Fractional flow reserve and the influence of bifurcation angle and degree of stenosis

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**Clinical problem: FFR of bifurcations**

- **FFR** is a widely accepted **measurement to assess myocardial ischemia** under high work load

- Since FFR is based on a simple model\(^1\), a **deeper comprehension of the physiological basis and diagnostic features is still needed**, in particular for **bifurcation lesions**\(^2\)

**Questions:**

- What is the contribution of pressure loss, because of the distal angle, to FFR?
- For which side branch stenosis is that relevant?

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Aim

To investigate the influence of distal angle and side branch stenosis on the FFR by performing CFD analyses in a literature-based coronary bifurcation model.
Methods: LAD / D1 bifurcation model

- Diameters defined according to Finet’s law
- Stenosis: PMB 60% - DMB 60% - SB 60% (40% / 80%)
- Curvature: bifurcation placed on a sphere representing the heart
- Asymmetric plaque

Godino et al. J Interv Cardiol, 2010; 23: 382-393
Onuma et al. EuroIntervention, 2008; 3:546-552
Investigated geometries

SB stenosis

40%

40° Distal angle

60%

60° Distal angle

80%  

80° Distal angle

40%  

40° Distal angle

60%  

60° Distal angle

80%  

80° Distal angle
Flow used to calculate the FFR

HEALTHY

Inlet: inflow = $120 \text{ mL/min}$  

$q = 1.43 \cdot d^{2.55} \frac{\text{m}^3}{\text{s}}$ (van der Giessen et al. 2011)

a scale factor 3 was used to simulate hyperemia  
(Papafaklis et al. 2014)
Flow used to calculate the FFR

HEALTHY

Inlet: \( \text{inflow} = 120 \text{ mL/min} \)

Outlet: \( \text{Outflow Side branch} = 42 \text{ mL/min} \) (35%)
\( \text{Outflow Distal main branch} = 78 \text{ mL/min} \) (65%)

flow split \( \frac{q_{D2}}{q_{D1}} = \left( \frac{d_{D2}}{d_{D1}} \right)^2 \)

(van der Giessen et al. 2011)

Flow used to calculate the FFR

**Healthy**

**Inlet:** inflow $= 120 \text{ mL/min}$

**Outlet:**
- Outflow Side branch $= 42 \text{ mL/min}$ (35%)
- Outflow Distal main branch $= 78 \text{ mL/min}$ (65%)

**Diseased**

25%, 35%, 45%

30, 42, 54 mL/min

55%, 65%, 75%

66, 78, 90 mL/min

FFR calculation Main Branch

- FFR – main branch:
\[ \frac{P_{DMB}}{P_{PMB}} = \frac{86}{100} = 0.86 \]
• FFR – main branch:
  \[ \frac{P_{DMB}}{P_{PMB}} = \frac{86}{100} = 0.86 \]

• FFR – side branch:
  \[ \frac{P_{SB}}{P_{PMB}} = \frac{65}{100} = 0.65 \]
Results: FFR main branch

influence of angle

Distal angle

→ no influence on FFR in main branch

(when PMB stenosis is 60%)
Results: FFR main branch influence of SB stenosis and angle

SB stenosis = 40%

SB stenosis = 60%

SB stenosis = 80%

Distal angle → no influence on FFR in main branch

SB stenosis → no influence on FFR in main branch

Q_{in} = 120 \text{ mL/min}
Results: FFR side branch influence of SB stenosis and angle

For lower SB stenosis: FFR in SB is dominated by proximal stenosis and thus insensitive to flow through side branch and distal angle

$Q_{in} = 120 \text{ mL/min}$
Results: FFR side branch influence of distal angle

SB stenosis = 80%

For higher SB stenosis:
FFR in SB is dependent on flow through side branch and distal angle
Results: Pressure drop – flow-rate relationship in the SB

SB stenosis = 80%

\[ \Delta P_{SB} = 0.010 Q_{SB}^2 + 0.45 Q_{SB} \]

- 80% - 40°
- 80% - 55°
- 80% - 70°

\[ \Delta P_{SB} = 0.015 Q_{SB}^2 + 0.56 Q_{SB} \]

\[ \Delta P_{SB} = 0.017 Q_{SB}^2 + 0.69 Q_{SB} \]
Conclusions

• Pressure drop – flow relationship across the SB stenosis is quadratic
  → SB flow resistance is higher when the distal angle is larger in bifurcations with severe SB stenosis

• Consideration on FFR in bifurcations:
  
  **DISTAL MAIN BRANCH:** FFR is combined result of distal and proximal main branch stenosis
  → SB stenosis has minimal effect on FFR
  → distal angle has minimal influence on FFR

  **SIDE BRANCH:** FFR is combined result of side branch and proximal stenosis
  → large influence of distal angle on FFR when SB stenosis is severe
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Thank you for your attention