CORONARY PHYSIOLOGY IN THE CATHLAB

Educational Training Program ESC
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Course directors:

Bernard De Bruyne, MD, PhD, Cardiovascular Center Aalst, Aalst, Belgium
William F. Fearon, MD, Stanford University School of Medicine, Stanford, USA
Nico H. J. Pijls, MD, PhD, Catharina Hospital, Eindhoven, The Netherlands
Potential conflicts of interest

Speaker’s name: NICO H J PIJLS

☒ I have the following potential conflicts of interest to report:

☒ Research contracts: St Jude Medical
☒ Consulting: St Jude Medical, Boston Scientific
☐ Employment in industry
☒ Stockholder of a healthcare company: Philips, GE, ASML, Heartflow
☐ Owner of a healthcare company
☐ Other(s):

☐ I do not have any potential conflict of interest
Gruentzig and other early investigators, intuitively noticed the importance of coronary pressure measurement.

*Trans-lesional gradient before and after balloon angioplasty*
But....they were limited by

- inadequate equipment to measure pressure:
  ➡️ balloon catheter instead of 0.014’ wire
  (overestimation of gradients)
But....they were limited by

- inadequate equipment to measure pressure:
  - balloon catheter instead of 0.014’ wire

- inadequate hemodynamic conditions:
  - no hyperemic stimuli available
  - measurements at baseline instead of using maximum hyperemia
\[ \Delta P = f \cdot Q + s \cdot Q^2 \]

- \( f \) = friction coefficient
- \( s \) = separation coefficient

**Moderate gradient at rest**

**Moderate increment at hyperemia**

**Small gradient at rest**

**Large gradient at hyperemia**

70% long prox LAD stenosis

50% ostial left main stenosis

Resting gradient cannot predict hyperemic gradient
“The resting gradient is far from enough but unfortunately, it’s all I have now”.
But....they were limited by

• inadequate equipment to measure pressure:
  → *balloon catheter instead of 0.014’ wire*

• inadequate hemodynamic conditions:
  → *measuring at baseline instead of using maximum hyperemia*

• inadequate interpretation:
  → *transstenotic gradients instead of Fractional Flow Reserve*
3 different patients with each hyperemic trans-stenotic gradient of 30 mmHg:

\[
\Delta P = 30 \text{ mmHg}
\]

- **First Patient:**
  
  \[
  FFR = \frac{70}{100} = 0.70
  \]

- **Second Patient:**
  
  \[
  FFR = \frac{40}{70} = 0.58
  \]

- **Third Patient:**
  
  \[
  FFR = \frac{25}{55} = 0.45
  \]
Fortunately, these 3 limitations were overcome:

- In the early nineties, 0.014” pressure guide wires became available, enabling reliable distal coronary pressure (Tenerz, 1988)

- Safe and reproducible hyperemic drugs were validated for use in the human coronary circulation (Wilson, 1985)

- And it was recognized that not gradients in itself are important, but the ratio of perfusion pressures at hyperemia (Pijls & De Bruyne, 1991)
Early nineties: development of FFR

2.8F infusion catheter

last 15 cm of 0.015 hollow guidewire

glued together at the kitchen table and sterilized by Ethylene Oxide
2.8F infusion catheter

last 15 cm of 0.015 hollow guidewire
Overestimation of the Pressure Gradient by the Presence of the Pressure Measuring Wire in the Stenosis, is negligible

The presence of a 0.014” pressure monitoring guide wire in the stenosis does not create any clinically significant additional resistance.

Flow of 200 ml/min in a 70 % stenosis results in overestimation of gradient of 2 mmHg.
1993: “the birth of Fractional Flow Reserve”

Experimental Basis of Determining Maximum Coronary, Myocardial, and Collateral Blood Flow by Pressure Measurements for Assessing Functional Stenosis Severity Before and After Percutaneous Transluminal Coronary Angioplasty

Nico H.J. Pijls, MD; Jacques A.M. van Son, MD; Richard L. Kirkcide, PhD; Bernard De Bruyne, MD; and K. Lance Gould, MD

Circulation Vol 87, No 4 April 1993

Description of the Model

The purpose of this model was to derive equations relating pressures to the regional distribution of maximum perfusion. Maximum flow through a stenotic artery is compared with what maximum flow would be in that same artery in the absence of that stenosis. Consequently, we express coronary flow reserve for a stenotic artery as a fraction of its normal expected value in that same artery in the absence of a stenosis. We therefore use the term “fractional flow reserve” (FFR). In the literature, the term “relative flow” reserve is used in the sense of a flow reserve relative to an adjacent normal coronary artery. However, a unique strength of the model described here is the theoretical capacity...
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Validation study of FFR in dogs

Horizontal axis: Measured FFR by perivascular flow meter

Vertical axis: Calculated FFR from coronary pressure

Pijls et al, Circulation 1993;87: 1354-1367
OPENING EUROPEAN HEART HOUSE, JANUARY 1994
First educational & training programm: **coronary physiology**
(course directors: Patrick Serruys and Carlo di Mario)
First pressure "wire"  Concept of FFR

1994
RADI
1994 – 1997 validation studies of FFR
1996
First demonstration of clinical usefulness of FFR and its validation versus a true gold standard of ischemia
1997
PressureWire (PW) -1
(RADI Medical Systems)
1997-2000: clinical trials on FFR
How to apply coronary physiology in the catheterization laboratory

Education and Training Program 2000

Nice
European Heart House

April 6 - 8, 2000
0.014 sensor-tipped electronic guidewires; Tremendous improvement of software and hardware
LCX, hyperemia

pull-back
IMR = Pd x Tmn
absolute coronary blood flow

\[ Q_b = 25 \times \left( \frac{-7.1}{-0.97} \right) \times 1.08 = 198 \text{ ml/min} \]
Specific software for LVP and LV dP/dt recording (used in CRT, HOCM, etc)
CABLELESS INTEGRATED PRESSURE WIRE SYSTEM

receiver
2.5 x 4 inch

Hemodynamic recording system

PressureWire®
Aeris

AO-transducer

PressureWire® Receiver

P2

P1
1996: First clinical validation of FFR

2009: Routine application of FFR (FAME)
We hypothesized that in patients with stable coronary artery disease and stenosis who were randomized to fractional flow reserve-guided percutaneous coronary intervention (FFR-guided PCI), the FFR-guided PCI would be superior to medical therapy.

Background
The preferred initial treatment for patients with stable coronary artery disease is a significant stenosis, as determined by measurement of fractional flow reserve (FFR) plus the best available medical therapy.
THE NUMBER OF INVASIVE PROCEDURES INVOLVING CORONARY PRESSURE MEASUREMENT, HAS INCREASED FROM 1,500 in 1997 TO AN ESTIMATED 800,000 IN 2014
A number of semi-hyperemic and non-hyperemic indices, both for epicardial and microvascular compartment have been introduced (Friday afternoon sessions):

Hyperemia: absolute flow, IMR, IHDPVR, hSRv
Semi-hyperemic: contrast FFR (cFFR) → LBT at euroPCR in may
Non-hyperemic: iFR, resting Pd/Pa, bSRv → friday afternoon
Non-invasive FFR: FFR$_{CT}$ → Saturday morning

And a number of “new” manufacturers of pressure wires are on (or close to) the market → Saturday morning session:

Founding father: RADI → St Jude Medical
Follower: Volcano, now Philips
Newcomers: Opsense, Acist, Boston Scientific
A few final remarks:
Logistics in the cath lab is paramount
(*fixed set-up, induction of hyperemia, pullback, etc*)
A few announcement & rules of this meeting:

- Speakers present their disclosures in their first presentation.
- Stupid questions do not exist.
- Be as open and frank as you can, take part in the discussion.
- Approach the speakers whenever you like and ask everything you ever wanted to ask about coronary physiology.
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- **Josefa Cano** (Bernards secretary)