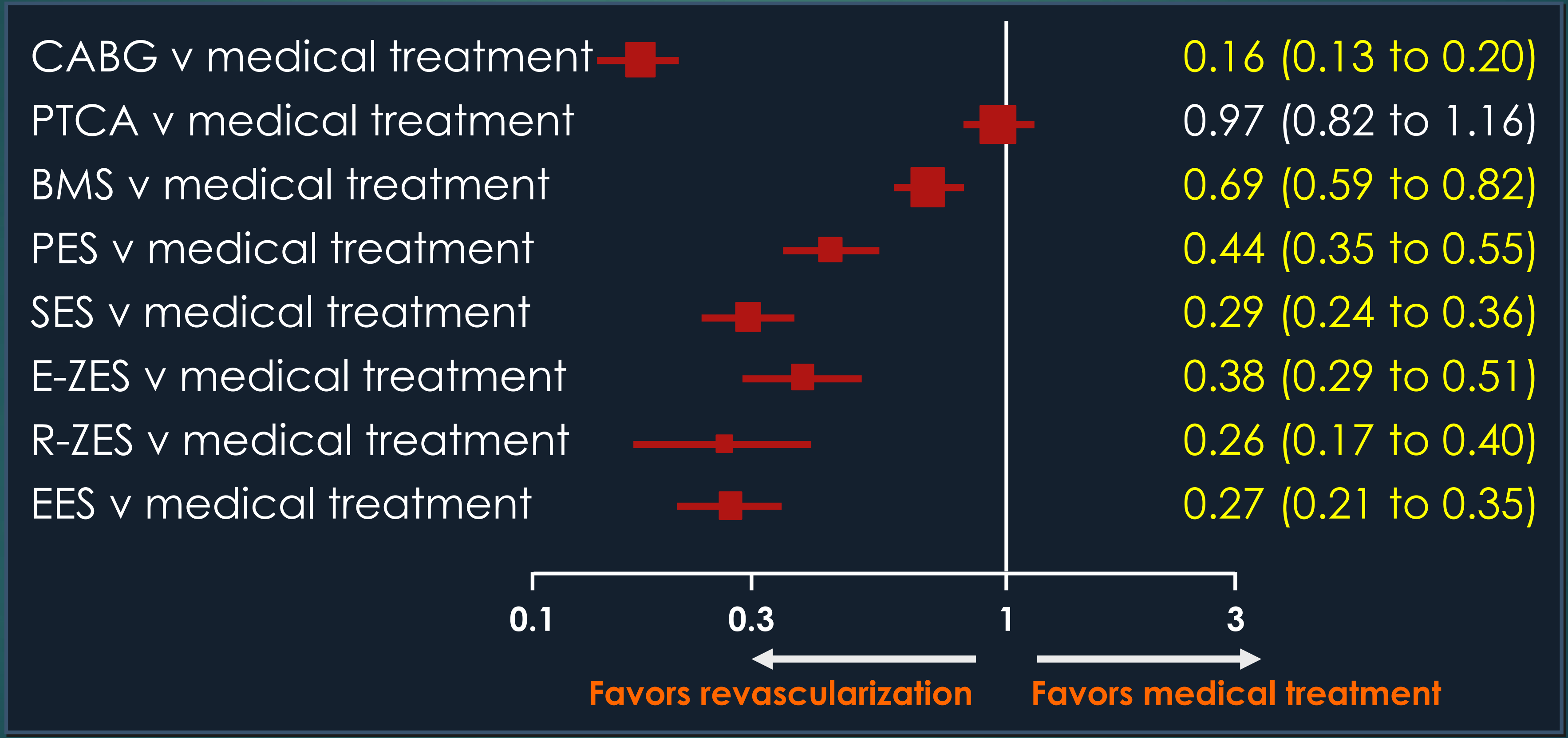


Windecker S et al. BMJ. 2014; 348: g3859

Revascularization vs. Medical Rx: SIHD
Impact of new DES

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

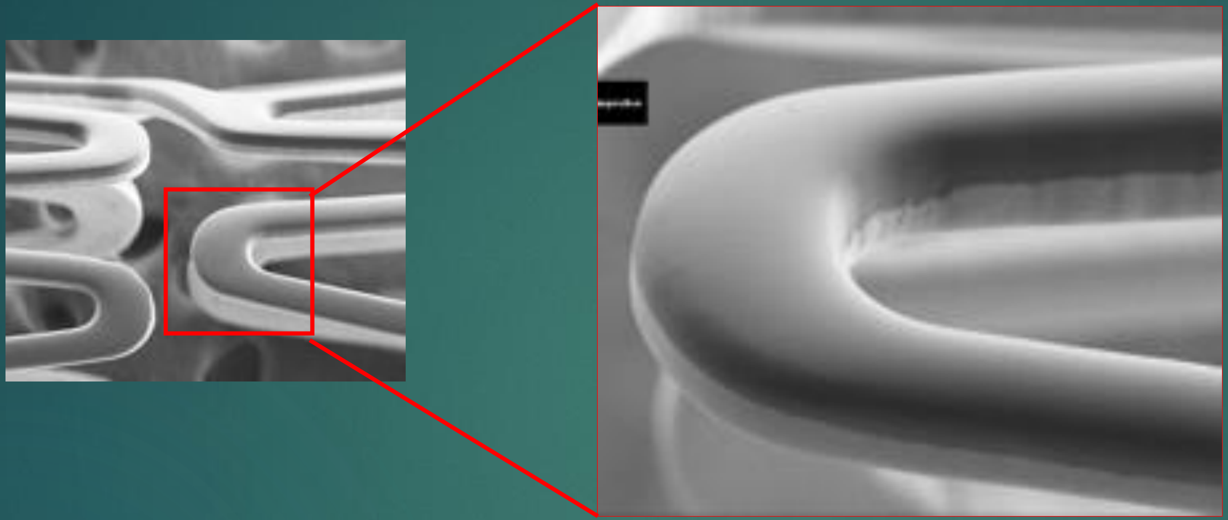
Revascularization (94 trials, 90,282 pts)



Windecker S et al. BMJ. 2014; 348: g3859

Abluminal Bioabsorbable Polymer

BSC Synergy stent



Bioabsorbable polymer (PLGA)

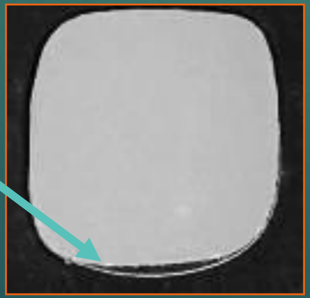
- gone in 4 months

Applied <u>only</u> to the abluminal surface

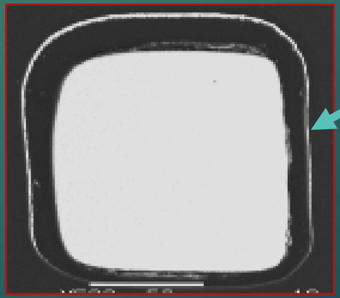
Thin strut (0.0028”) PtCr Stent

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

Abluminal Bioabsorbable Polymer



Current Durable Polymer



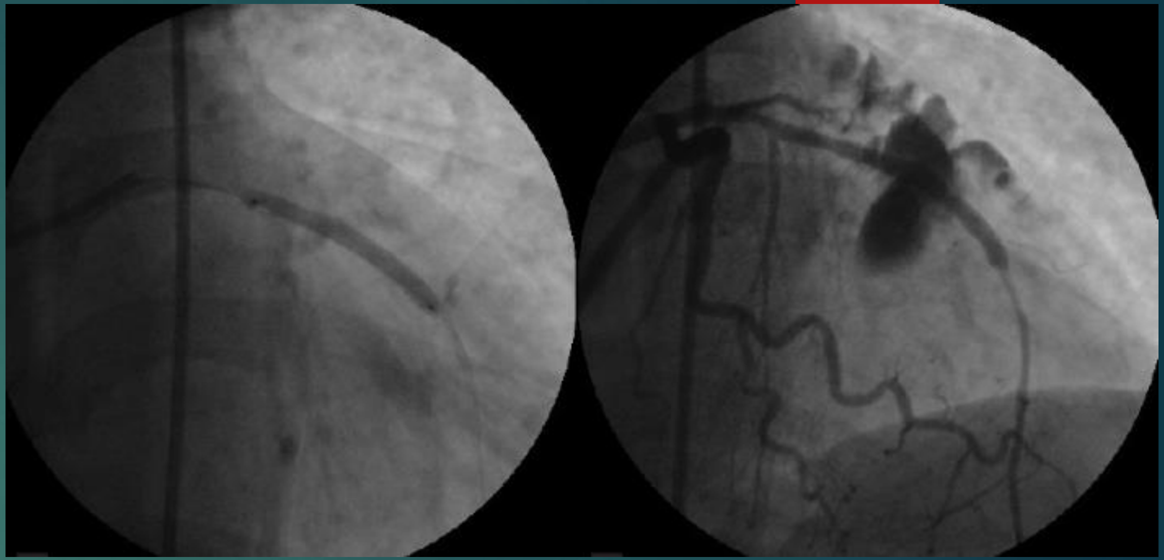
Durable Permanent Polymer
+
Drug
360° Around Stent

Current Drug Eluting Stent Options--

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

FDA Approved

Covered Stents



- ❖ Graftmaster Rx Stent (Abbott Labs)
  - ❖ Previously know 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

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

Long term patency is not well studied

- Need to Size to Outer Diameter

Inner Diameter Compliance Chart

ATM	2.80 mm	3.50 mm	4.00 mm	4.50 mm	4.80 mm
11	1.37	1.83	2.30	2.86	2.98
12	1.67	2.34	2.74	3.20	3.57
13	1.91	2.47	2.90	3.30	3.89
14	2.08	2.63	3.08	3.52	3.98
15 (NOM)	2.18	2.81	3.31	3.79	4.16
16 (RBP)	2.32	3.01	3.54	3.98	4.34
17	2.47	3.19	3.72	4.15	4.52
18	2.62	3.32	3.86	4.31	4.64
19	2.73	3.43	3.96	4.42	4.77

Outer Diameter Compliance Chart

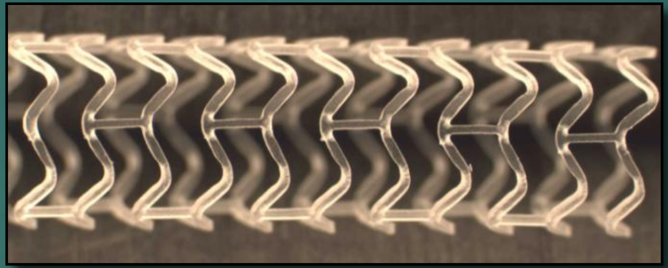
ATM	2.80 mm	3.50 mm	4.00 mm	4.50 mm	4.80 mm
11	1.89	2.35	2.82	3.38	3.50
12	2.19	2.86	3.26	3.72	4.09
13	2.43	2.99	3.42	3.82	4.41
14	2.60	3.15	3.60	4.04	4.50
15 (NOM)	2.70	3.33	3.83	4.31	4.68
16 (RBP)	2.84	3.53	4.06	4.50	4.86
17	2.99	3.71	4.24	4.67	5.04
18	3.14	3.84	4.38	4.83	5.16
19	3.25	3.95	4.48	4.94	5.29

Fully Bioresorbable Stents (Scaffolds)

Igaki-Tamai

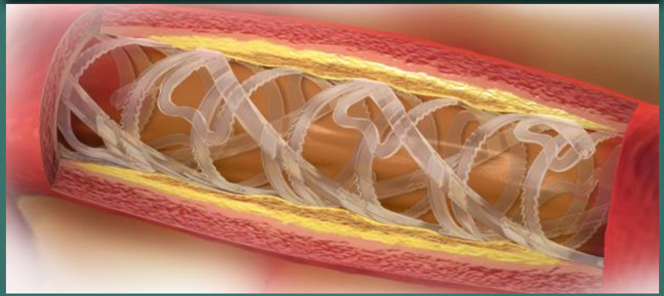
PLA

BVS



PLA (everolimus coat)

REVA



Iodinated tyrosine-polycarbonate (with PTX)

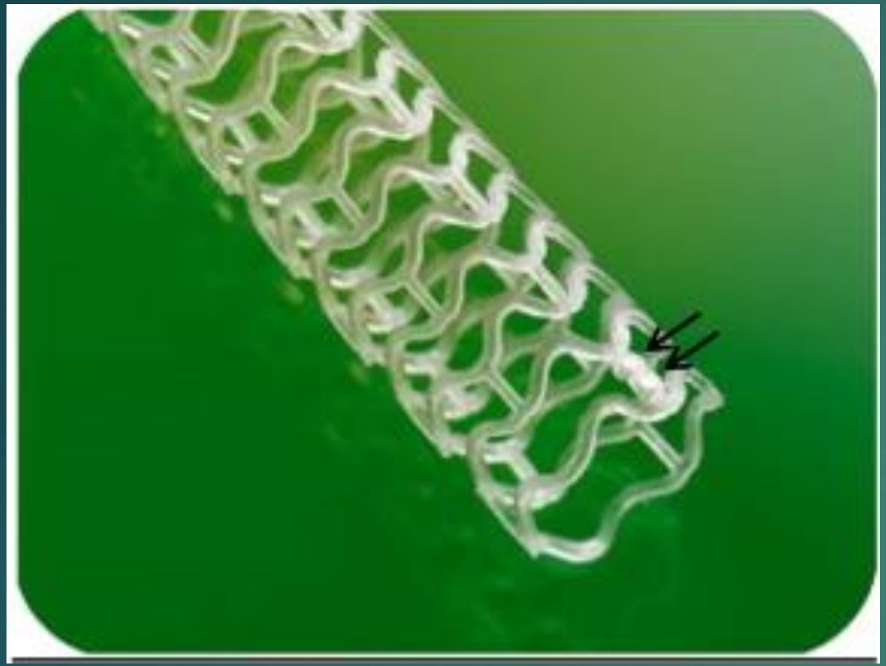
BTI

PAE-salicylate (with sirolimus)

Biotronik

Magnesium

ABSORB



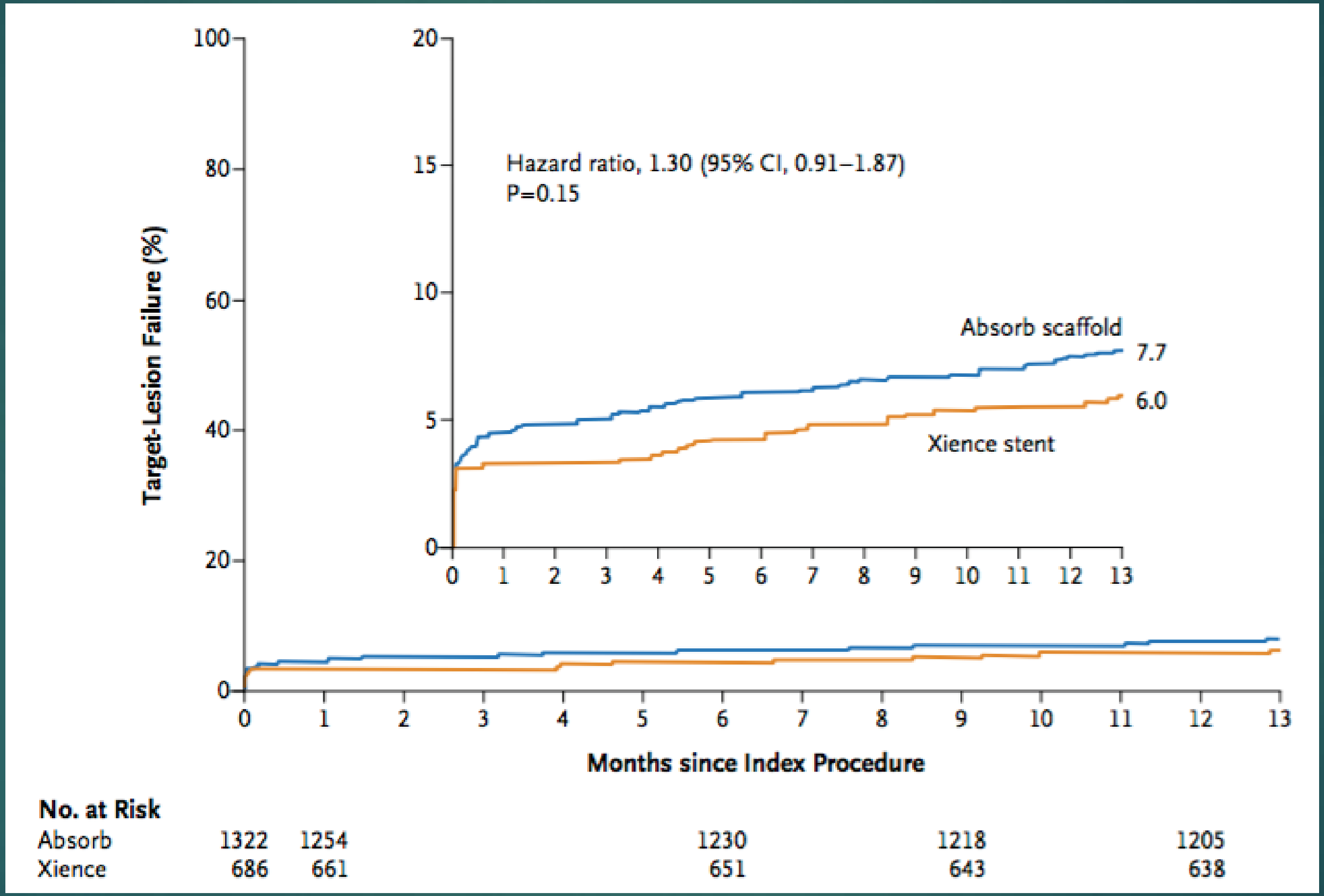
Bioresorbable Vascular Scaffold (BVS) System (Abbott Vascular, Santa Clara, CA)

Diameters: 2.5, 3.0 and 3.5 mm
Lengths: 8, 12, 18 and 28 mm lengths

Ellis SG et al. N Engl J Med 2015; 373:1905-1915

- 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

Ellis SG et al. N Engl J Med 2015; 373:1905-1915

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