Αντιμετώπιση επασβεστωμένων αθηρωματικών στενώσεων

CHRISTOS GRAIDIS

INTERVENTIONAL CARDIOLOGIST
EUROMEDICA GENERAL CLINIC
THESSALONIKI
No conflict of interest
The prevalence of moderate/severe coronary artery calcification in the PCI patient population is 32%, of which 6-20% is considered severe.
Coronary Calcium: The Growing Challenge

Several health behaviors and risk factors, as well as chronic inflammatory conditions, lead to coronary deposition in the coronary arteries.

<table>
<thead>
<tr>
<th>CAC risk factors</th>
<th>Advanced age</th>
<th>Family history and genetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking/tobacco use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical inactivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight and obesity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High blood cholesterol and other lipids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolic syndrome</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced age</td>
<td>Family history and genetics</td>
<td></td>
</tr>
<tr>
<td>Family history and genetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic kidney disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Impact of Age on Vascular Calcification

A

Prevalence of calcium per vascular pattern in women

B

Prevalence of calcium per vascular pattern in men

>70 years, all have calcium in at least 1 vascular bed and 2/3 in all arterial beds

Hellenic Institute of Cardiovascular Diseases

www.e-Cardio.gr
In one of the initial articles on interventional cardiology, Gruntzig et al noted, “At present, the technique is limited by anatomic factors, such as vessel tortuosity... and calcified stenosis.”

Despite the many advances in the field, these words proved to be prophetic, as coronary artery calcification continues to pose many challenges to successful percutaneous coronary intervention (PCI).
Coronary Calcification: A Predictable Problem

Challenges of Treating Calcified Coronary Lesions

Increased Coronary Calcification

PCI adverse events due to CAC
Unsuccessful PCI due to un-dilatable lesions
Balloon ruptures
Vessel dissection during PCI
Vessel perforation or vessel rupture during PCI
Asymmetric, malapposed, and under expanded stents

5. Von Birgelen et al. Am J Cardiol 2003;92:5-10

Mintz et al. J Am Coll Cardiol 2014;64(2):207-222

Hellenic Institute of Cardiovascular Diseases
www.e-Cardio.gr
Challenges of Treating Calcified Coronary Lesions

➢ Higher incidence of MACE
➢ High frequency of restenosis and TLR
➢ Higher incidence of peri-procedural MI
➢ Increasing the likelihood of stent thrombosis
➢ Reduced drug concentration and uptake into the vessel wall from DES
The greater the arc, length, or thickness of calcium, the greater the likelihood of stent underexpansion.

Increase in Arc of Ca++ leads to decrease in stent expansion.
Have You Ever Experienced
“Stent Regret?”

Post Stent Result:
single 2.75mm stent

Post Dilatation:
3.5x9mm non-compliant balloon for 30 seconds @ 22atm followed by 4.0x9mm non-compliant balloon for 30 seconds @ 16atm

Post Dilatation Result

Hellenic Institute of Cardiovascular Diseases

www.e-Cardio.gr
Can we have the right tool to do the job?

A thorough knowledge of the basic angioplasty equipment is required for coronary intervention.

- The correct choice of equipment can make a complex intervention appear effortless,

- whereas the less appropriate equipment choices can make a straightforward intervention, laborious and challenging.
Lesion preparation prior to PCI has become increasingly important when calcified coronary disease is present.

✓ Lesion preparation alters the morphology of the lesion, changing the lesion/vessel compliance.

✓ Modification of lesion compliance may allow for complete stent expansion and lead to improved procedural success.
Treatment of Calcified Lesions: Options

- NC balloons
- Cutting balloon
- Angiosculpt
- Laser
- Rotational atherectomy
- Orbital atherectomy

Hellenic Institute of Cardiovascular Diseases
Mild to moderately calcified lesions can often be managed with noncompliant balloons.
Mild to moderately calcified lesions can often be managed with noncompliant balloons with high-pressure inflations, as well as with cutting and scoring balloons.

Cutting and scoring balloons do not remove calcium in the coronary artery. However,

- they improve vessel compliance by creating discrete incisions in the atherosclerotic plaque,
- enabling greater lesion expansion and reducing recoil
- while preventing uncontrolled dissections.
However, *moderate to severely calcified lesions require an atherectomy strategy for optimal lesion preparation.*

Focus on *rotational and orbital atherectomy*, as they are the two modalities in current use for severely calcified coronary lesions to facilitate stent delivery.
Despite the development of more supportive catheters, very low profile balloons with higher inflation pressure facility, and alternative plaque modifying technology, the crossing of a heavily calcified lesion might require rotational atherectomy.
Rotablator: Benefits

- Minimises vessel wall stretch and elastic recoil
- Eliminates vessel barotrauma
- Removes all plaque morphologies; *Soft, fibrotic, calcified*
- *Produces a smooth lumen channel* for improved hemodynamic flow
- *Facilitate stent delivery and expansion*

post-PTCA procedure

post-Rotablator® procedure (with minimal vessel injury)
The Rotablator is mainly used to improve procedural success rate in heavily calcified lesions.

In heavily calcified lesions procedural success rate with RA ranges from 93.4% to 98.6%, superior to rates reported separately in the absence of preceding plaque modification.
<table>
<thead>
<tr>
<th>First Author (Ref. #)</th>
<th>Year</th>
<th>Patients</th>
<th>Follow-Up</th>
<th>MACE, %</th>
<th>Repeat Revascularization, %</th>
<th>ST, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdel-Wahab et al. (17)</td>
<td>2013</td>
<td>205 DES</td>
<td>15 months</td>
<td>17.7</td>
<td>9.9 TVR, 6.8 TLR</td>
<td>1.0</td>
</tr>
<tr>
<td>Mangiacarpa et al. (72)</td>
<td>2012</td>
<td>104 DES</td>
<td>1 yr</td>
<td>12.0*</td>
<td>5 TVR*</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>83 BMS</td>
<td></td>
<td>23.5</td>
<td>12.3 TVR</td>
<td>4.9</td>
</tr>
<tr>
<td>Naito et al. (18)</td>
<td>2012</td>
<td>179 SES</td>
<td>630 days</td>
<td>14.8</td>
<td>6.8 TVR, 4.9 TLR</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>54 PES</td>
<td>625 days</td>
<td>13.7</td>
<td>11.8 TVR, 9.8 TLR</td>
<td>4.9</td>
</tr>
<tr>
<td>Benezet et al. (19)</td>
<td>2011</td>
<td>102 DES</td>
<td>15 months</td>
<td>12.7</td>
<td>8.8 TLR</td>
<td>2.9</td>
</tr>
<tr>
<td>Dardas et al. (20)</td>
<td>2011</td>
<td>184 DES</td>
<td>49 months</td>
<td>14.9</td>
<td>3.3 TVR, 2.8 TLR</td>
<td>2.9</td>
</tr>
<tr>
<td>Fujimoto et al. (73)</td>
<td>2010</td>
<td>54 DES</td>
<td>12 months</td>
<td>26 RA+</td>
<td>11.5 TLR*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28 RA−</td>
<td>35.7 TLR</td>
<td>7.1</td>
</tr>
<tr>
<td>Garcia de Lara et al. (21)</td>
<td>2010</td>
<td>50 DES</td>
<td>1 yr</td>
<td>6 (CV death)</td>
<td>6 TLR</td>
<td>7.1</td>
</tr>
<tr>
<td>Rathore et al. (22)</td>
<td>2010</td>
<td>391 DES</td>
<td>6–9 months</td>
<td>9.5</td>
<td>10.6 TLR*</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>125 BMS</td>
<td></td>
<td></td>
<td>25.0 TLR</td>
<td>0.8</td>
</tr>
<tr>
<td>Vaquerizo et al. (23)</td>
<td>2010</td>
<td>63 DES</td>
<td>15 months</td>
<td>9.5</td>
<td>4.8 TLR</td>
<td>2.8</td>
</tr>
<tr>
<td>Furuichi et al. (24)</td>
<td>2009</td>
<td>96 DES</td>
<td>15 months</td>
<td>15.8</td>
<td>11.6 TVR, 9.5 TLR</td>
<td>4.2</td>
</tr>
<tr>
<td>Tamekiyo et al. (74)</td>
<td>2009</td>
<td>79 DES</td>
<td>2 yrs</td>
<td>30.1*</td>
<td>25.0 TLR*</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>144 BMS</td>
<td></td>
<td>43.1</td>
<td>39.1 TLR</td>
<td>4.2</td>
</tr>
<tr>
<td>Clavijo et al. (25)</td>
<td>2006</td>
<td>150 DES</td>
<td>6 months</td>
<td>(Death)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>81 RA+</td>
<td></td>
<td>6.8</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>69 RA−</td>
<td></td>
<td>7.9</td>
<td>4.9</td>
<td></td>
</tr>
</tbody>
</table>

MACE 6.8-30.1%
TVR 3.3-25%
ST 0.8-4.2%
Study Design

Prospective, randomized, active-controlled clinical trial in two German centers

PCI in 200 patients with severely calcified lesions

Lesion preparation with modified balloon* (scoring/cutting)  \[ \text{randomization} \quad 1:1 \quad \text{Lesion preparation with rotational atherectomy} \]

SES implantation (*Orsiro*)

9-month angiographic & clinical follow-up

1 & 2-years clinical follow-up
### QCA at 9 Month

<table>
<thead>
<tr>
<th></th>
<th>Modified balloon (n = 112 lesions)</th>
<th>Rotational atherectomy (n = 97 lesions)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimal lumen diameter (mm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-stent</td>
<td>2.68±0.59</td>
<td>2.64±0.51</td>
<td>0.59</td>
</tr>
<tr>
<td>In-segment</td>
<td>2.50±0.54</td>
<td>2.50±0.55</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>Diameter stenosis (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-stent</td>
<td>18.83±13.42</td>
<td>19.75±11.54</td>
<td>0.49</td>
</tr>
<tr>
<td>In-segment</td>
<td>22.40±11.36</td>
<td>23.30±11.43</td>
<td>0.52</td>
</tr>
<tr>
<td><strong>Late lumen loss (mm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-stent</td>
<td>0.16±0.40</td>
<td>0.22±0.41</td>
<td>0.21</td>
</tr>
<tr>
<td>In-segment</td>
<td>0.07±0.52</td>
<td>0.18±0.74</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Binary restenosis (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-stent</td>
<td>6 (5.3%)</td>
<td>2 (2.1%)</td>
<td>0.30</td>
</tr>
<tr>
<td>In-segment</td>
<td>5 (4.5%)</td>
<td>2 (2.1%)</td>
<td>0.32</td>
</tr>
</tbody>
</table>

### Clinical Outcome at 9 Month

<table>
<thead>
<tr>
<th></th>
<th>Modified balloon (n = 100 pts.)</th>
<th>Rotational atherectomy (n = 100 pts.)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Death</strong></td>
<td>2 (2%)</td>
<td>2 (2%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Cardiac death</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Non-cardiac death</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>3 (3%)</td>
<td>2 (2%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Target vessel MI</td>
<td>1 (1%)</td>
<td>2 (2%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Periprocedural MI</td>
<td>1 (1%)</td>
<td>2 (2%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Spontaneous MI</td>
<td>2 (2%)</td>
<td>0 (0%)</td>
<td>0.50</td>
</tr>
<tr>
<td>Stent thrombosis (def./prob.)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1.00</td>
</tr>
<tr>
<td>TVR</td>
<td>8 (8%)</td>
<td>3 (3%)</td>
<td>0.21</td>
</tr>
<tr>
<td>Target vessel failure</td>
<td>8 (8%)</td>
<td>6 (6%)</td>
<td>0.78</td>
</tr>
</tbody>
</table>
# Cross-Over Patients

<table>
<thead>
<tr>
<th>Strategy success</th>
<th>Modified balloon (n = 100 pts.)</th>
<th>Rotational atherectomy (n = 100 pts.)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final TIMI flow &lt; III</td>
<td>0 (0%)</td>
<td>1 (1%)</td>
<td>0.99</td>
</tr>
<tr>
<td>Residual stenosis &gt; 20%</td>
<td>2 (2%)</td>
<td>0 (0%)</td>
<td>0.49</td>
</tr>
<tr>
<td>Stent failure</td>
<td>4 (4%)</td>
<td>1 (1%)</td>
<td>0.36</td>
</tr>
<tr>
<td>Crossover</td>
<td>16 (16%)</td>
<td>0 (0%)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

- **not crossable by any balloon**
- **not crossable by modified balloon**
- **not adequately dilatable**
- **stent not deliverable**
Rotablation is recommended for preparation of heavily calcified or severely fibrotic lesions that cannot be crossed by a balloon or adequately dilated before planned stenting

secondary or rescue rotablation
Although routine use of rotational atherectomy did not improve outcomes after DES, *such a device might technically be required in cases of tight and calcified lesions, to allow subsequent passage of balloons and stents.* There is a resurgence in the use of rotational atherectomy for the purpose of optimal lesion preparation among patients undergoing implantation of bioresorbable stents.
Rota-Rescue

Inability to cross the lesion with the balloon

We were unable to cross the lesion with a:

1.5 x 15 mm Maverick balloon

1.25X15 mm Ryujin balloon

1.25 mm over-the-wire Sprinter balloon and

0.85X10 mm NIC NANO balloon
6F Guideliner catheter deeply into the RCA, just proximal to the point of the lesion.

Inability to cross the lesion with the same balloons.

Rotational Atherectomy (RA) was first performed using a 1.25-mm Rotablator burr.
Rota-Rescue

Inability to cross the lesion with the balloon
Rota-Rescue
Non Dilatable lesions
Rota-Rescue
Non Dilatable lesions
In ostial lesions, the success rate of the Rotablator procedure is > 90%

<table>
<thead>
<tr>
<th>Author</th>
<th>lesion</th>
<th>N</th>
<th>Success (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koller (1994)</td>
<td>Ostial</td>
<td>29</td>
<td>93</td>
</tr>
<tr>
<td>Zimarino (1994)</td>
<td>Ostial</td>
<td>69</td>
<td>92</td>
</tr>
<tr>
<td>Popma (1993)</td>
<td>Ostial</td>
<td>105</td>
<td>97</td>
</tr>
</tbody>
</table>
Rotablator: ostial lesions
Complications specifically seen with Rotational Atherectomy

- Slow/no reflow
- Distal embolization
- Coronary spasm
- Coronary perforation
- Coronary dissection.

- **Burr entrapment** is one of rare but serious complications of the Rotablator, and previous report indicated that it occurred in 6 of 1,403 procedures (0.4%)
• Death 1.0%
• Q-Wave myocardial infarction (MI) 1.2%
• Coronary Artery Bypass Graft (CABG) 2.5%

The decision to use rotablation should be made early, before large dissections appear.
Orbital atherectomy was approved for use in coronary arteries in 2013.

The Diamondback 360 coronary orbital atherectomy system (Cardiovascular Systems, Inc.) uses a diamond-coated, eccentrically mounted burr that rotates over a ViperWire guidewire (Cardiovascular Systems, Inc.) at 80,000 rpm on low speed and 120,000 rpm on high speed.

The standard crown size is 1.25 mm.

ViperSlide lubricant (Cardiovascular Systems, Inc.) is infused during ablation.
Orbital atherectomy

Device features
- Easy set-up and use <2 mins
- Control of device in operating field
- Compatible with 6 Fr approach

0.012 ViperWire Advance®

ViperSlide® Lubricant
- ViperSlide reduces friction during operation
- 20 ml ViperSlide per litre of saline

6 Fr guide-compatible saline sheath

Electric motor powered handle

Eccentrically mounted diamond-coated 1.25 mm classic crown

OAS pump
- Mounts directly onto an IV pole
- Provides power
- Delivers fluid
- Includes saline sensor

On-handle speed control
- Low (80 K) and High speed (120 K rpm)

Power on/off switch
- 8 cm axial travel knob

Hellenic Institute of Cardiovascular Diseases

www.e-Cardio.gr
 Orbital Technology for Calcified Coronary Arteries

- **Differential orbital sanding**
  - Increased speed = Increased centrifugal force
  - Greater centrifugal force = Larger orbital diameter

- **Continuous flow of blood and saline during orbit**
  - Minimizes thermal injury
  - Potentially decreases no-reflow and periprocedural cardiac enzyme elevation

- **Different vessel diameters can be treated based on orbiting speed**

Actual results may vary depending on device to lumen ratio, run time, and speed, and plaque morphology.
## Orbital atherectomy-ORBIT I

<table>
<thead>
<tr>
<th>Treatment</th>
<th>OAS+DES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>50</td>
</tr>
<tr>
<td>Dissection (%)</td>
<td>12(^a)</td>
</tr>
<tr>
<td>No reflow/slow flow (%)</td>
<td>0</td>
</tr>
<tr>
<td>Perforation (%)</td>
<td>2</td>
</tr>
<tr>
<td>Abrupt closure (%)</td>
<td>0</td>
</tr>
<tr>
<td>In-hospital MACE (%)</td>
<td>4</td>
</tr>
<tr>
<td>Cardiac death (%)</td>
<td>0</td>
</tr>
<tr>
<td>MI (%)</td>
<td>4</td>
</tr>
<tr>
<td>TVR (%)</td>
<td>0(^e)</td>
</tr>
</tbody>
</table>

### Long-term follow-up

<table>
<thead>
<tr>
<th></th>
<th>6 months</th>
<th>3 years(^f) ((N = 33))</th>
<th>5 years(^f) ((N = 33))</th>
</tr>
</thead>
<tbody>
<tr>
<td>MACE at follow-up (%)</td>
<td>8</td>
<td>18.2</td>
<td>21.2</td>
</tr>
<tr>
<td>Cardiac death (%)</td>
<td>2</td>
<td>9.1</td>
<td>12.1</td>
</tr>
<tr>
<td>MI (%)</td>
<td>6</td>
<td>6.1</td>
<td>6.1</td>
</tr>
<tr>
<td>TVR/TLR (%)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>TLR (%)</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Three-year follow-up from the ORBIT II trial demonstrated the durability of these results, with a 7.8% target lesion revascularization rate in patients treated with orbital atherectomy.
Procedural complications that occur with orbital atherectomy include

✓ dissection,
✓ perforation, and
✓ slow flow/no reflow phenomenon.

Production of microparticulate debris averaging \text{less than 2 mm in size} with continuous blood flow maintained during ablation helps to reduce thermal injury, transient heartblock and the no-reflow phenomenon.
OCT imaging with angiographic co-registration of coronary OAS treatment.
In addition to advantages including a more rapid set-up with use of a single size burr, bi-directional ablation might reduce the likelihood of crown entrapment.

OA was found to result in deeper tissue modification as compared to PTRA by optical coherence tomography (OCT) assessment. This may lead to improved stent strut apposition and more complete stent expansion following lesion preparation with OA.
No large-scale multicentre randomised head-to-head trials have yet occurred comparing the two devices.

Because it is new technology, recommendations for the use of orbital atherectomy have not yet been included in the latest guidelines.
The results of this unprecedented study will help inform interventional cardiologists treating patients with severely calcified lesions and will likely change the standard of care and guidelines.

**ECLIPSE**

Evaluation of Treatment Strategies for Severe Calcifc Coronary Arteries: Orbital Atherectomy vs. Conventional Angioplasty Prior to Implantation of Drug Eluting Stents

- ~2000 pts with severely calcified lesions; ~60 US sites
- Randomize 1:1
- Orbital Atherectomy Strategy
  - (1.25 mm Crown followed by non-compliant balloon optimization)
- Conventional Angioplasty Strategy
  - (conventional and/or specialty balloons per operator discretion)
- 2nd generation DES implantation and optimization
- 1º endpoints: 1) Post-PCI in-stent MSA (N~400 in imaging study) 2) 1-year TVF (all patients)
- 2º endpoint: Procedural Success (stent deployed w/RS<20% & no maj complications)

Principal investigators: Ajay J. Kirtane, Philippe Généreux; Study chairman: Gregg W. Stone
Sponsor: Cardiovascular Systems Inc.
Proposed Algorithm for Use of Rotational Atherectomy in Management of de Novo Calcified Lesions
Recent evidence indicates that coronary atherectomy is only utilized in less than 5% of PCI patients even though it has been shown that the prevalence of moderate/severe CAC in the PCI patient population is 32%.

Unfortunately for patients with CAC, atherectomy devices are underutilized.
Thus, the majority of patients with CAC are still only treated with POBA and DES.

Solution

SHOCKING THE CALCIUM
Intravascular Lithotripsy (IVL)-Lithoplasty for calcified coronary artery
Lithoplasty Technology Uses Sonic Pressure Waves To Crack Calcium Inside the Vessel Wall

1. Integrated Balloon is inflated to a constant, ultra-low pressure of 4 atm prior to activating emitters to ensure complete vessel wall apposition.

2. Emitters are the source of the Sonic Pressure Waves emitted at 1 pulse per second for 1 microsecond.

3. Sonic Pressure Waves are emitted in the shape of a sphere, creating a field effect, thereby addressing calcium around the entire circumference and deep into the vessel wall.

4. Sonic Pressure Waves transmit ~50 atm of instantaneous pressure to the site of calcium, but pass through soft tissue.

5. Sonic Pressure waves crack calcium, softening vessel compliance. Fractured calcium remains inside the vessel wall.

6. Softened vessel then able to be dilated at low pressure of 6 atm, minimizing vessel trauma and complications.
IVL Catheters
IVL Catheters are prepared and delivered exactly like traditional balloon angioplasty devices. The catheters have proximal and distal markers, so they can be accurately placed within the lesion. At the touch of a button, miniaturized lithotripsy emitters apply pulsatile mechanical energy along the length and diameter of the balloon.

IVL Connector Cable
The balloon catheter easily attaches to the connector cable. Lithotripsy pulsing is activated by pushing a button on the connector cable. Disruption starts with a pulse.

IVL Generator
The small, battery-powered rechargeable generator is linked to the balloon catheter via the connector cable. A chip in the catheter provides pre-set lithotripsy delivery parameters, so no dials or settings need to be adjusted.
The Shockwave IVL system consists of a catheter that houses the emitters and is enclosed in an integrated angioplasty balloon mounted on a rapid exchange system, shockwave generator and connector cable.

### Balloon Sizes

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>2.75 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>3.0 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>3.25 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>3.5 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>3.75 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>4.0 mm</td>
<td>12 mm</td>
</tr>
</tbody>
</table>

- **Lithotripsy delivery**: 4 atm
- **Nominal pressure**: 6 atm
- **Rated burst pressure**: 10 atm

- **0.014” guidewire compatible**
- **138 cm working length**
- **6F sheath compatibility**
Lithoplasty

Lesion modification using lithotripsy in a balloon

- Tissue-selective:
  - Hard on hard tissue, Soft on soft tissue
  - Lithotripsy waves travel outside balloon
  - Designed to disrupt both superficial, deep calcium

- Designed to normalize vessel wall compliance prior to controlled, low pressure dilatation
- Effective lesion expansion with minimized impact to healthy tissue
- “Front-line” balloon-based Rapid Exchange 014 platform

Hellenic Institute of Cardiovascular Diseases

www.e-Cardio.gr
The mechanism for vessel expansion was circumferential calcium fractures.
Disrupt CAD Study Design

Stable angina, unstable angina or silent ischemia

Moderate and severely calcified, de novo coronary lesions
RVD 2.5 – 4.0 mm, stenosis ≥50%,
Lesion length ≤ 32 mm

60 patients enrolled
31 subject OCT sub-study
30 day & 6 months follow-up
Core Angiographic & OCT Labs
(Yale University & CRF)

• **Objective:** To assess the safety and performance of the Shockwave Medical Coronary Rx Lithoplasty® System
• **Primary Safety Endpoint:** MACE within 30 days defined as: Cardiac death, MI or TVR
• **Primary Performance Endpoint:** Clinical Success defined as residual stenosis (<50%) after stenting with no evidence of in-hospital MACE.
Consistent, reproducible luminal gain, with an average inflation of 6 atms

<table>
<thead>
<tr>
<th>Procedural Angiographic Complications</th>
<th>Final N = 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissection</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>100% (60)</td>
</tr>
<tr>
<td>A to C</td>
<td>0.0%</td>
</tr>
<tr>
<td>D to F</td>
<td>0.0%</td>
</tr>
<tr>
<td>Perforation</td>
<td>0.0%</td>
</tr>
<tr>
<td>Abrupt Closure</td>
<td>0.0%</td>
</tr>
<tr>
<td>Slow flow</td>
<td>0.0%</td>
</tr>
<tr>
<td>No reflow</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Freedom from 30-day MACE: 95%

Freedom from 6-month MACE: 91.5%
Primary Performance Outcomes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>N= 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical Success</td>
<td>95.0%</td>
<td>(57)</td>
<td></td>
</tr>
<tr>
<td>Device Success</td>
<td>98.3%</td>
<td>(59)</td>
<td></td>
</tr>
<tr>
<td>Facilitated Stent Delivery</td>
<td>100%</td>
<td>(60)</td>
<td></td>
</tr>
</tbody>
</table>

Performance Outcomes

% Diameter Stenosis

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLD (mm)</td>
<td>0.9 ± 0.4</td>
<td>2.6 ± 0.5</td>
</tr>
<tr>
<td>Acute Gain (mm)</td>
<td>NA</td>
<td>1.7 ± 0.6</td>
</tr>
</tbody>
</table>

Cumulative Frequency Distribution

Hellenic Institute of Cardiovascular Diseases

www.e-Cardio.gr
3.6mm RVD
87.6% stenosis
37.5mm length

4.0mm Lithoplasty

4.0% stenosis
Acute gain 3.1
Stent length 40.5mm
A Surprising Case of Intravascular Lithotripsy

Dr. Nilesh Pareek, Dr. Julian Yeoh, Dr. Fernando Macaya Tan, Dr. Todd Brinton, Dr. Ian Webb, Dr. Jonathan Hill

Case Summary

- 80 year old gentleman
- High risk ACS with severe calcified LAD disease and RCA CTO

Urgent Heart Team discussion – Deemed to be at high surgical risk

For PCI to the severely calcified proximal LAD and staged PCI to RCA CTO
Failure of 3.0 x 20mm Semi-compliant balloon to dilate

Rotational atherectomy with 1.75mm burr

Persistent balloon under-expansion
IVL After Rotablation Failure

Use of IVL

Initial Delivery of IVL pulses

Complete Expansion at 6 Atmospheres
IVL After Rotablation Failure

Stent Deployment and Post-dilatation

Excellent expansion of 3.0 x 20mm semi-compliant balloon

Deployment of 3.0 x 48mm stent
Conclusions

• IVL enables controlled modification of heavily calcified atherosclerotic plaques.
• This case highlights its utility in the most challenging cases, including after failure of rotational atherectomy.
A 73-year old man was found to have proximal left anterior descending (LAD) in-stent stenosis (ISS) secondary to stent underexpansion as a cause of limiting angina.

Despite serial dilations, including 3.5 mm OPN NCVR High-Pressure PTCA (SIS Medical AG; Switzerland) to >40 atm, percutaneous coronary intervention (PCI) was unsuccessful.
(Panel A) Ultra-high-pressure inflation of non-compliant OPN balloon failed to expand the lesion within the stent (arrowheads).

(Panel B) Angiography shows a severe proximal left anterior descending stenosis (arrowheads) at the site of previous stent implantation.

(Panels C–F) OCT identifies severe stent underexpansion secondary to concentric calcification with minimal lumen area of 1.09 mm².

(Panel F) Stent rendering shows the severity of stent underexpansion (white arrowheads).

Following IVL, 60 shocks delivered during six rounds of therapy, with a 4.0 × 12 mm device.

(Panel G) Balloon expansion is considerably improved and (Panel G) there is angiographic success with minimal residual diameter stenosis.

(Panels I–K) Minimal lumen area increased from 1.09 mm² to 6.47 mm² following IVL with OCT showing multiple calcium fractures (arrowheads).

(Panel L) Stent rendering shows significant improvement in stent expansion (white arrowheads).
It is a highly accessible technology, which is simple to use (delivering a balloon to the lesion on any 0.014-inch guidewire) with short learning curve and less procedural complications could facilitate rapid uptake and can be rapidly deployed in the cath lab.”

However, this is dependent on further studies demonstrating outcomes in patients, including comparisons with existing technologies.
Shockwave Coronary Lithoplasty® Study (Disrupt CAD II)

Detailed Description:
The study will be conducted at 15 sites in Europe

Up to 120 participants will be followed for 30 days post procedure.

Patients ≥18 years of age scheduled for stent procedure with evidence of significant calcified stenosis of left main, or left anterior descending, right coronary artery or left circumflex will be eligible to enroll in the study. The primary endpoint of the study will evaluate major adverse cardiac events post procedure including

1) cardiac related death,
2) heart attack, and
3) intervention to treat the coronary artery that was previously treated at the procedure visit.

Estimated Study Completion: May 30, 2019
Summary and Conclusions

- Proper lesion preparation is needed in severely calcified lesions prior to PCI
  - Ineffective lesion prep can lead to stent underexpansion and greater complications.

- Current vessel prep strategies have similar and predictable challenges with severe CAC leading to less effective intervention
  - No major intra-procedural complications is DISRUPT CAD, including perforation, embolization, slow-flow or no reflow.

- Lithoplasty treatment addresses limitations of current options
  - Utilizes standard technique and devices utilized in PCI procedures
  - Lithoplasty performed at low-pressure, minimizing mechanical vascular trauma
  - Calcium modified in-situ, no physical removal of tissue; risk of embolization similar to PTCA
  - Eliminates guidewire bias leading to symmetrical luminal gain
  - Modifies superficial and deep-seated calcium, improving vascular compliance.
The prevalence of coronary calcium is increasing in the modern era. Coronary calcification is associated with more difficult procedures and adverse short and long-term outcomes. A variety of strategies exist to compact calcium with focus on delivery plus expansion. The ongoing studies seek to further define and solidify the role of atherectomy for severely calcified lesions.

CONCLUSIONS

Thank you for your attention !!!

Cracking the calcium
Comparison Between the 3 FDA Approved Atherectomy Devices

<table>
<thead>
<tr>
<th></th>
<th>Rotational</th>
<th>Orbital</th>
<th>Laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balloon noncross</td>
<td>+++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Nondilatable lesion</td>
<td>+++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Eccentric calcium</td>
<td>+</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Rapid exchange</td>
<td>–</td>
<td>–</td>
<td>+++</td>
</tr>
<tr>
<td>6F guide</td>
<td>++</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>Underexpanded stent</td>
<td>+</td>
<td>–</td>
<td>++</td>
</tr>
</tbody>
</table>

There are no randomized or clinically powered trials comparing rotational and orbital atherectomy.

Device selection otherwise is highly dependent on local expertise and operators’ comfort with the technology.