CORONARY PHYSIOLOGY IN THE CATHLAB:

FFR POST - PCI

Educational Training Program ESC
European Heart House
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Do we have systematic data?

only a few good studies

Because the extreme heterogeneity of patients (inherent to the nature of coronary artery disease) there does not exist one single “uniform” FFR post-stent value indicative for a good result.

Nevertheless, FFR post-stent can give very useful Information, if measured and interpreted in the right way.
ROC curve, showing sensitivity and specificity for several FFR cut-off values, compared to intravascular ultrasound, for assessment of optimal stent deployment.

Hanekamp et al; Circulation 1999;99:1015-1024
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FFR post-stent versus IVUS

FFR $\leq 0.88 \rightarrow$ IVUS always abnormal
FFR post-stent versus IVUS

- **ROC curve**, showing sensitivity and specificity for several FFR cut-off values, compared to intravascular ultrasound, for assessment of optimal stent deployment.

- **FFR ≥ 0.95** → IVUS is normal in 95% of cases

**Hanekamp et al.; Circulation 1999;99:1015-1024**
FFR-post-STENT Registry (N = 750)

% ADVERSE EVENTS AT 6 MONTHS

- **0.96-1.00**: 266 patients, 5% adverse events
- **0.91-0.95**: 241 patients, 6% adverse events
- **0.86-0.90**: 130 patients, 16% adverse events
- **0.81-0.85**: 63 patients, 22% adverse events
- **0.76-0.80**: 44 patients, 30% adverse events

Circulation 2002
The Stent – Registry was performed more than 10 years ago, when the extent of disease and atherosclerotic burden in the average patient was much less than today.

It is unknown in the stent Registry, if a persistent gradient was due to focal pressure drop across the stent, or to (focal or diffuse) disease more proximal or distal in the artery.

Events might be promoted by both: by inadequately deployed stents as well as high atherosclerotic burden elsewhere in the artery.
A residual gradient within the coronary artery after apparently successful stenting, can be caused by:

- *inadequate stent deployment (focal gradient across stent)*, or by

- *diffuse disease or other lesions (more proximal or distal) along the course of the stented artery*

The most reliable way to discriminate this, is a hyperemic pullback recording (i.v adenosine, i.c.papaverine, or i.v. regadenoson bolus) after stenting.
FFR post PCI:

HOW SHOULD WE DO IT IN CLINICAL PRACTICE?

Let’s have a look at 3 different patients but all with chest pain and a positive MIBI in the inferior wall.
Typical chest pain; positive MIBI-Spect inferior wall
Typical chest pain; positive MIBI-Spect inferior wall
Very obese male,

Typical chest pain; positive MIBI-Spect inferior wall
PressureWire in RCA
resting → hyperemia (i.v. adenosine)

RCA: pullback - advance - etc
resting  hyperemia (i.v. adenosine)

Pd/Pa = 0.99  pullback - advance - etc
iFR      = 1.00
FFR      = 0.54
RCA after stenting

Resting hyperemia
(adenosine)
Distal stenosis

Mid in-stent restenosis

Dist. stenose

Prox. stenose

Hyperemia: Pull back recording

FFR = 0.65
Dist. Stenosis after treatment

Prox. stenosis after treatment

Hyperaemia: sensor in PLRCA

FFR = 116/118 = 0.98
Very obese male,

Typical chest pain; positive MIBI-Spect inferior wall
Hyperemic pull-back recording along the RCA

Fundamentally impossible to treat this patient by stenting
Be aware that after stenting a stenosis, blood flow in the artery will increase and other gradients within the vessel may be unmasked or increase!
RCA:

$FFR = 0.34$
resting  adenosine  pullback

Pull-back across distal stenosis

58 mmHg

† 5 mmHg
RCA after one stent:

FFR = 0.74
FFR 0.34 $\rightarrow$ 0.74

- Resting adenosine pullback
- Pullback across stent & across proximal stenosis
  - 58 $\rightarrow$ $\sim$ 0 mmHg
  - 5 $\rightarrow$ 22 mmHg
RCA after 2 stents: 

FFR = 0.87

(pullback shows diffuse disease but no gradient across any of the stents)
Pressure sensor back at the ostium of the RCA
What is a “normal” (or “acceptable”) gradient across a well-deployed stent?

- immediately after implantation
- at follow up

Mechanistic study by Van ‘t Veer et al:

“Hemodynamic Characteristics of DES at Implantation and at 6-m Follow-up”

Eur Heart J 2006;27:1811-1817
• 20 patients
• 2 stenoses
• comparable (diameter / length)
• 1 DES (Cypher)
• 1 ‘normal’ stent (BX Velocity)
• assigned randomly

Sirolimus study (Van ‘t Veer et al, Eur Heart J 2006)
Sirolimus study
( Van ‘t Veer et al, Eur Heart J 2006)

• quantitative coronary angiography (QCA)
  – % diameter (area) stenosis
  – Minimal Luminal Diameter (MLD)
  – Late loss

• Physiologic measurements
  – Pressure
  – Blood flow velocity
  – Wall shear stress

• all measurements repeated after 6 months
FFR and hyperemic Pd/Pa before & immediately after stenting, and at 6-month follow-up

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<tr>
<th></th>
<th>DES</th>
<th>Bare metal</th>
<th>P value</th>
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<td><strong>before</strong></td>
<td>0.61±0.20</td>
<td>0.61±0.16</td>
<td>NS</td>
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<tr>
<td><strong>immediately after</strong></td>
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**Hyperemic pressure ratio across stent**

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Van ‘t Veer et al, Eur Heart J 2006
FFR and hyperemic Pd/Pa before & immediately after stenting, and at 6-month follow-up

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Hyperemic pressure ratio across stent

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Van ‘t Veer et al, Eur Heart J 2006
Stent boost technique

Tanaka et al, Japan Circulation J, 2012: *Stent boost vs FFR post-stenting*

Imperfect stent boost $\rightarrow$ hyperemic grad $\geq 5$ mmHg in 90% of cases

Opposite not true: of all cases with hyperemic grad $\geq 5$ mmHg, imperfect stent boost in 50% of cases only
I. When we use pressure wire for deciding whether or not to stent, we use it as primary guidewire and standardly measure FFR post stenting.

II. After angiographically successful stenting, place the sensor in distal third part of the artery (and at least distal to stented lesion(s)) and induce hyperemia for pullback recording:
   - i.v. adenosine infusion, preferably central line
   - i.v. peripheral bolus injection of 400 µg regadenoson
   - 12-20 mg of i.c. papaverine

III. Perform manual pullback recording under fluoroscopy: and check if remaining gradient is across stent or elsewhere in the coronary artery, accepting the consequences.
If a stent is deployed adequately, only a negligible hyperemic gradient should be present across the stent.

If a hyperemic gradient of > than 5 mm Hg persists across the stent, there is definitely a problem and IVUS or preferably OCT is indicated.

The opposite is not true: even without an hyperemic gradient, a stent can be insufficiently deployed (5% of cases).

Therefore, FFR post-stent cannot replace IVUS or OCT.
FFR post PCI: CONCLUSIONS (2)

- FFR post PCI is *extremely useful to detect residual lesions or diffuse disease* with direct consequence for further treatment or preventing unnecessary repeat procedures when recurrent chest pain or ischemia occurs.

- The hyperemic pressure pullback recording is the most accurate method to analyse the remaining disease along the coronary artery and cannot be replaced by any other technology.
EINDE
FFR: The Pressure Pull-back Curve

**Pressure pull-back curve at maximum hyperemia:**

- place sensor in distal coronary artery
- induce sustained maximum hyperemia by i.v. adenosine, or i.c. papaverine or peripheral bolus of regadenooson
- pull back the sensor slowly under fluoroscopy
- the individual contribution of every segment and spot to the extent of disease can be studied in this way

*Coronary pressure is unique in this respect and such detailed spatial information cannot be obtained by any other invasive or non-invasive method*
roughly identical MIBI in all 3 patients: reversible defect inferior wall
Nu voorbeelden:

1x sprongetje over stent waarna verdere inflatie

1x sprongetje elders

1x diffuse ziekte
Mr. W.G., born 29-07-1941 (65-year-old)

- hypercholesterolemia, borderline hypertension
- typical chest pain at exercise, class III
- normal LV at echo
- frankly positive exercise test at 100 W ( = 64 %)

→ coronary angiography
RCA: Tandem lesion
Start of procedure:
sensor close to tip of JR guiding catheter to verify equal pressures at that point
RCA:

FFR = 0.34
Pull-back across distal stenosis
RCA after one stent:

FFR = 0.74

resting adenosine
resting adenosine pullback

pullback across stent & across proximal stenosis

58 → ~ 0 mmHg
5 → 22 mmHg

FFR 0.34 → 0.74
RCA after 2 stents:

FFR = 0.87

adenosine pullback
Pressure sensor back at the ostium of the RCA
Shear stress within and hyperemic gradient across stent at baseline and follow-up

**DES**

- **Cypher**
  - Average shear stress $1.7 \pm 0.7$ Pa

**Bare metal**

- **Bx Velocity**
  - Average shear stress $2.6 \pm 1.5$ Pa

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<td>$2 \pm 2$ mmHg</td>
<td>P=NS</td>
</tr>
<tr>
<td><strong>Follow-up</strong></td>
<td>$3 \pm 3$ mmHg</td>
<td>$9 \pm 8$ mmHg</td>
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