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

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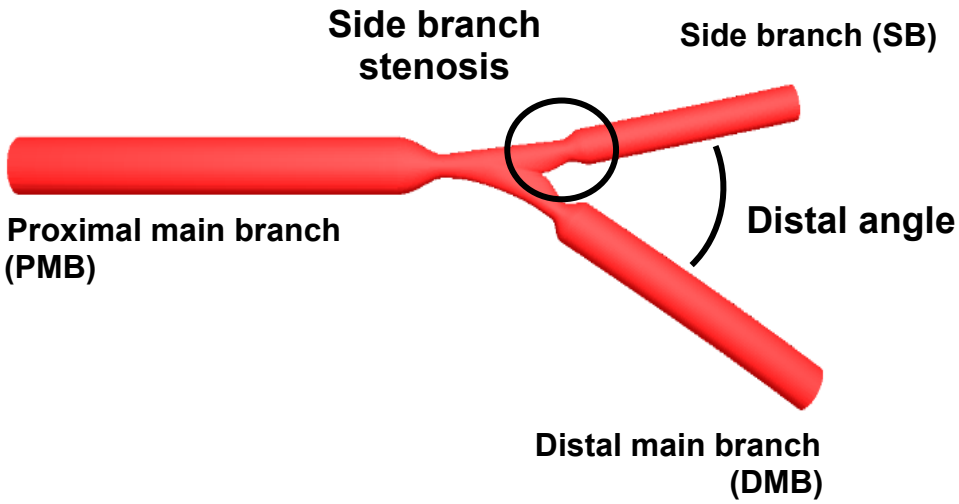
Clinical problem: FFR of bifurcations

- **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?



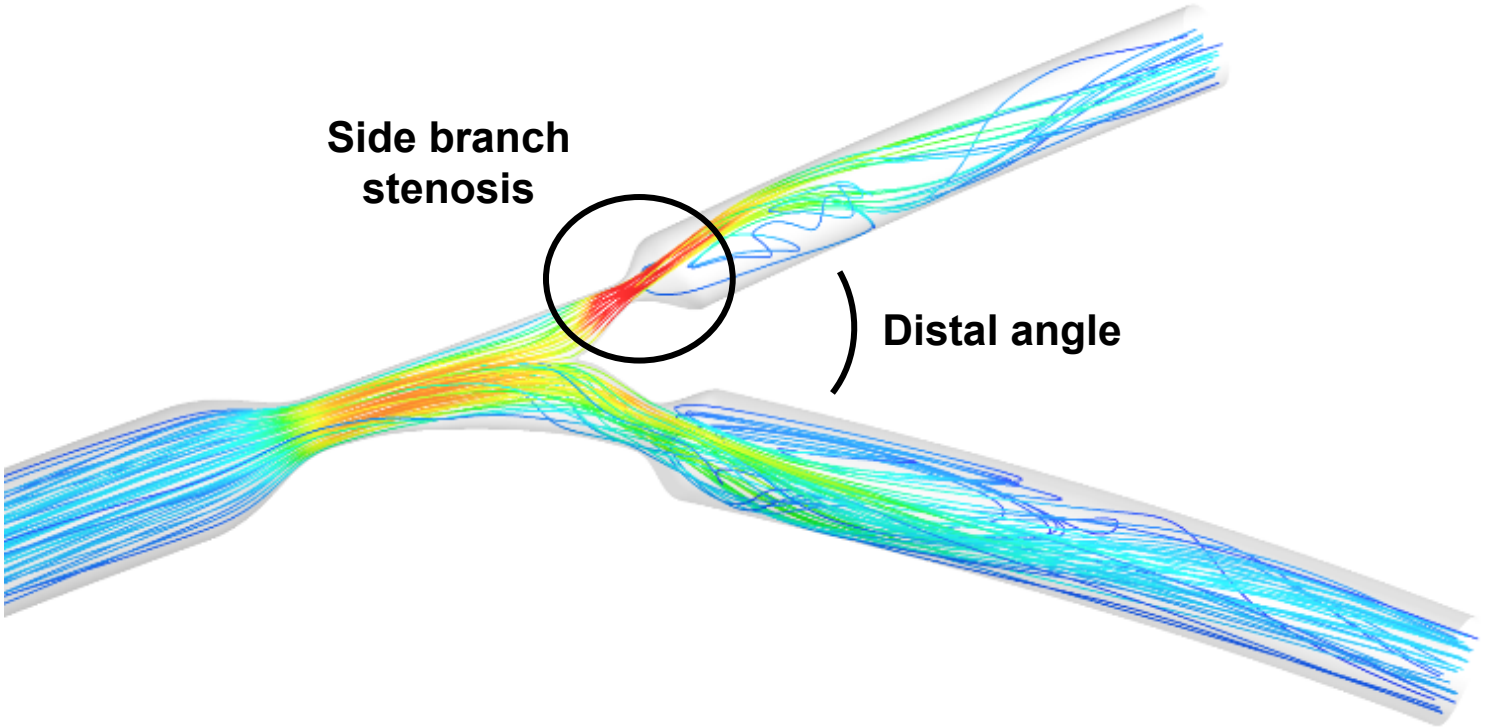
1. Pijls et al. Circulation. 1993;87:1354-1367
2. Lee et al. EuroIntervention. 2015; 11:V59-V63

Aim

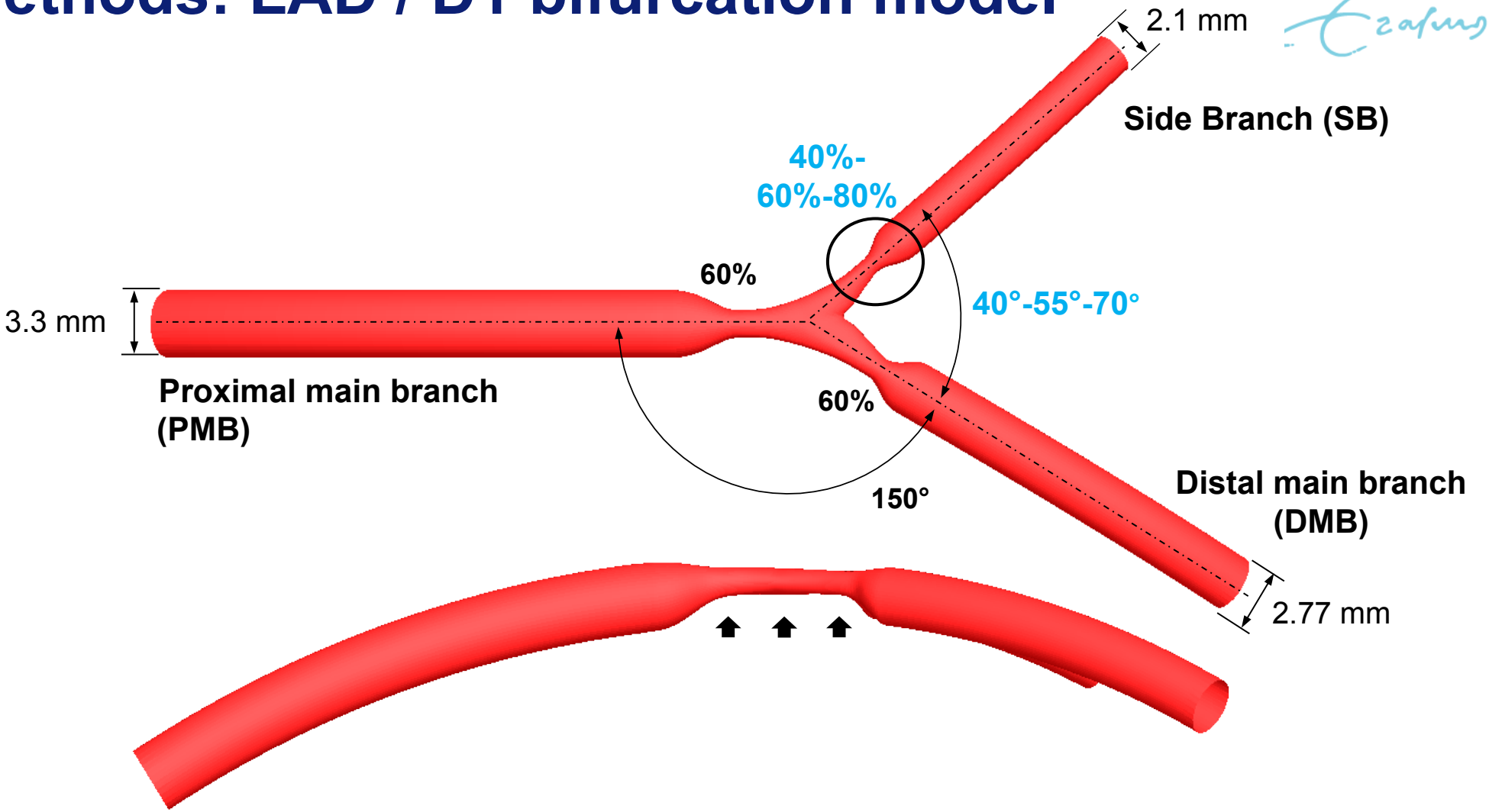
To investigate the influence of

distal angle and **side branch stenosis on the FFR**

by performing **CFD analyses** in a literature-based coronary bifurcation model



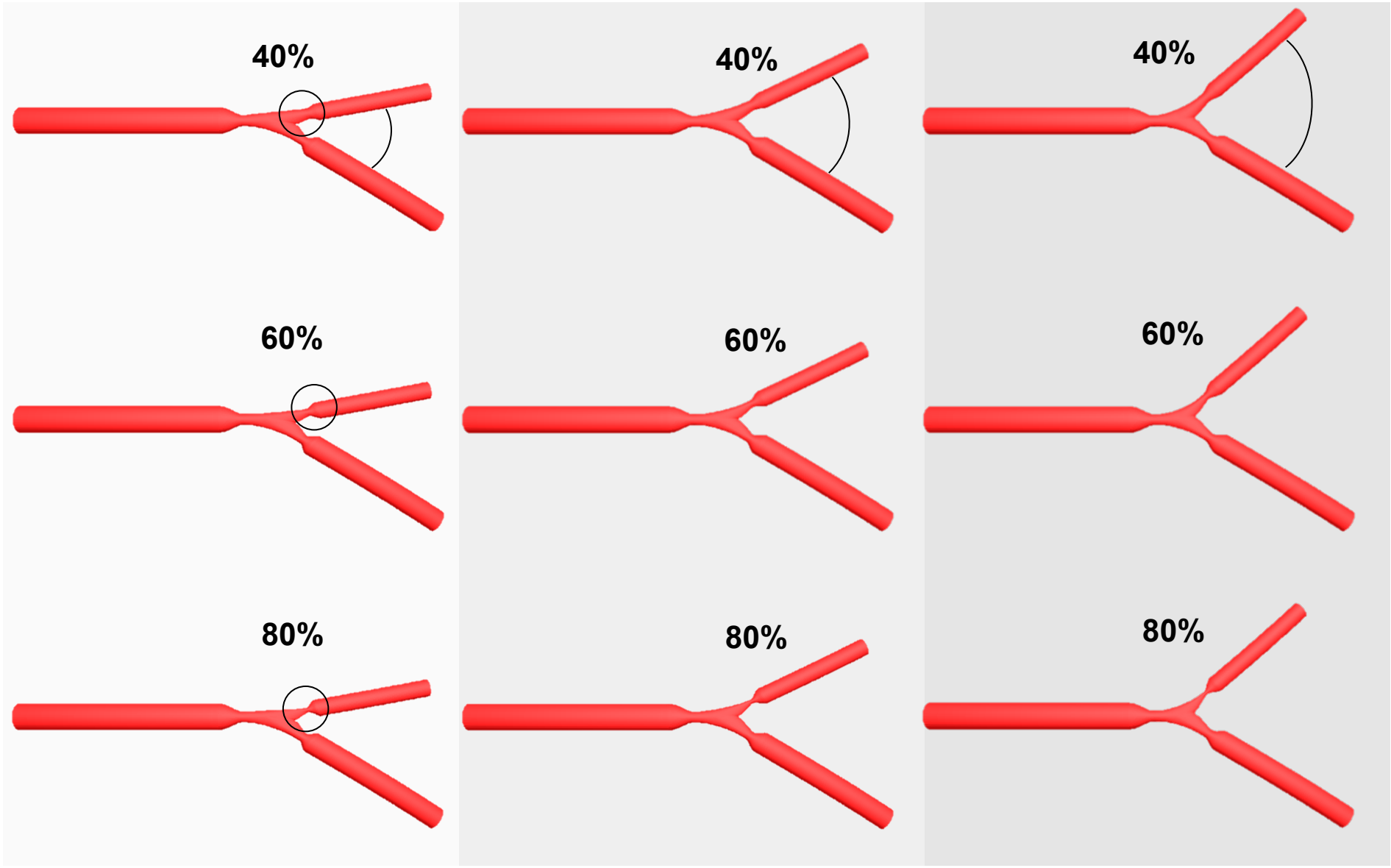
Methods: LAD / D1 bifurcation model



- **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
Elsaban et al. J Invasive Cardiol 2013; 25:118-122
Finet et al. EuroIntervention, 2007; 3: 490-498
Kimball et al. J Cardiol, 1990; 65: 767-771

Investigated geometries



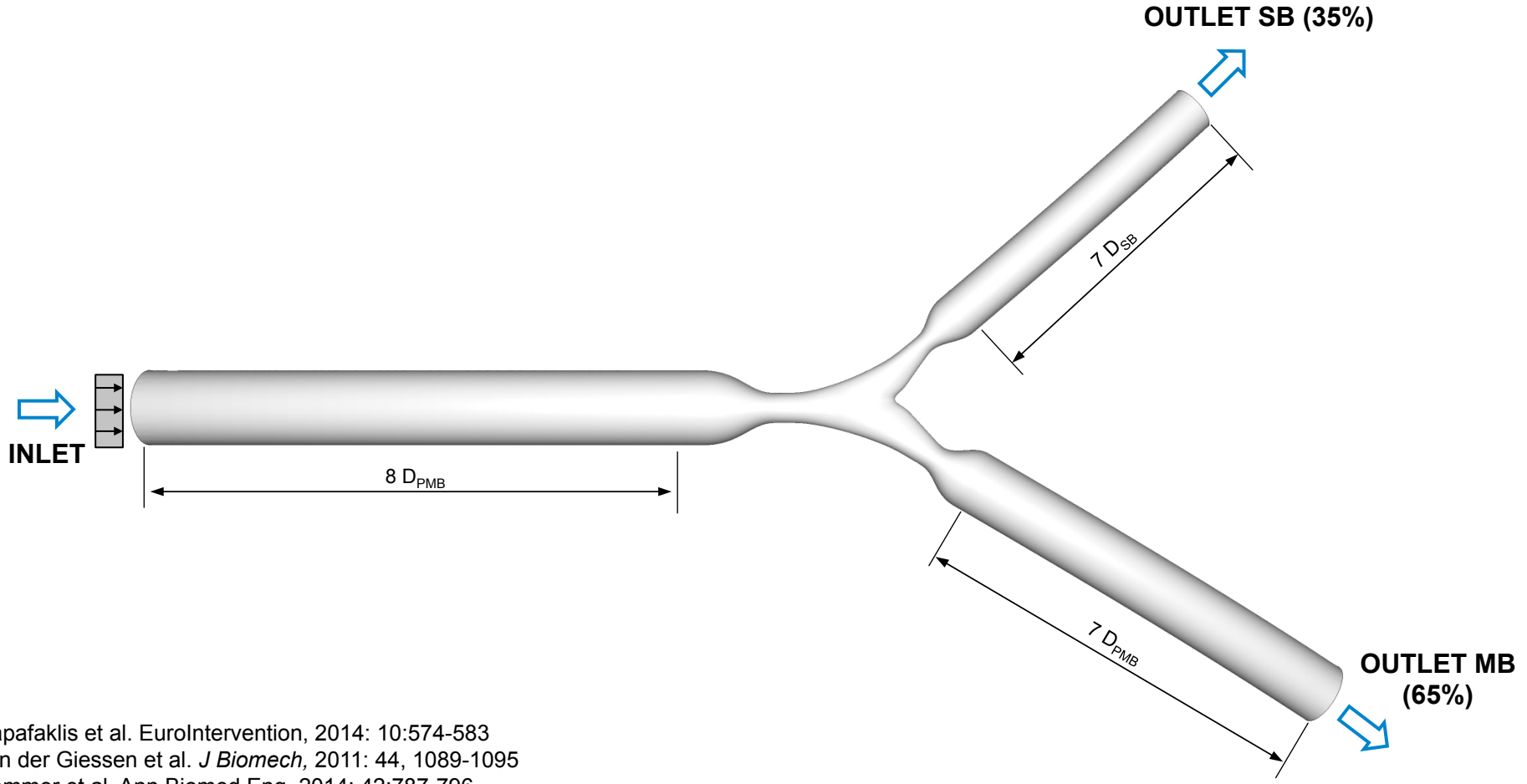
Flow used to calculate the FFR

HEALTHY

$$q = 1.43 \cdot d^{2.55} \quad [m^3/s]$$ (van der Giessen et al. 2011)

Inlet: inflow $= 120$ mL/min

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



Papafaklis et al. EuroIntervention, 2014: 10:574-583
van der Giessen et al. *J Biomech,* 2011: 44, 1089-1095
Sommer et al. Ann Biomed Eng, 2014: 42:787-796

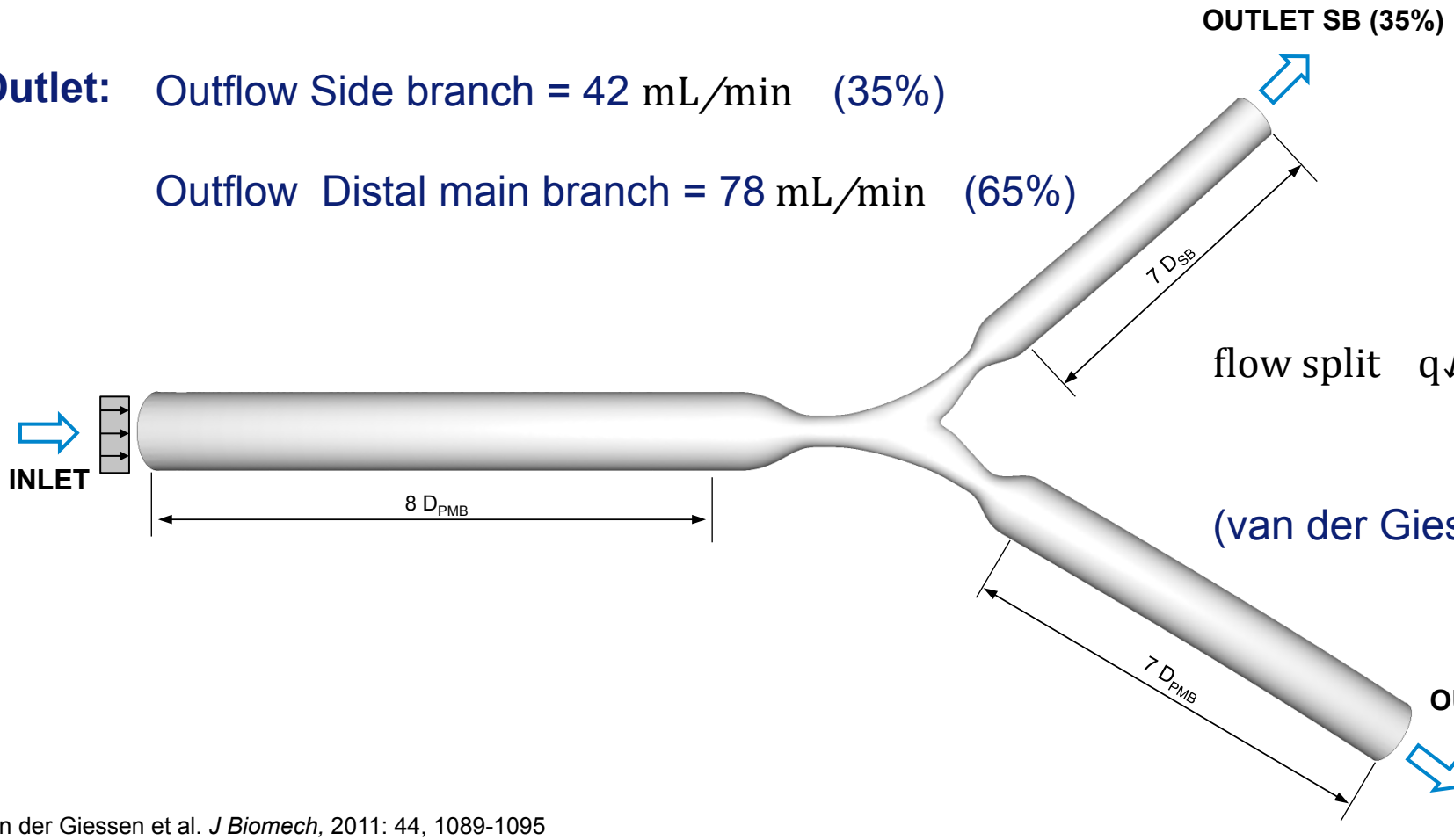
Flow used to calculate the FFR

HEALTHY

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

Outlet: Outflow Side branch = 42 $\mathrm{mL/min}$ (35%)

Outflow Distal main branch = 78 $\mathrm{mL/min}$ (65%)



flow split $q\downarrow D2 / q\downarrow D1 = (d\downarrow D2$

(van der Giessen et al. 2011)

van der Giessen et al. *J Biomech,* 2011: 44, 1089-1095

Flow used to calculate the FFR

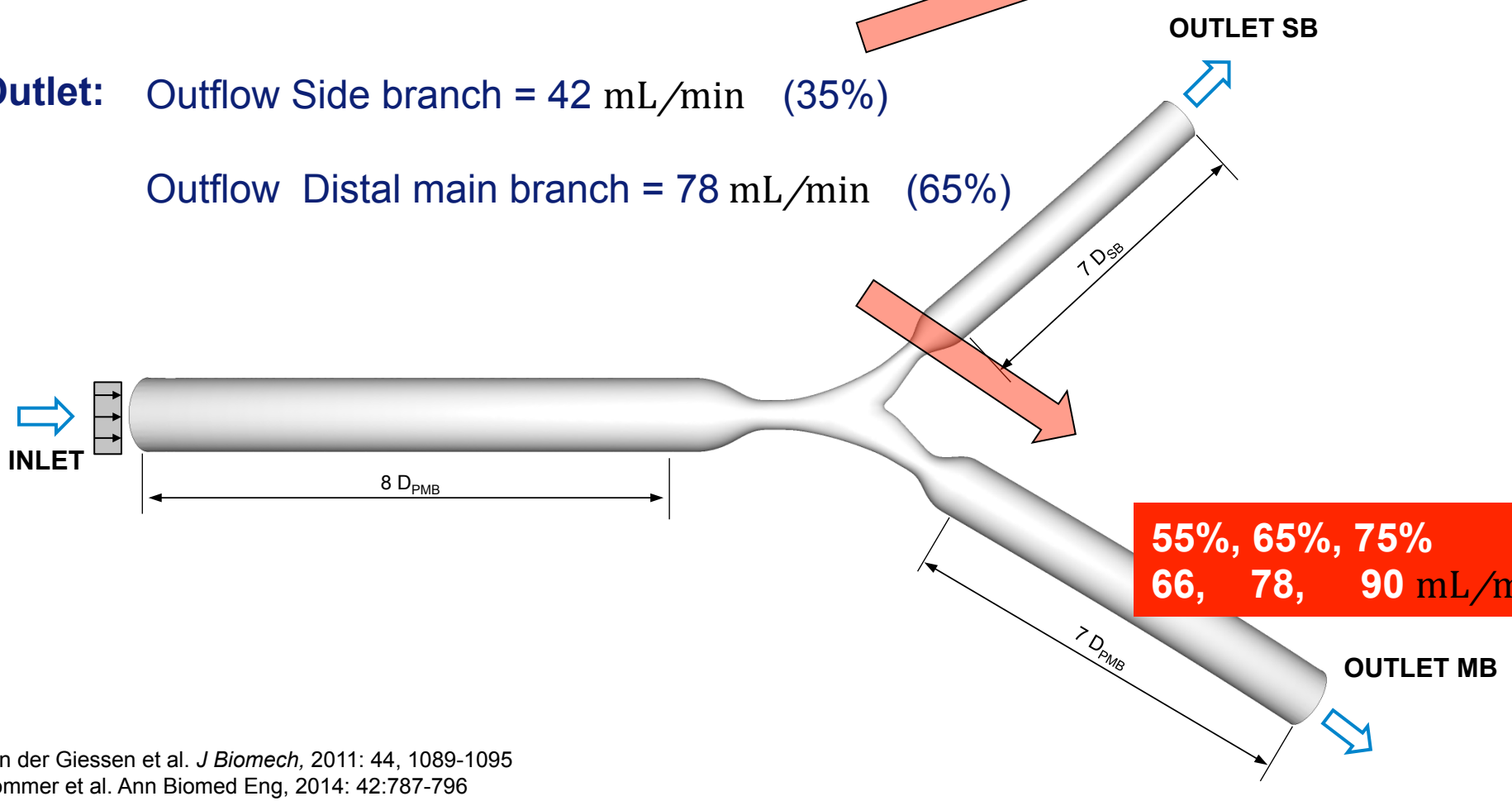
~~HEALTHY~~ → DISEASED

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

25%, 35%, 45%
30, 42, 54 mL/min

Outlet: Outflow Side branch = 42 $\mathrm{mL/min}$ (35%)

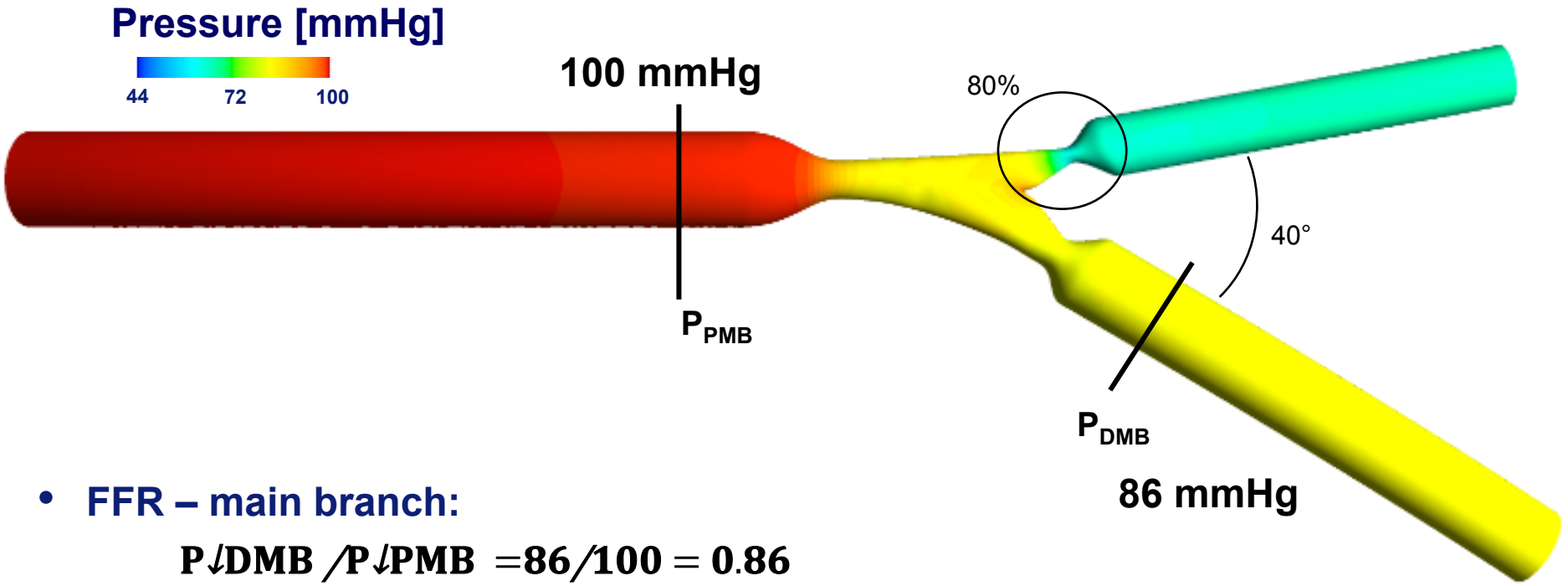
Outflow Distal main branch = 78 $\mathrm{mL/min}$ (65%)



55%, 65%, 75%
66, 78, 90 mL/min

van der Giessen et al. *J Biomech,* 2011: 44, 1089-1095
Sommer et al. Ann Biomed Eng, 2014: 42:787-796

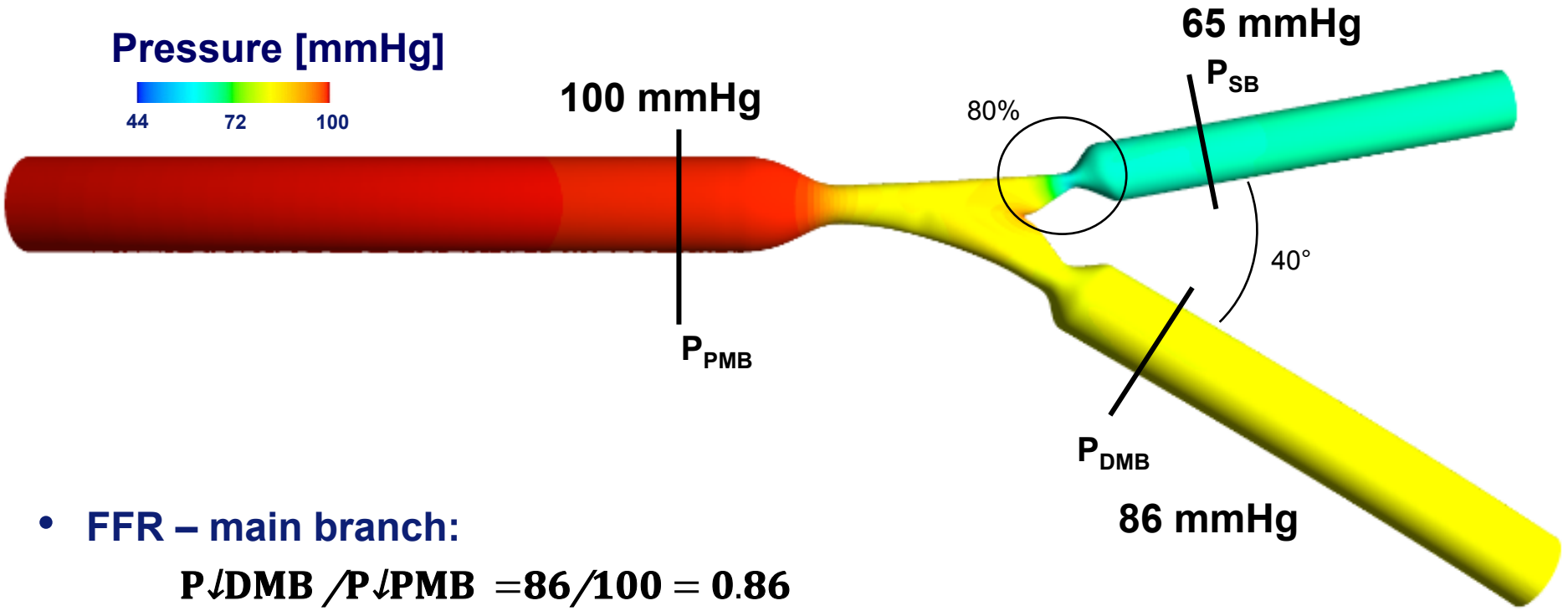
FFR calculation Main Branch



- **FFR – main branch:**

$$P_{DMB} / P_{PMB} = 86/100 = 0.86$$

FFR calculation Side Branch



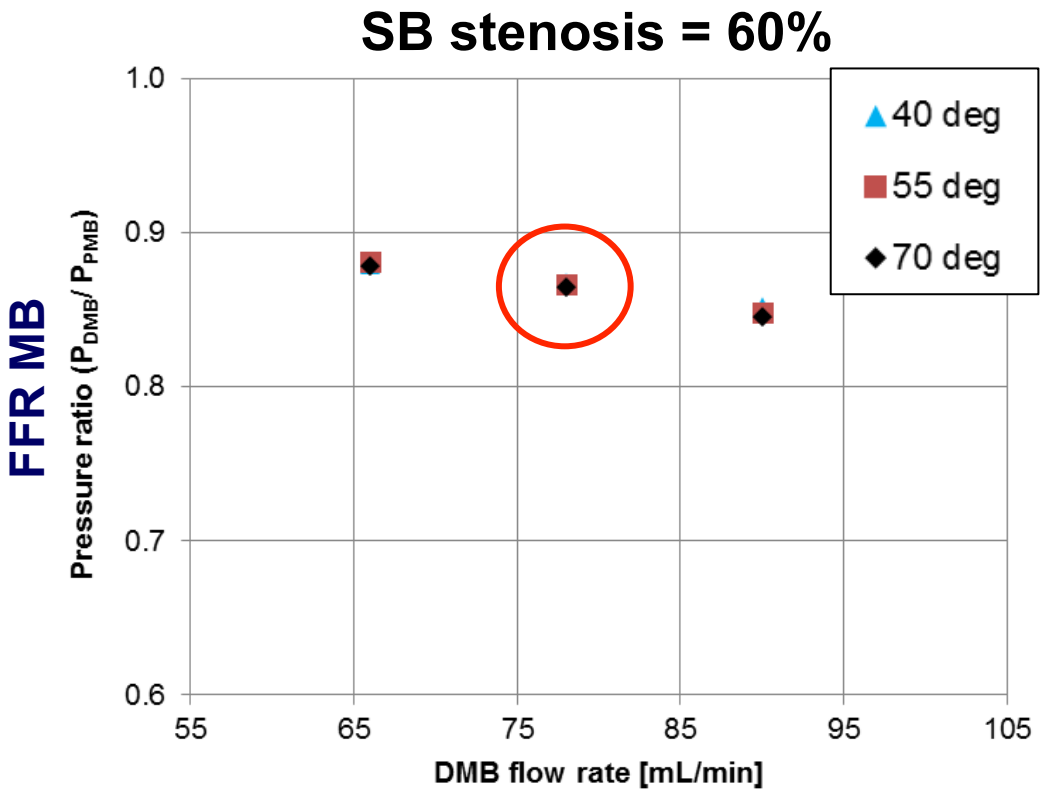
- **FFR – main branch:**

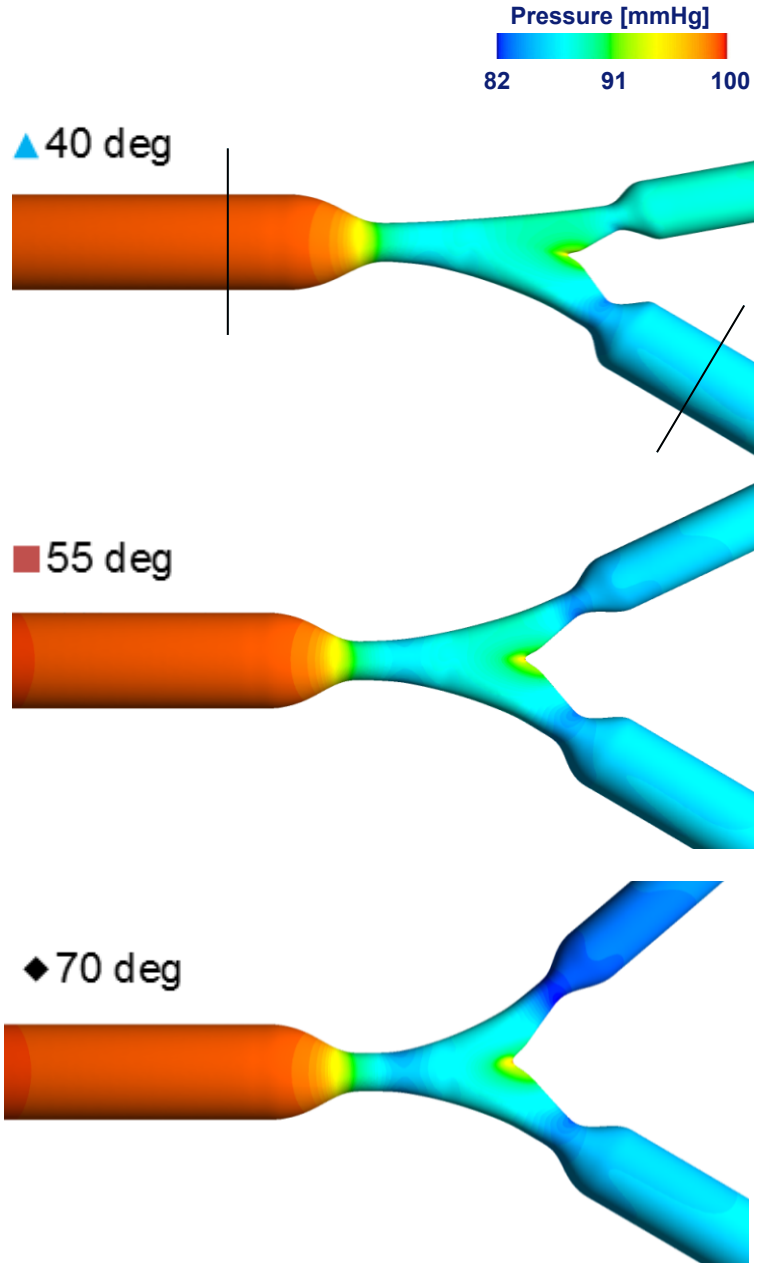
$$P_{DMB} / P_{PMB} = 86/100 = 0.86$$

- **FFR – side branch:**

$$P_{SB} / P_{PMB} = 65/100 = 0.65$$

Results: FFR main branch influence of angle





Distal angle

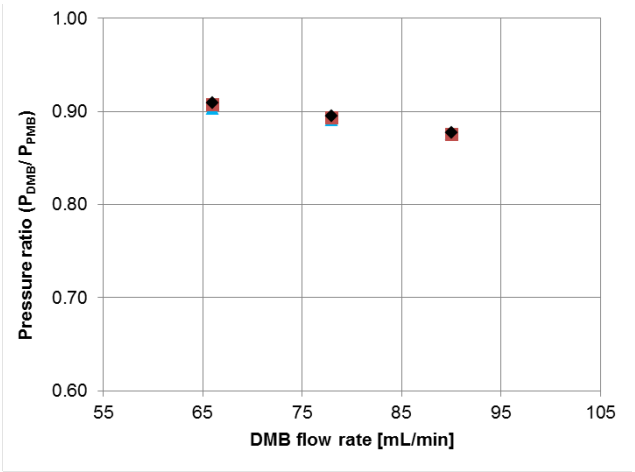
→ **no influence on FFR in main branch**

(when PMB stenosis is 60%)

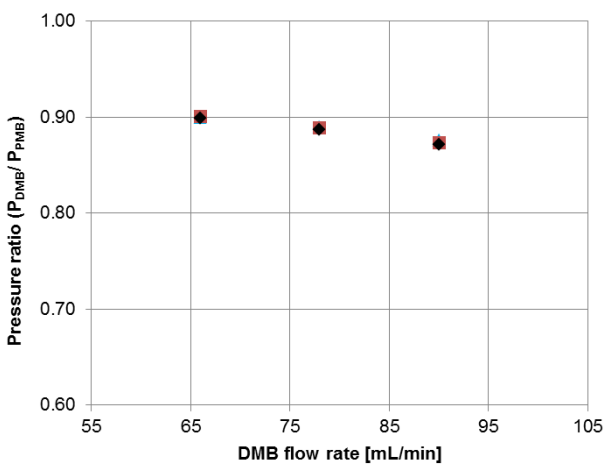
Results: FFR main branch influence of SB stenosis and angle

FFR MB

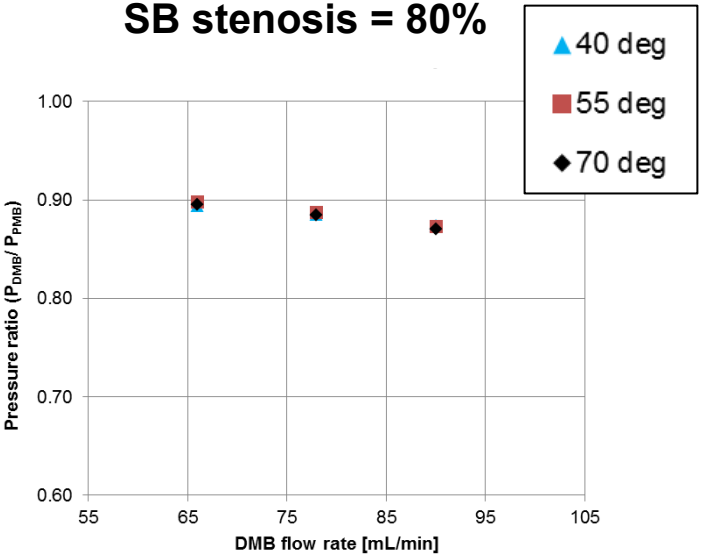
SB stenosis = 40%



SB stenosis = 60%



SB stenosis = 80%



Q_{in} = 120 mL/min

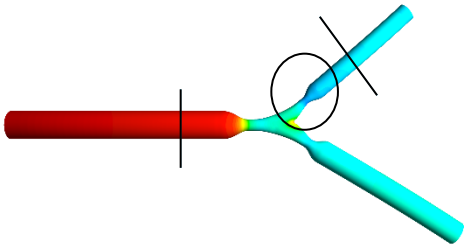
Distal angle

→ no influence on FFR in main branch

SB stenosis

→ no influence on FFR in main branch

Results: FFR side branch influence of SB stenosis and angle

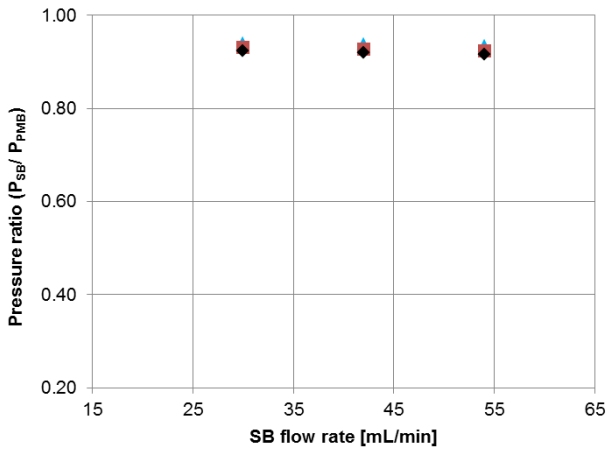


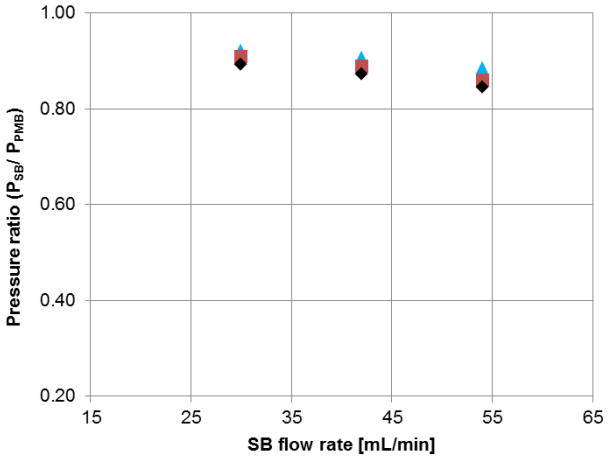
SB stenosis = 40%

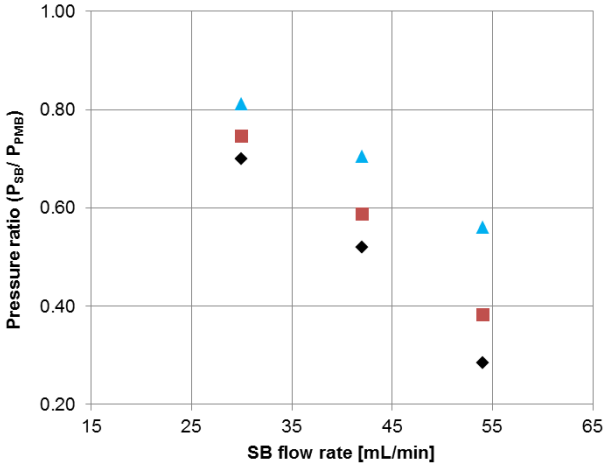
SB stenosis = 60%

SB stenosis = 80%

FFR SB





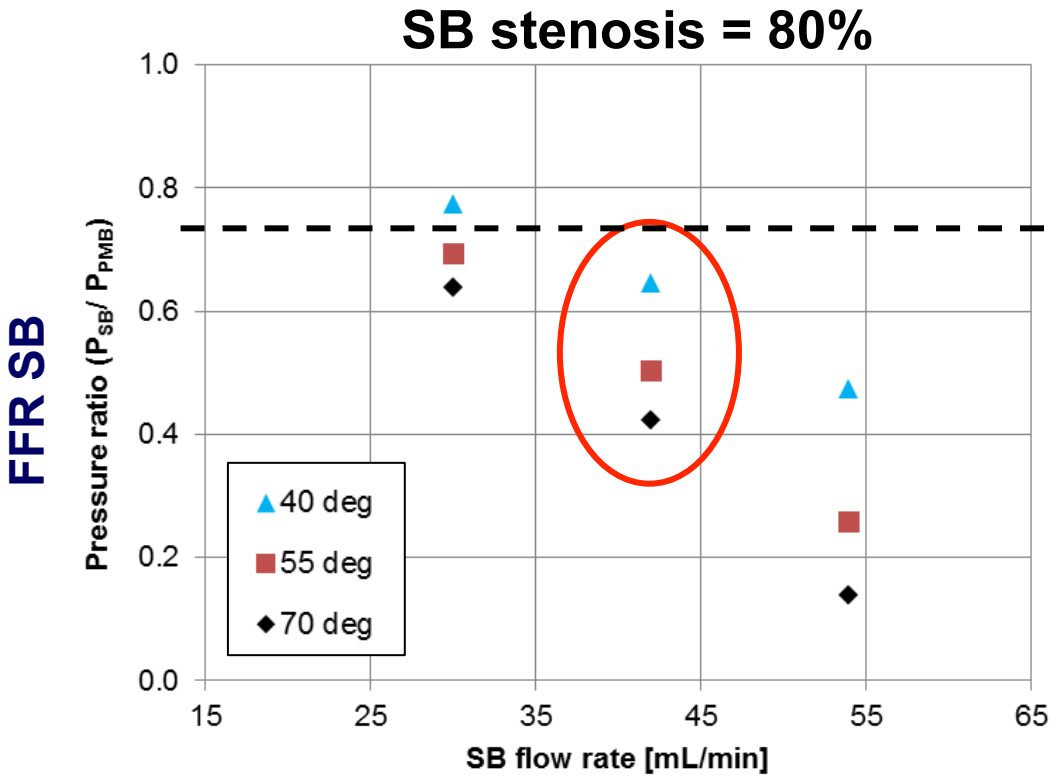


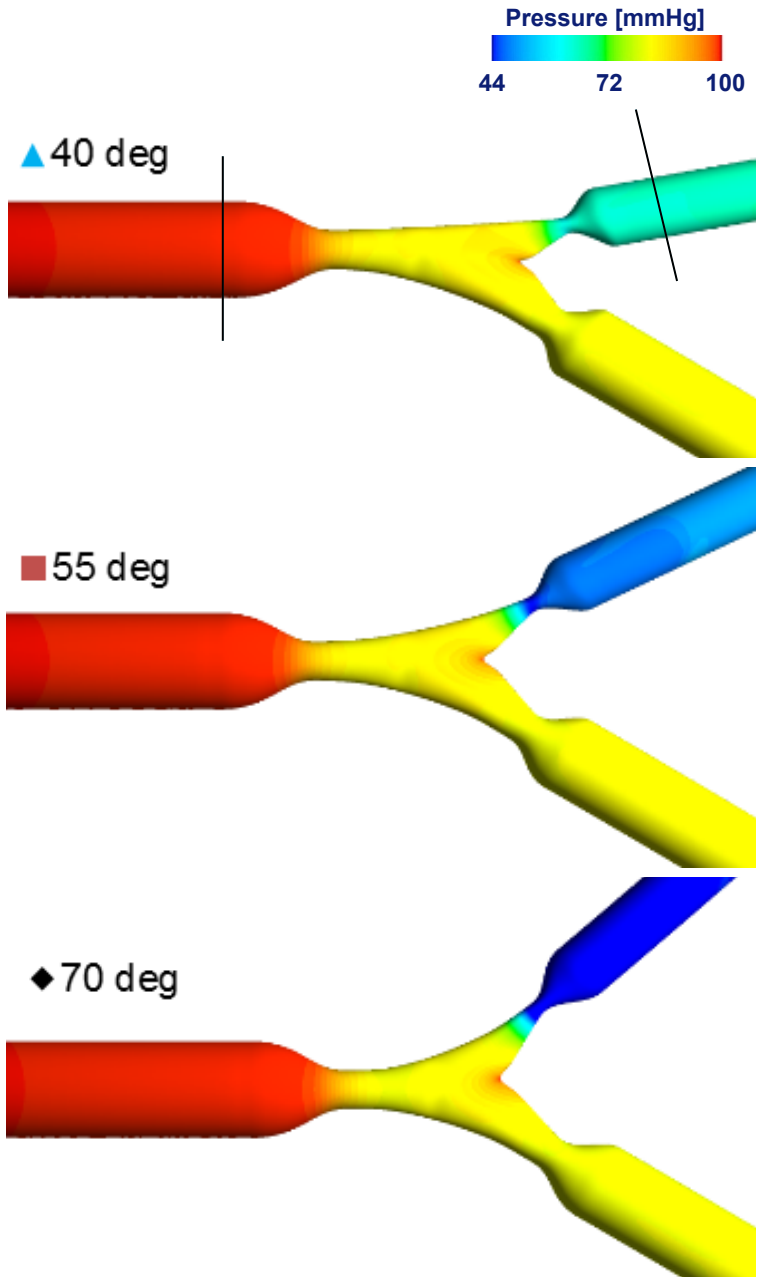
40 deg
55 deg
70 deg

Q_{in} = 120 mL/min

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

Results: FFR side branch influence of distal angle

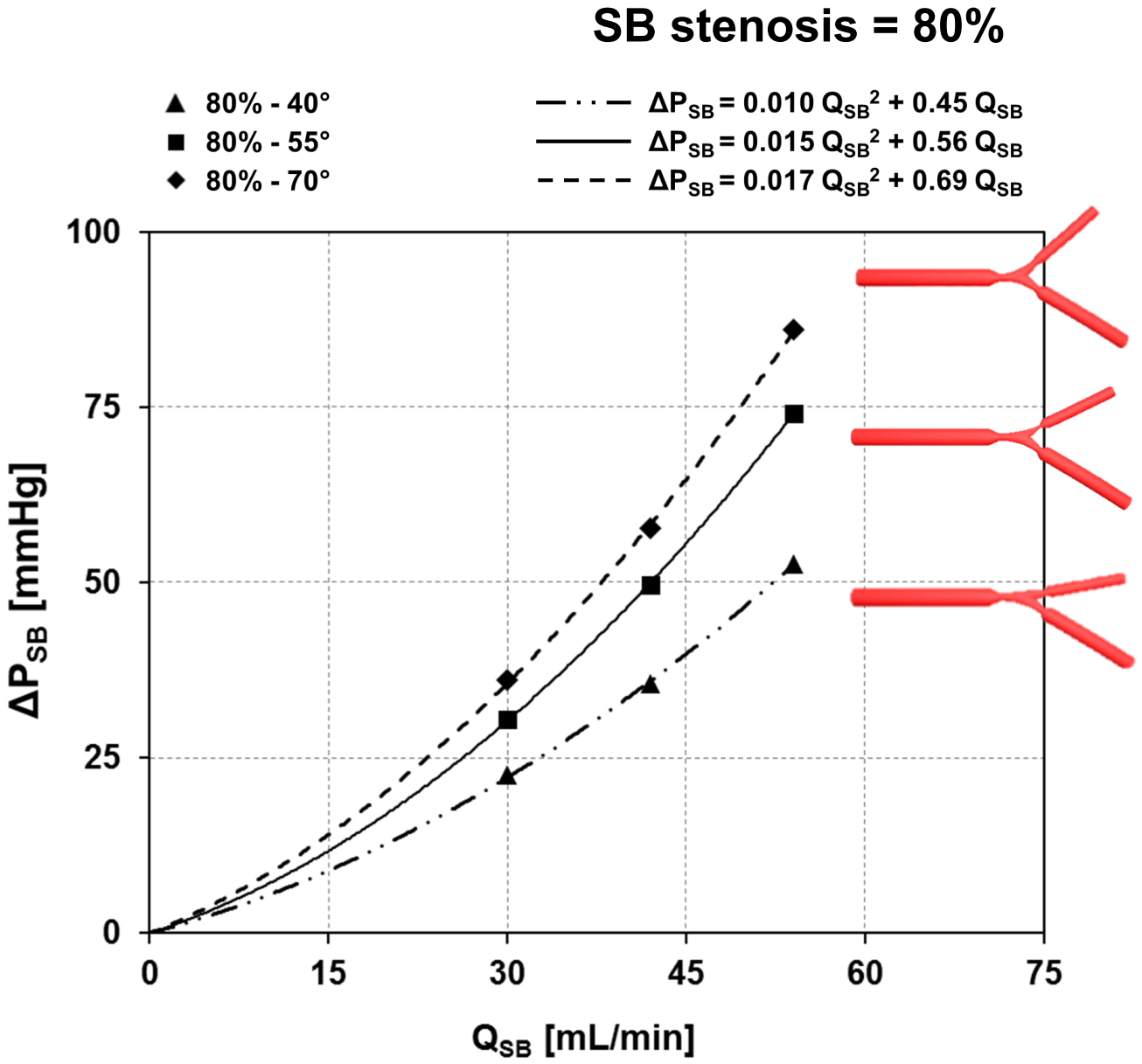




For higher SB stenosis:

FFR in SB is dependent on flow through side branch and distal angle

Results: Pressure drop – flow-rate relationship in the SB



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**

Acknowledgments

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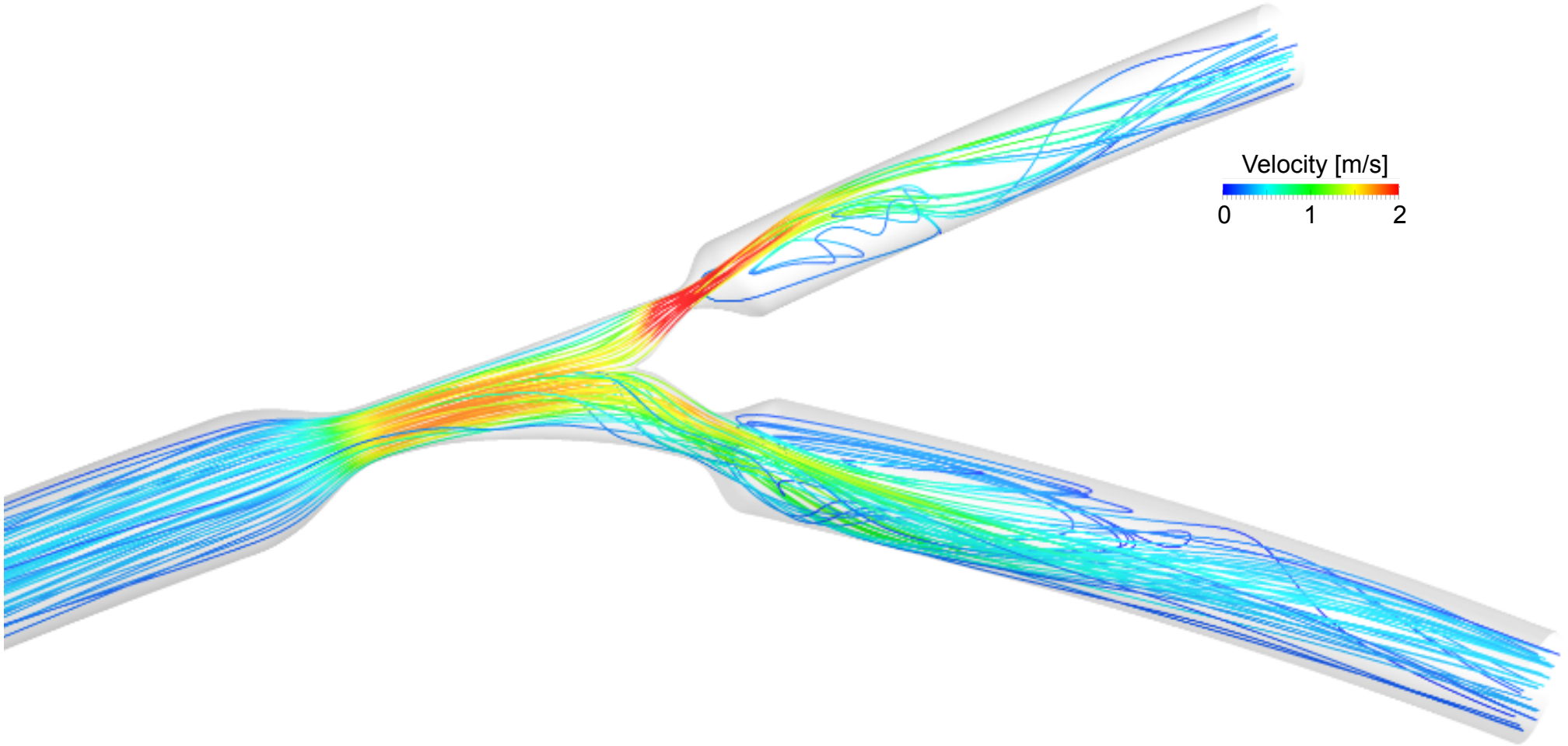

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