Geometric Consideration in Bifurcation Stenting with Two-stent Technique

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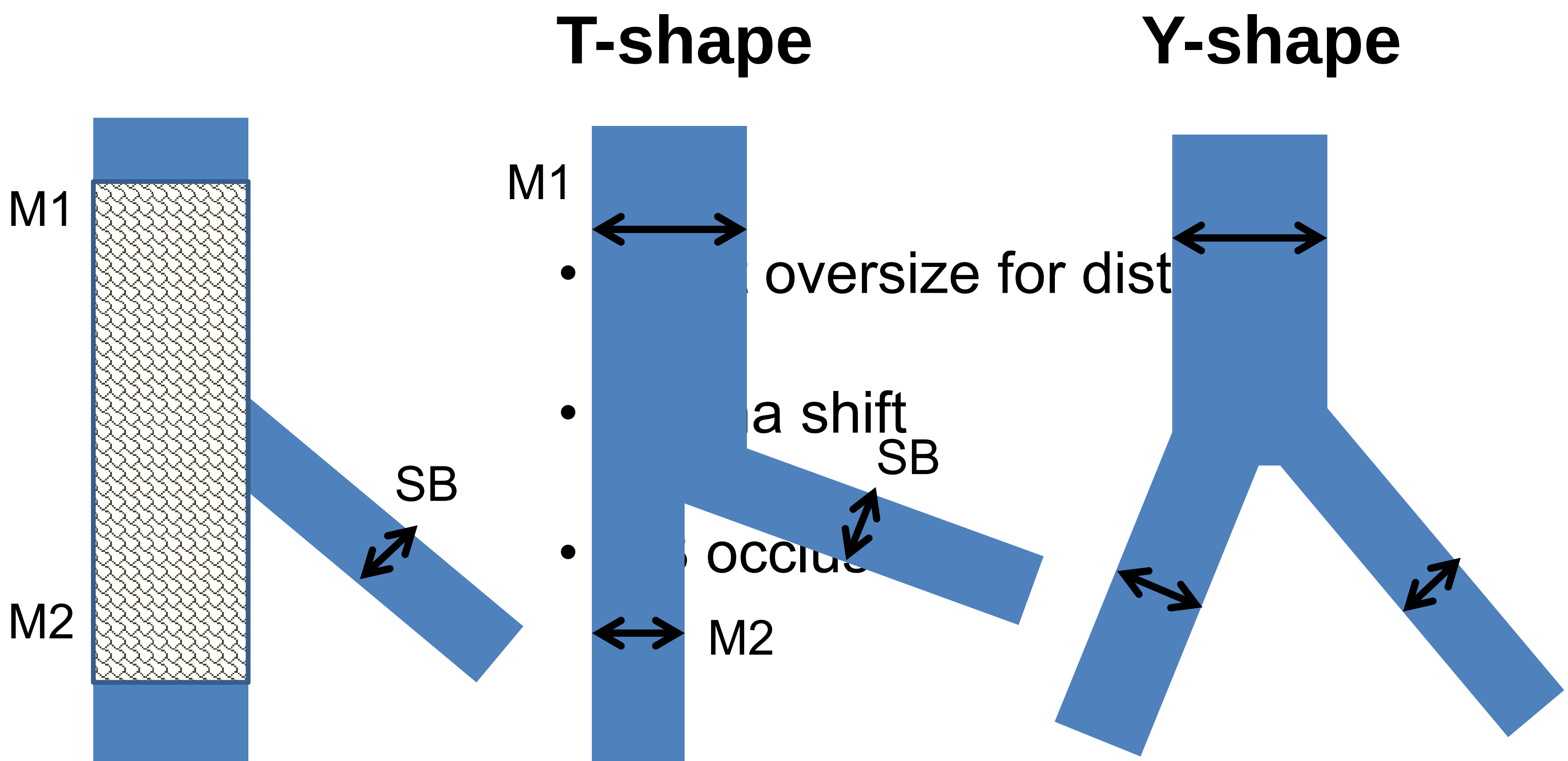
Previous concept

Current concept

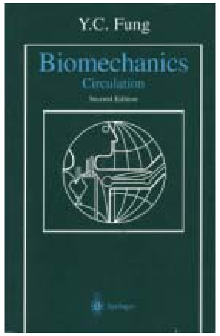


$M1 = M2 > SB$

$M1 > M2 \geq SB$

Geometric factors in coronary bifurcation

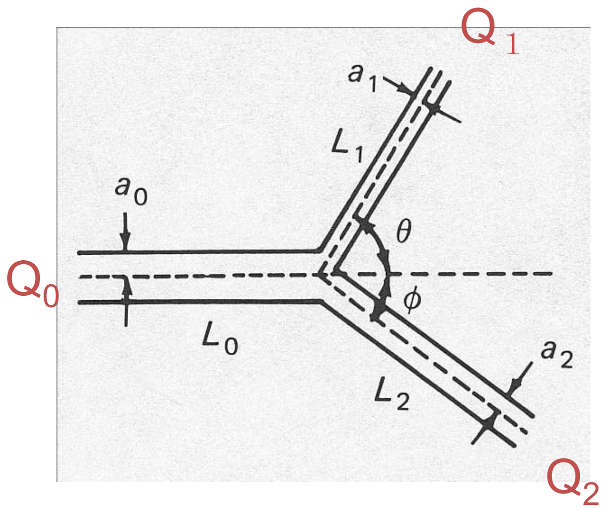
- Anatomy
  - Vessel size: vascular branching law
- Rheology (wall shear stress)
  - Plaque distribution
  - Thrombus formation
- Bifurcation angle
- 3-dimensional structure
- LV wall motion



Prof. Y.C.Fung, 1997

Murray's Law of Vascular Branching

Kajiya F, Bifurcation Club in KOKURA, 2009



Q : Flow

ΔP : Pressure gradient

Poiseuille formula : $Q = \frac{\pi a^4}{8\mu} \frac{\Delta P}{L}$

→ Conductance $= \frac{1}{\text{Resistance}}$

Cost Function $= Q\Delta P + K\pi a^2 L$ ←--- Metabolism

$$= \frac{8\mu L}{\pi a^4} Q^2 + K\pi a^2 L$$

＜Minimize Cost Function＞

$$\frac{d\,(\text{Cost Function})}{da} = -\frac{32\mu L}{\pi} Q^2 a^{-5} + 2K\pi a L \quad (=0)$$

$$\frac{32\mu}{\pi} Q^2 = 2K\pi a^6$$

$$a = \left(\frac{16\mu}{\pi^2 K}\right)^{1/6} Q^{1/3} \quad \rightarrow \quad \boxed{Q \propto a^3}$$

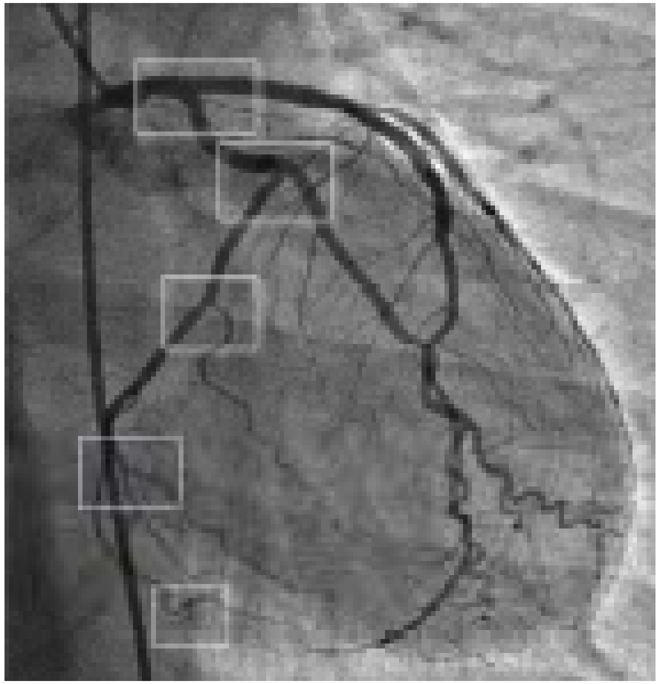
$Q_0 = Q_1 + Q_2$ → $\mathbf{a_0^3 = a_1^3 + a_2^3}$ Cube Law

Multi-scale analysis

Quantification of coronary artery bifurcations according to mother-vessel diameter
Values obtained on quantitative coronary bifurcation angiography

	For all
# of bifurcation	173
D_m (mean?DS)	3.339 ± 0.948
$D_{d\text{-larger}}$ (mean?DS)	2.708 ± 0.774
$D_{d\text{-smaller}}$ (mean?DS)	2.236 ± 0.689
Reduction in mm (mean?DS)	0.631 ± 0.365
% reduction	18.9
Mean ratio	**0.678**

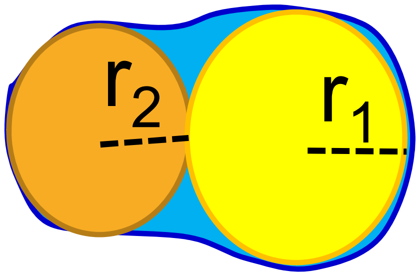
Variables are presented as mean ± SD
D in mm
D_m: Diameter of the mother vessel
$D_{d\text{-larger}}$: Diameter of the larger daughter vessel
$D_{d\text{-smaller}}$: Diameter of the smaller daughter vessel
Reduction: difference between the diameter of mother vessel and the diameter of the larger daughter vessel
Ratio: $D_m / (D_{d\text{-larger}} + D_{d\text{-smaller}})$



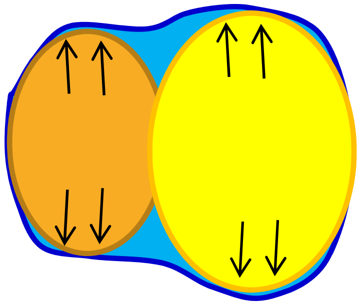
$$R = \frac{D_{mother}}{D_{daughter\ 1} + D_{daughter\ 2}}$$

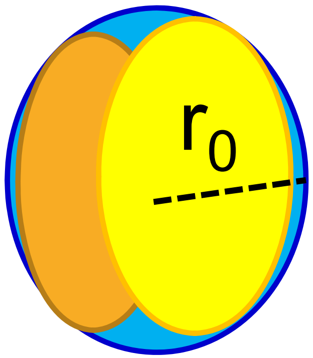
Finet G. et al. EuroIntervention 2007;3:1-9.

Kissing balloon inflation

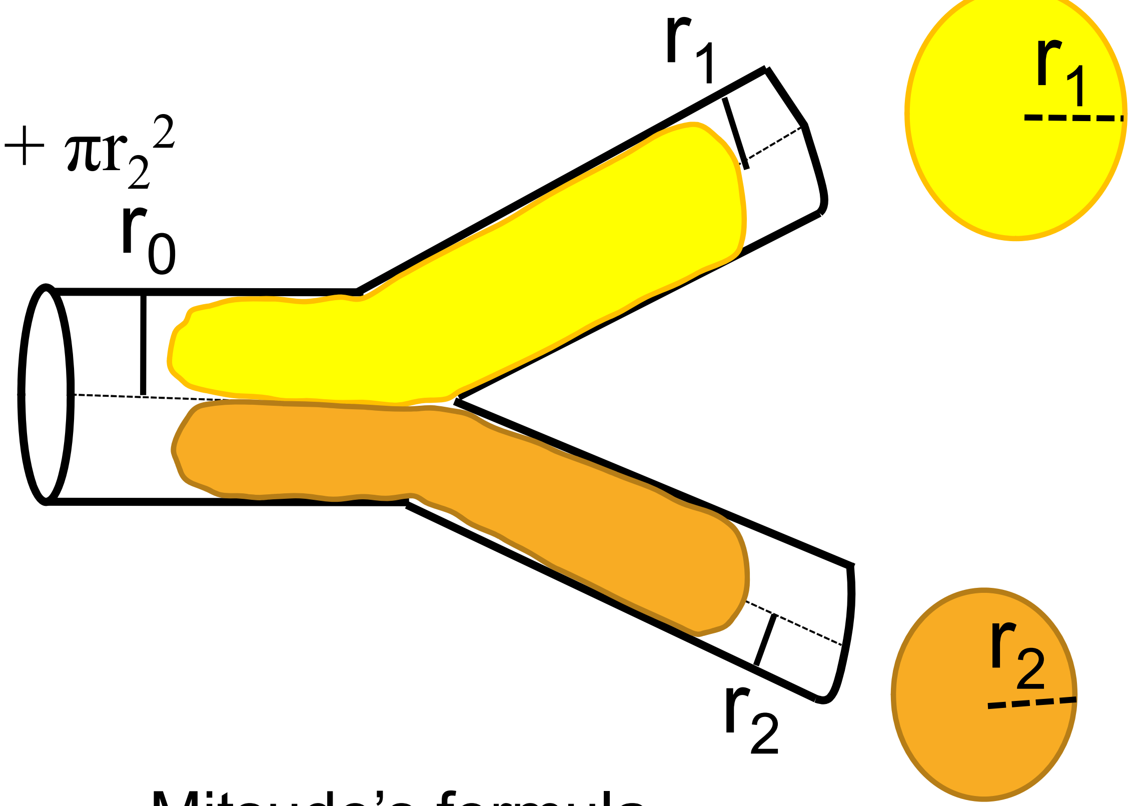


PMV area = $\pi r_1^2 + \pi r_2^2$





$\pi r_0^2 = \pi r_1^2 + \pi r_2^2$



Mitsudo's formula

$$r_0^2 = r_1^2 + r_2^2$$

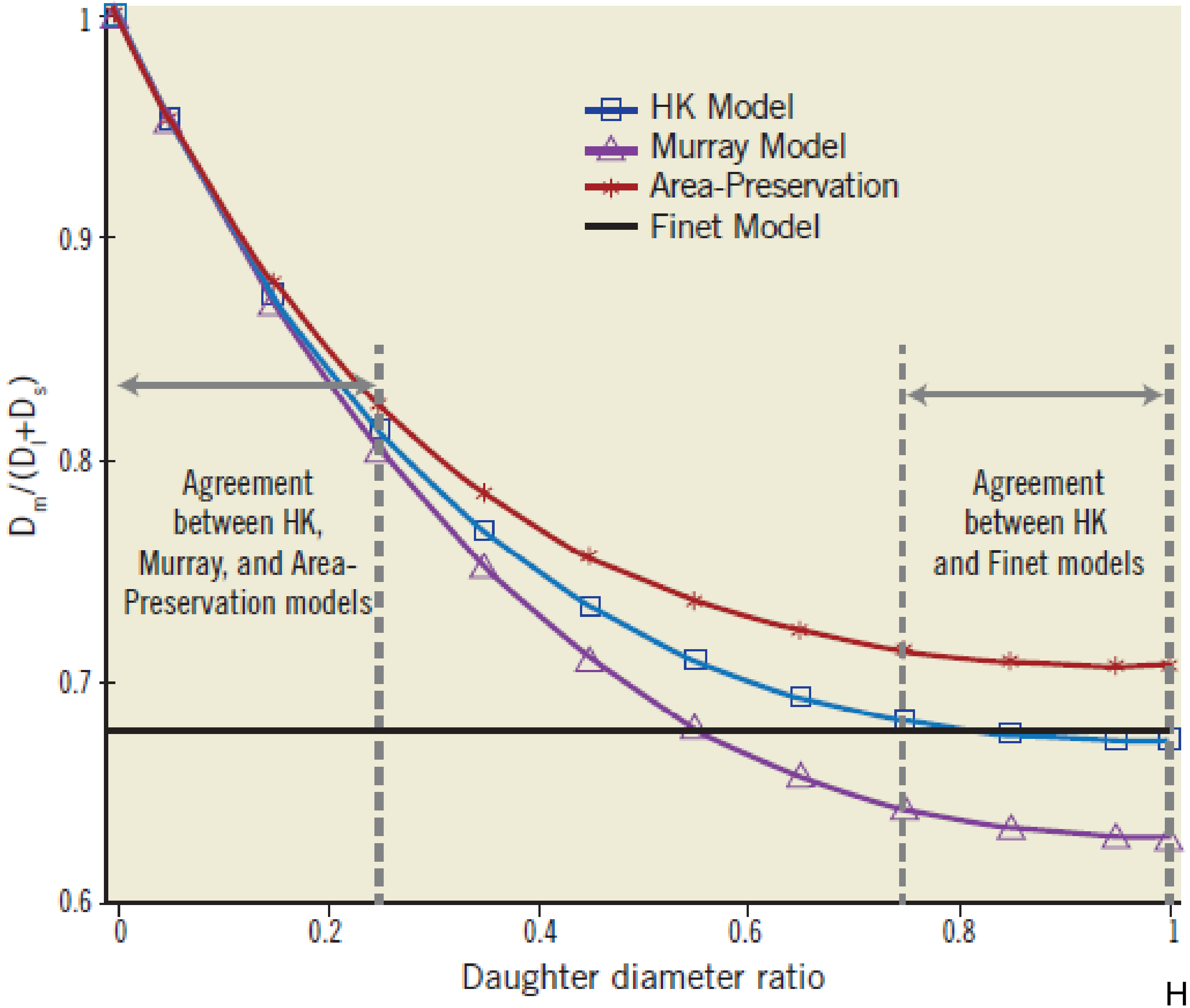
Vascular Branching Laws

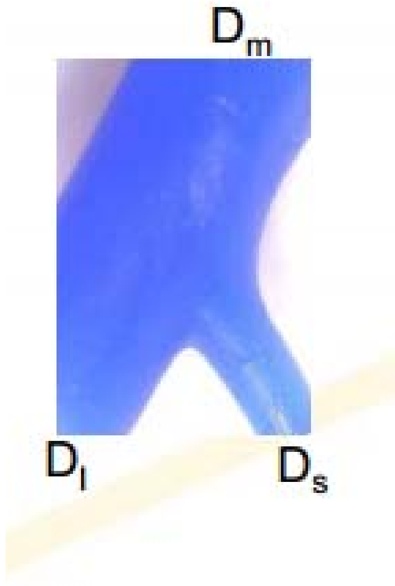
Bifurcation diameter models	Relationship	Physical mechanisms
HK	$D_m^{\frac{7}{3}} = D_l^{\frac{7}{3}} + D_s^{\frac{7}{3}}$	Minimum Energy
Finet	$D_m = 0.678 \times (D_l + D_s)$	"Fractal"-type relation
Murray	$D_m^3 = D_l^3 + D_s^3$	Minimum Energy & WSS ~ Constant
Area-preservation	$D_m^2 = D_l^2 + D_s^2$	Velocity ~ Constant
where D_m, D_l, and D_s are the diameters of mother, larger and smaller daughter vessels, respectively.		

Area-preservation and Finet models area empirical and do not have a physical basis.

Huo Y. EuroInterv, 2012, 7, 1310

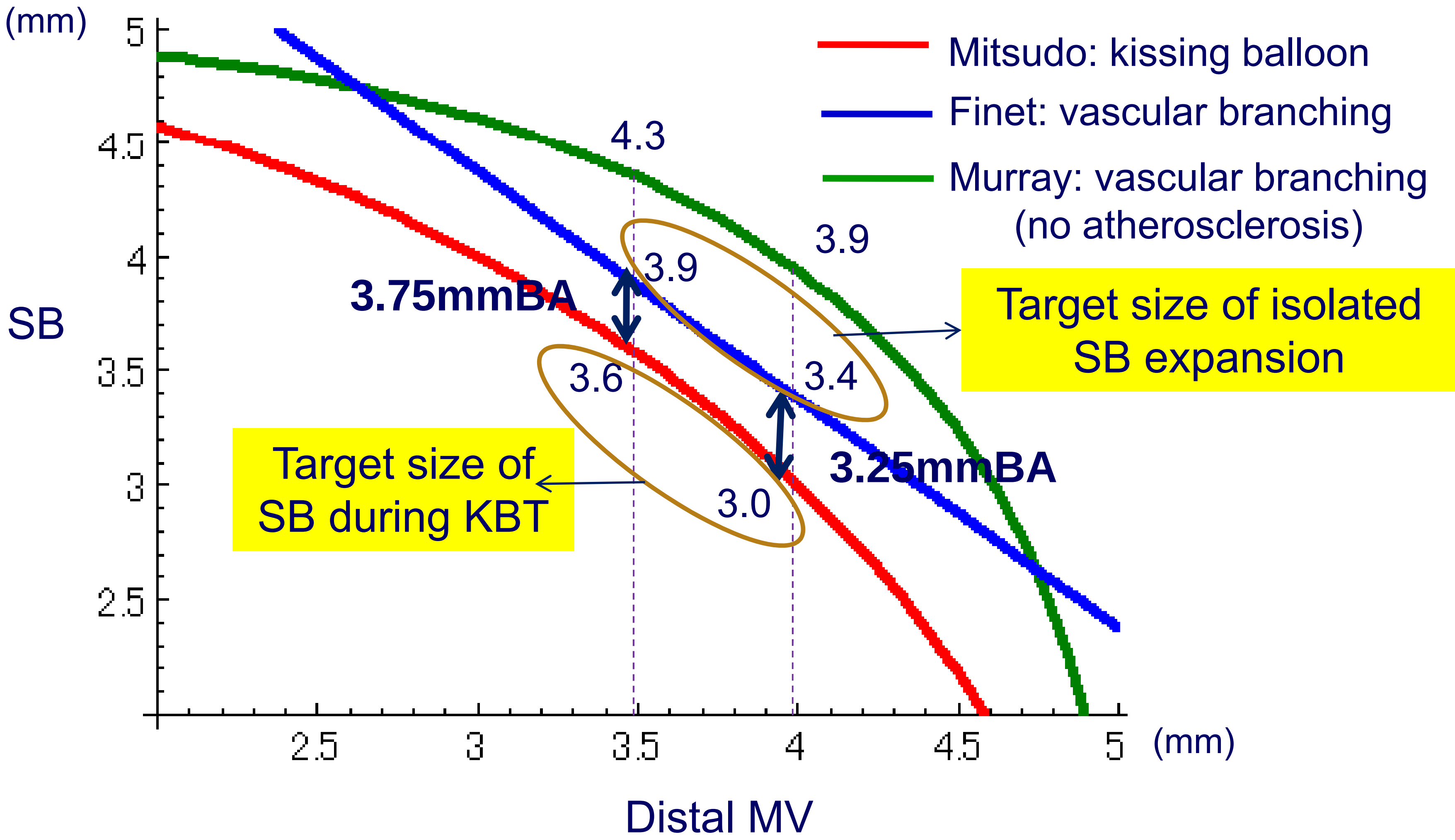
Comparison among branching-law models



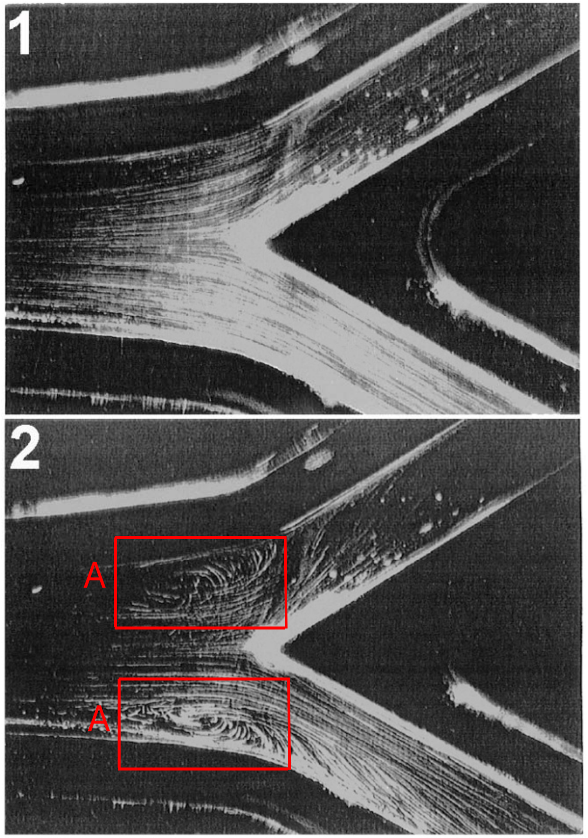


Huo Y. EuroInterv, 2012, 7, 1310

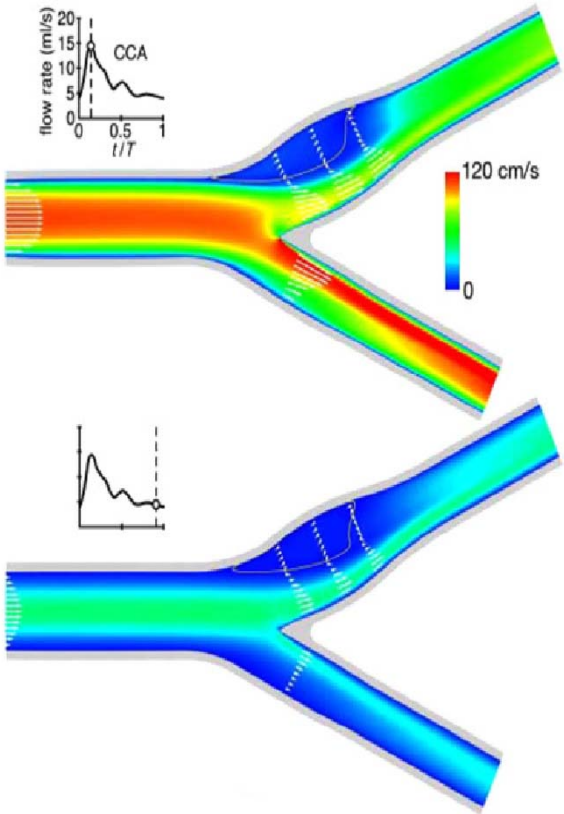
How to decide balloon size proximal MV 5mm



Blood flow at bifurcation site



Qualitative experimental visualization
(Fabregues, 1998, *J. of Biomechanics* 31)



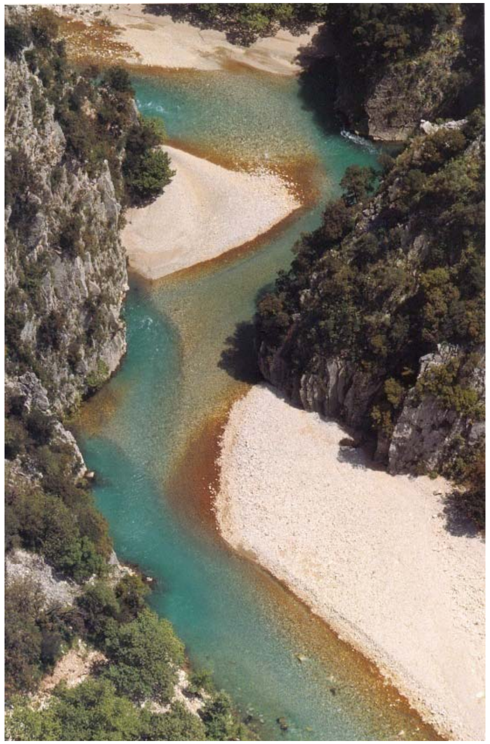
CFD results (Tada, 2005, *Ann. of Biomed. Eng.*33)

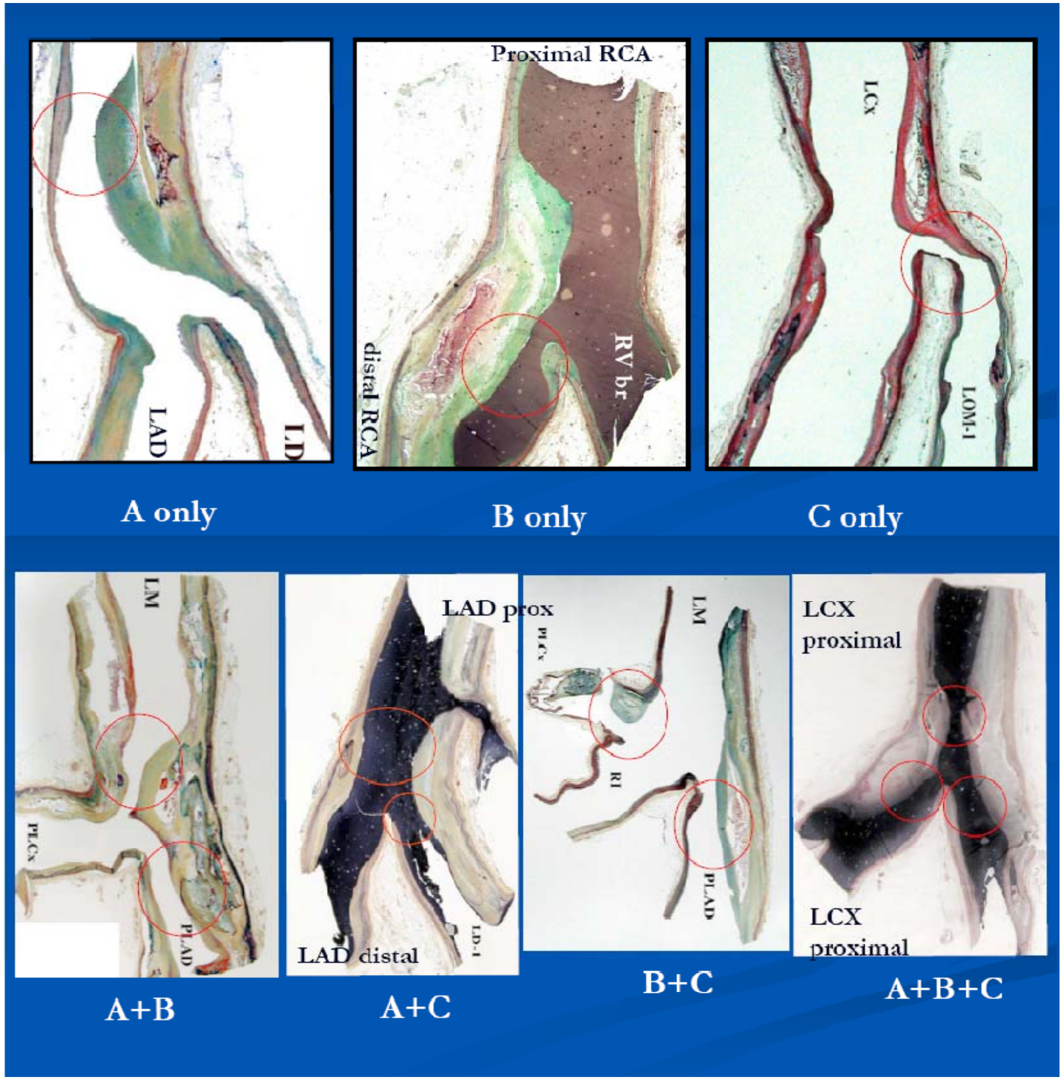
Large recirculations (A) are observed at the bifurcation apex or in the daughter branches

Types of Involvement of Coronary Bifurcations by Atherosclerosis

Atherosclerosis occur predominantly close to bifurcation

Carinal involvement by atherosclerosis is extremely unusual.

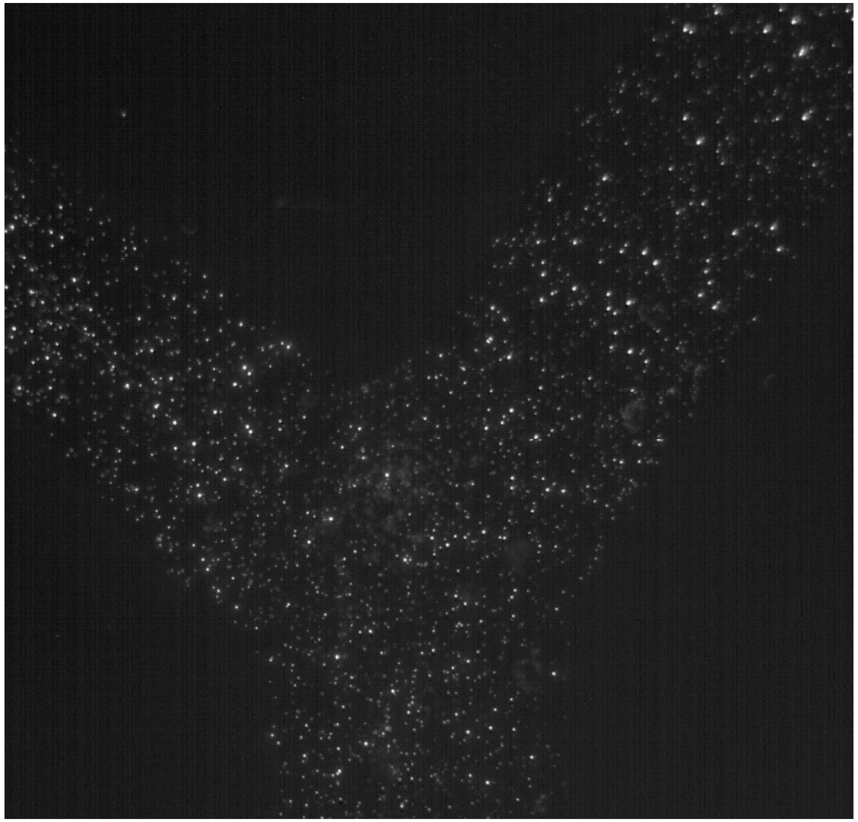




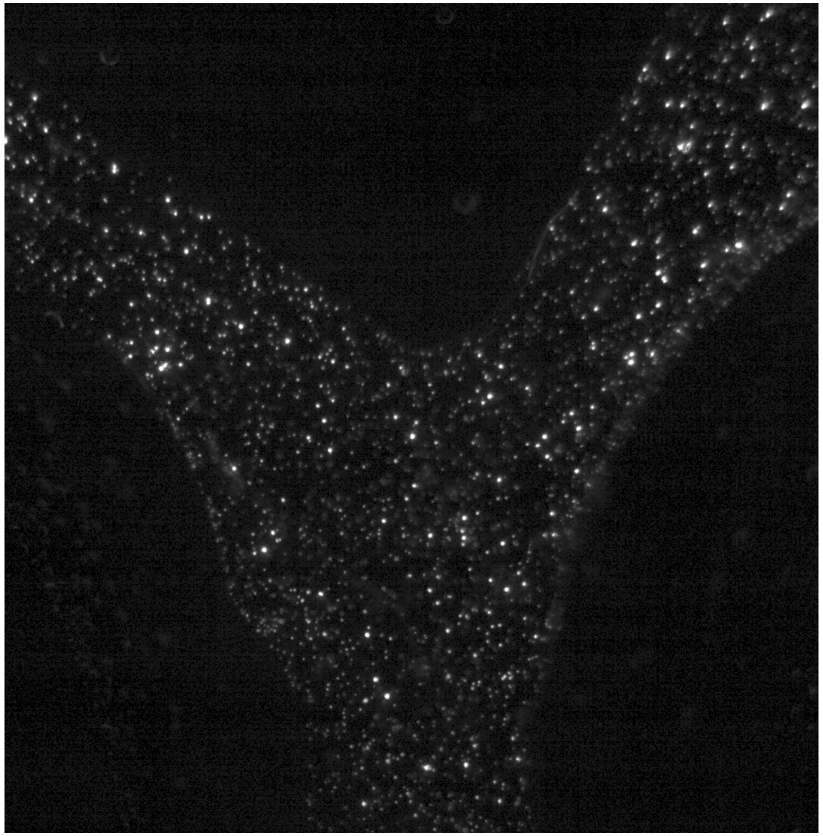
Renu Virmani

High Speed Flow Visualization during Peak Phase [Low Magnification]

Normal model

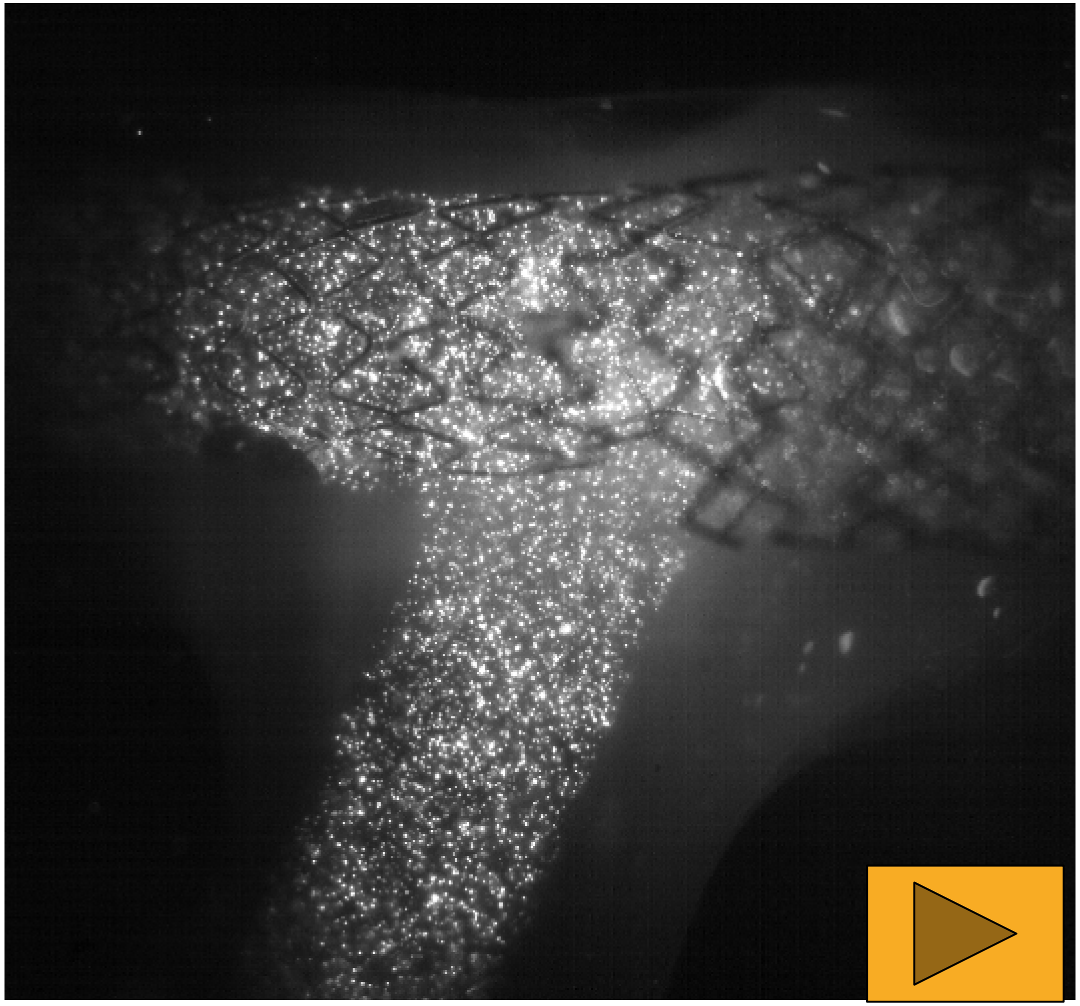


Stenosis model



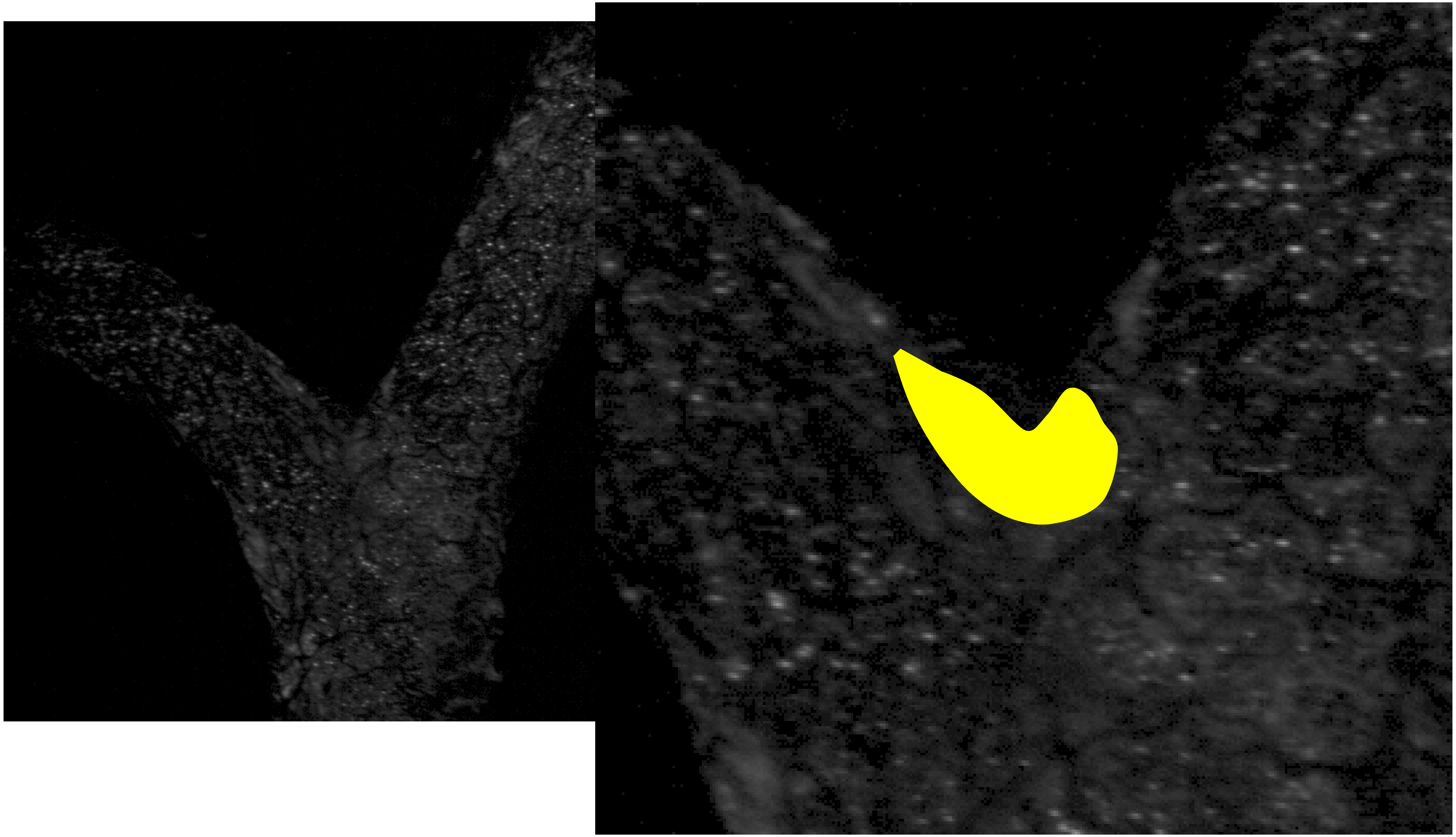
Courtesy of Iwasaki K (Waseda Univ)

Visualization of coronary flow at the bifurcation



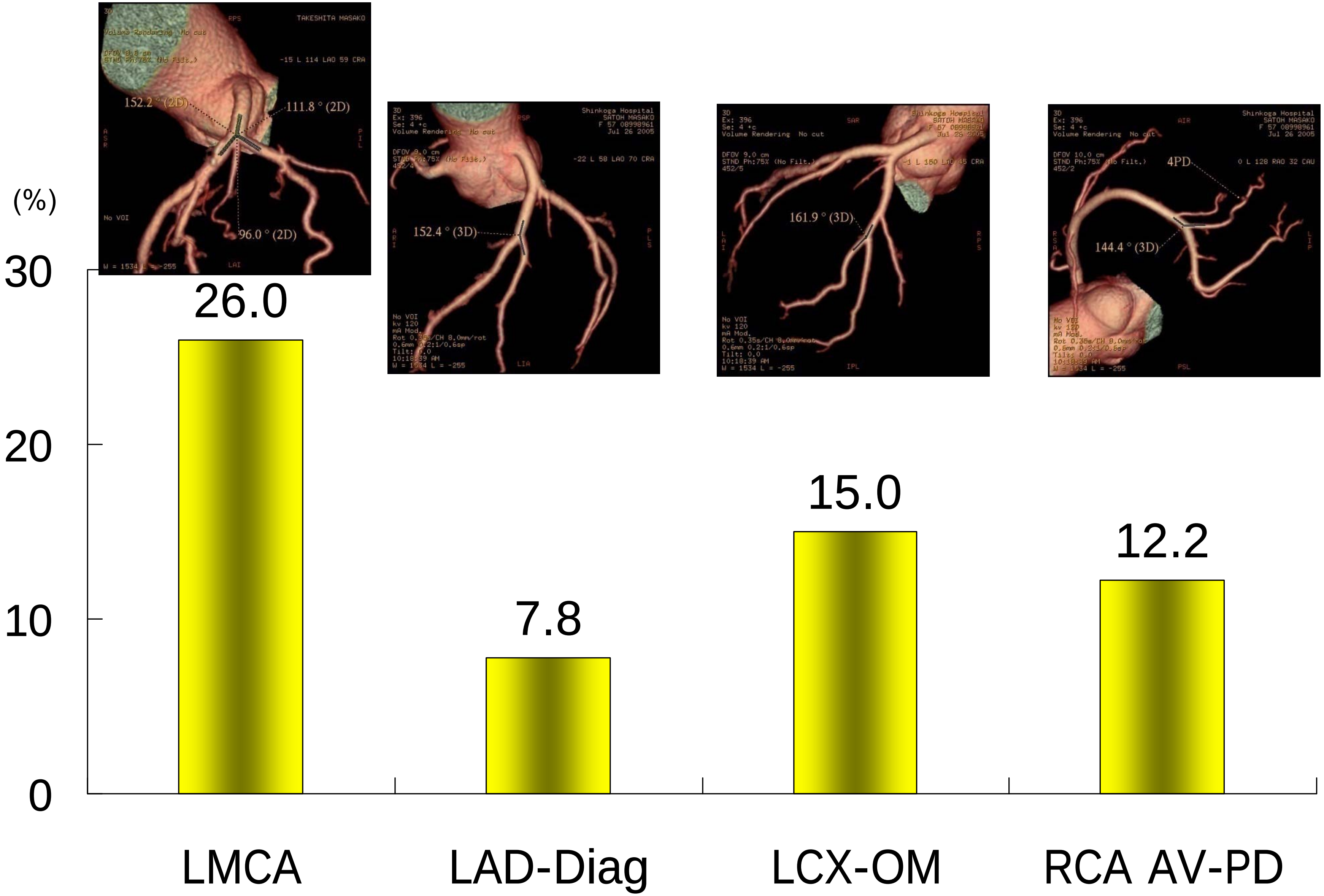
Iwasaki K (Waseda Univ) & Murasato Y

Culotte stenting



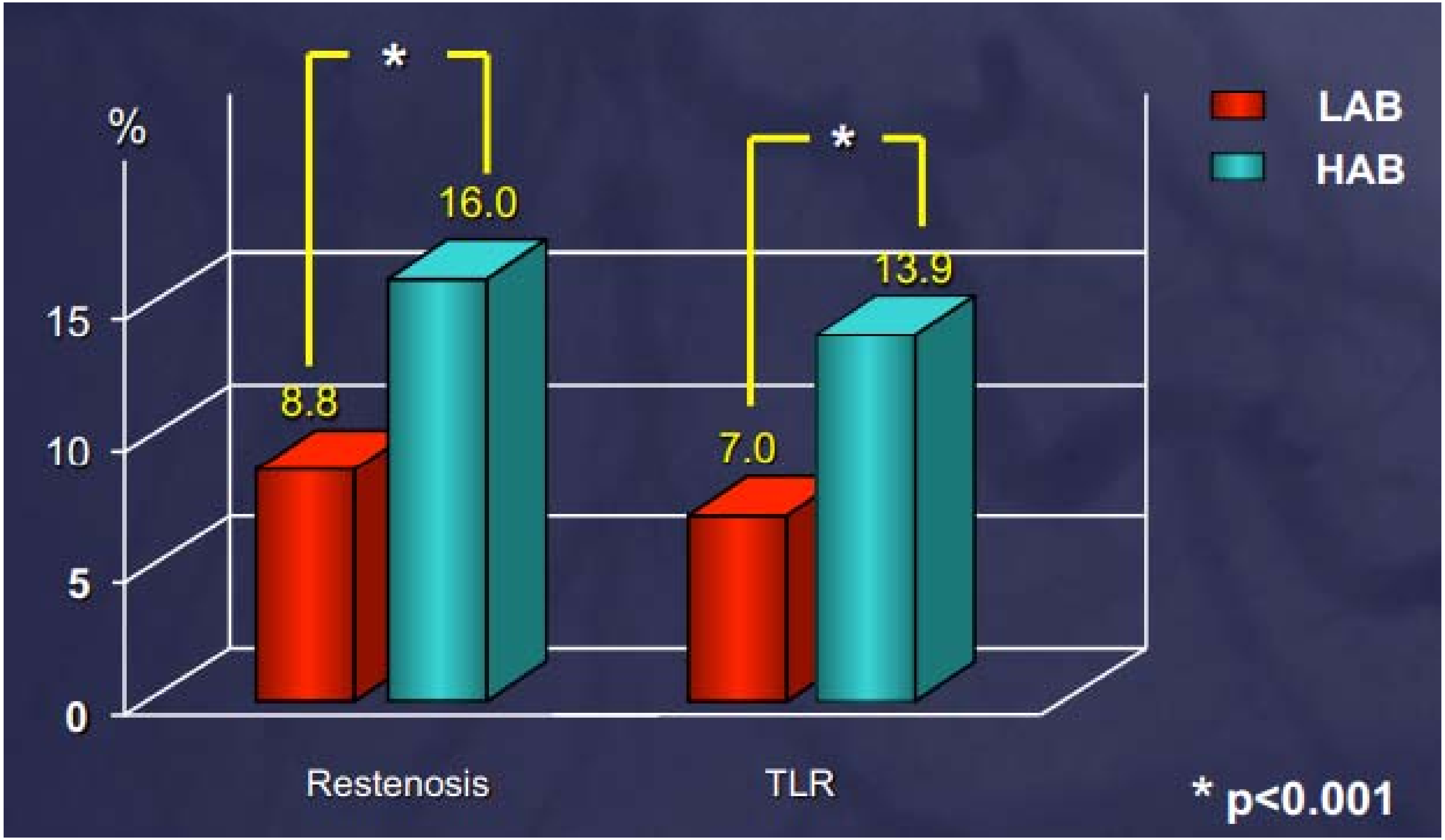
Murasato Y, Iwasaki K et al. J Interv Cardiol, 2010

Distribution of high-bifurcated angle (> 80°)



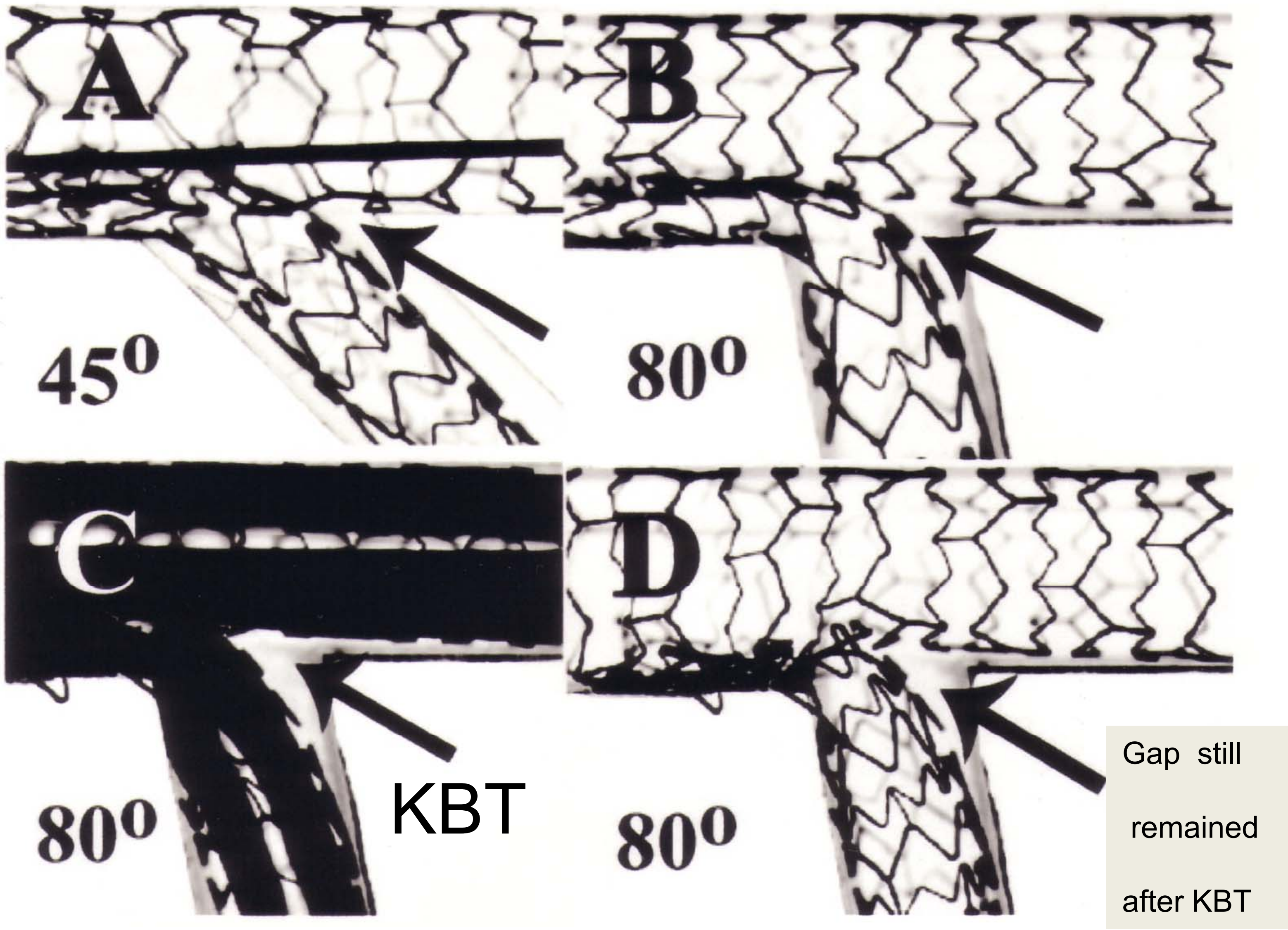
Kawasaki T. Catheter Cardiovasc Interv. 2009;73:653

Comparison between low-angle bifurcation (LAB) and high-angle bifurcation (HAB)



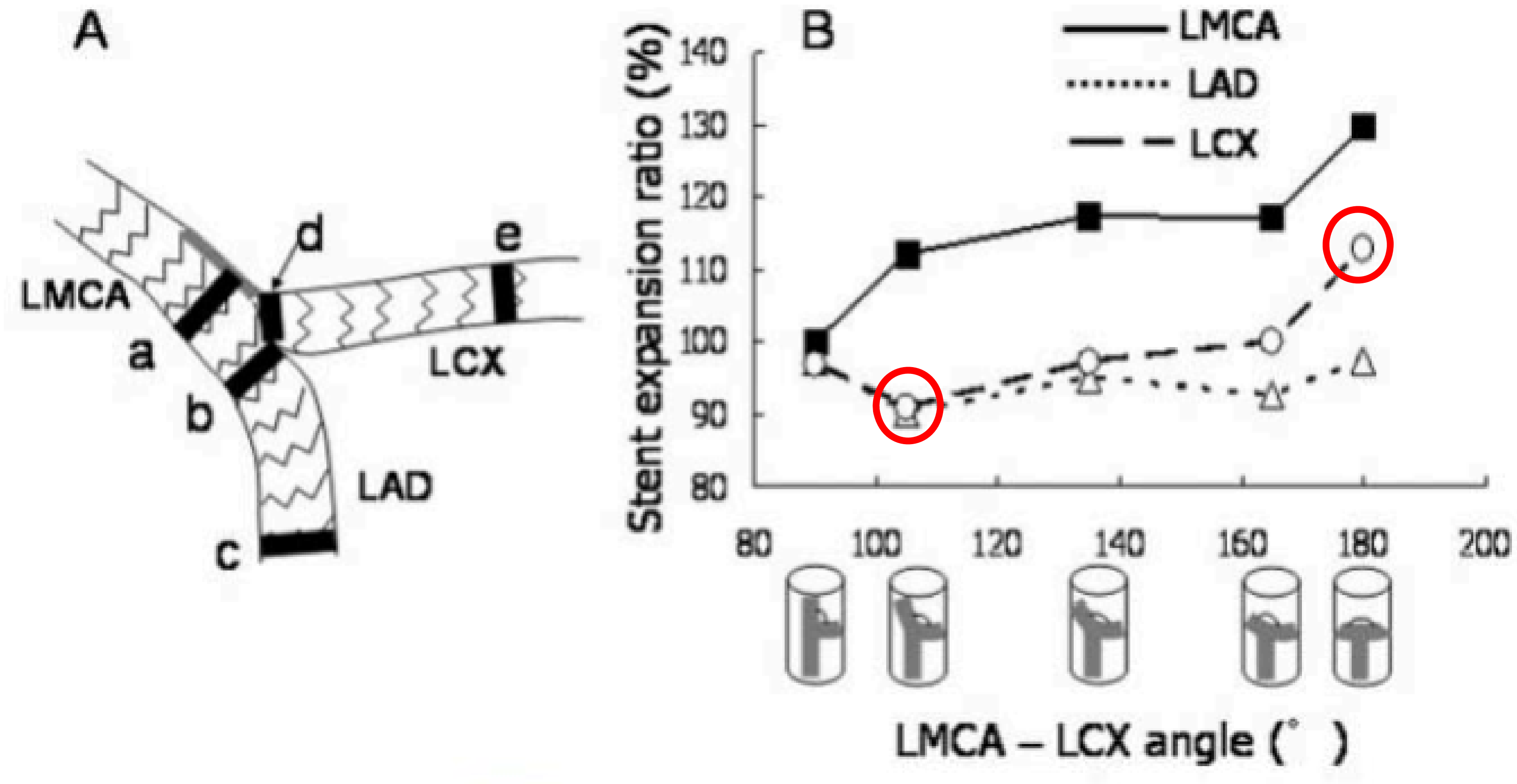
Nakamura S. Asian Multicenter Left Main Registry, EBC 2010

Crush stenting



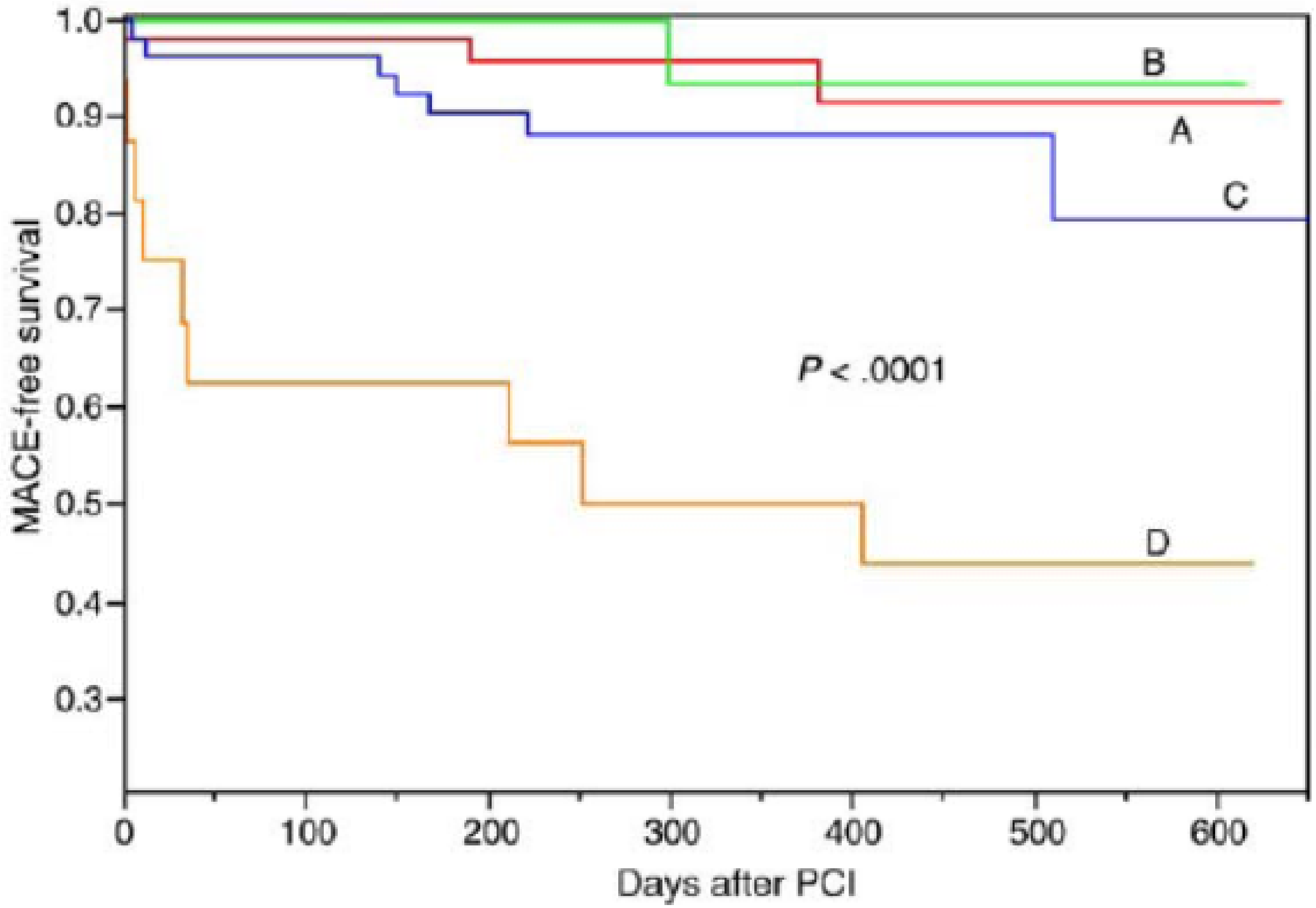
Ormiston JA et al. Catheter Cardiovasc Interv. 2004; 63: 332-6

Crush stenting: LCX ostium under-expanded in narrow LMCA-LCX angle



Murasato Y. Cathet Cardiovasc Interv. 69(2):248-256, 2007

Crush stenting: MACE



A: BA<50°, KBP
B: BA<50°, no KBP
C: BA≥50°, KBP
D:BA≥50°, no KBP

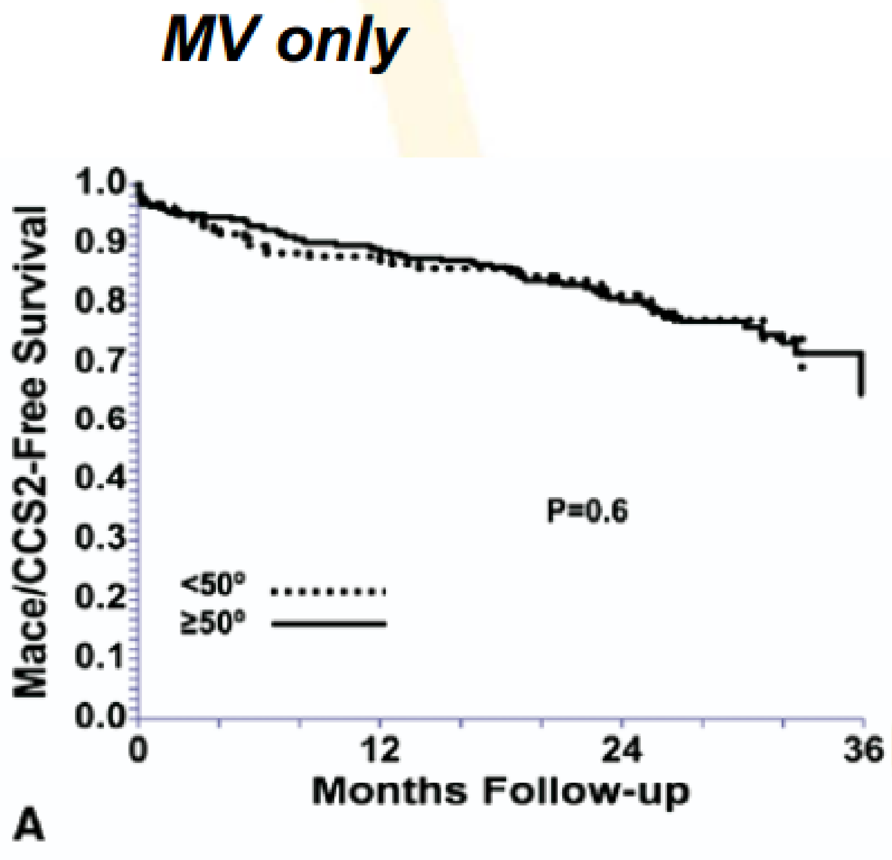
Dzavik et al. Am Heart J 2006;152:762-9.

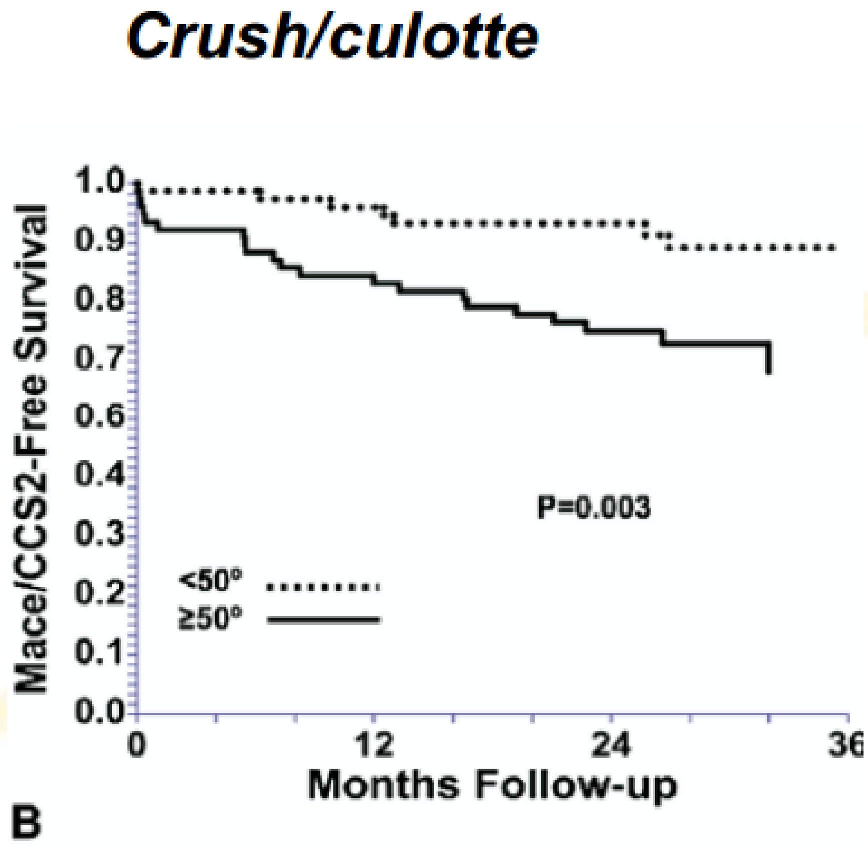
Culotte stenting: Impact of bifurcation angle on MACE

Variable	Odds ratio (95% CI)	*P*-value
Age increase by 10 years	2.38 (1.21–4.96)	0.01
Diabetes	3.43 (0.71–16.60)	0.13
Male sex	0.62 (0.15–2.53)	0.51
Medina classification	0.42 (0.13–1.32)	0.14
Restenotic lesion	0.52 (0.12–2.24)	0.38
Bifurcation angle increase by 10°	1.53 (1.04–2.23)	0.03
Calcified lesion	0.53 (0.12–2.24)	0.39
Proximal main vessel		
Reference vessel diameter decrease by 1 mm	4.55 (0.17–123.36)	0.37
Baseline stenosis increase by 10%	0.91 (0.67–1.23)	0.54
Distal main vessel		
Reference vessel diameter decrease by 1 mm	0.10 (0.00–3.17)	0.19
Baseline stenosis increase by 10%	1.47 (1.03–2.09)	0.03
Side branch vessel		
Reference vessel diameter decrease by 1 mm	31.83 (1.71–592.77)	0.02
Baseline stenosis increase by 10%	0.97 (0.82–1.15)	0.75
Kissing balloon post-dilatation	0.37 (0.13–1.10)	0.07

Adriaenssens et al. Eur Heart J 2008, 29: 2868

Cross-over stenting vs. Crush/Culotte



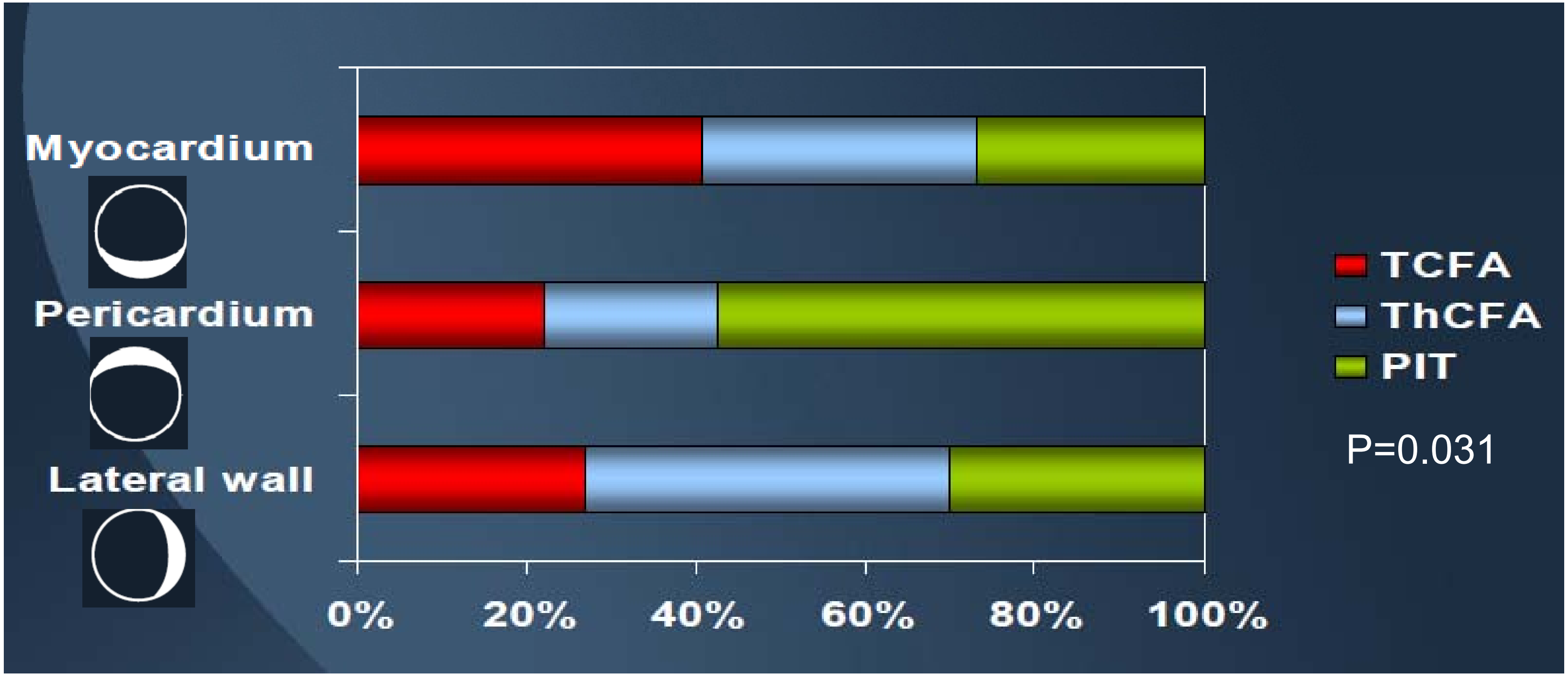


ST: all in wide BA : 8.6 vs 0%

Collins et al. Am J Cardiol 2008; 68:249-253.

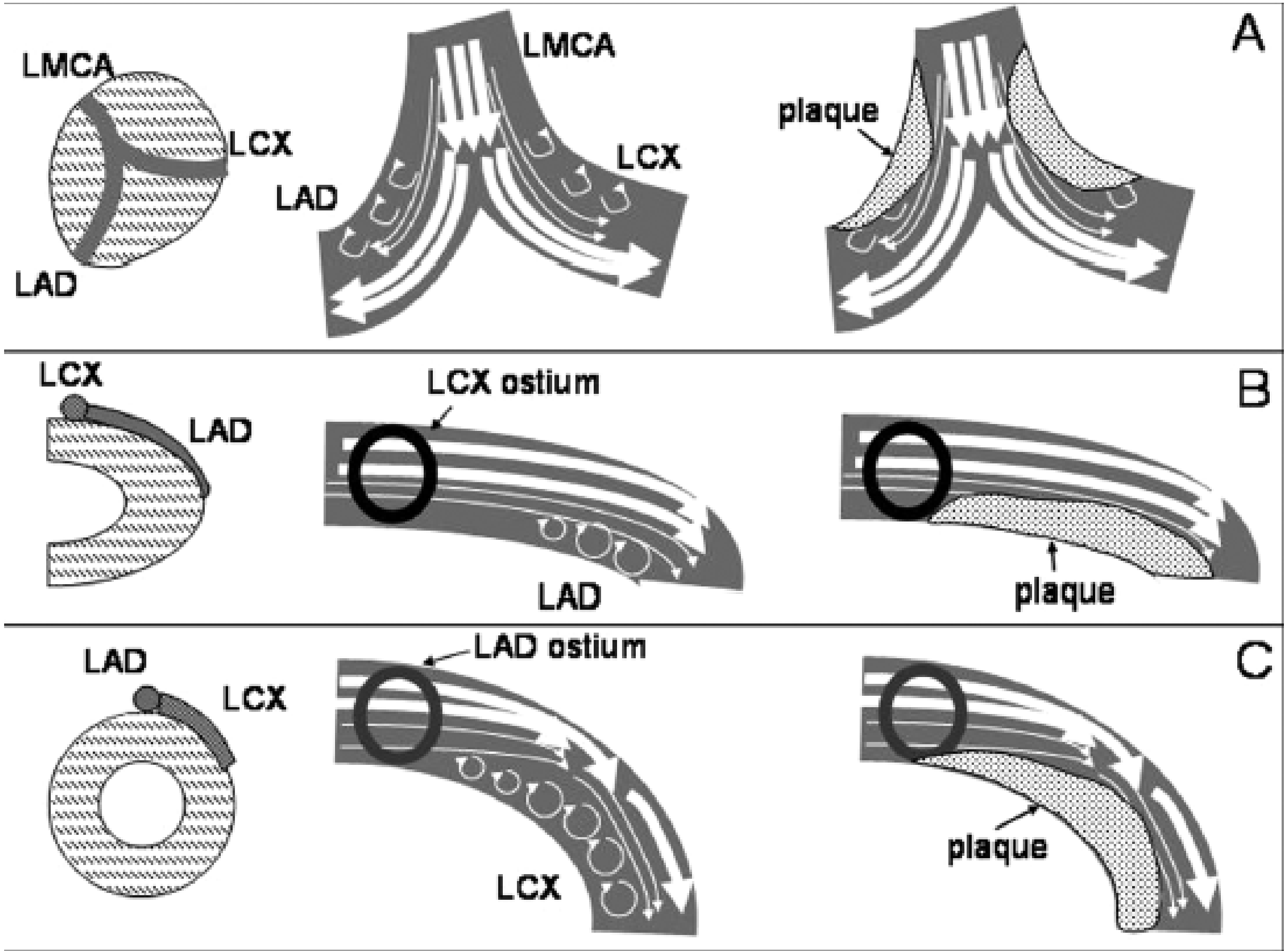
Plaque Distribution in Left Main Bifurcation: IVUS Examination

Maehara A, TCT 2011



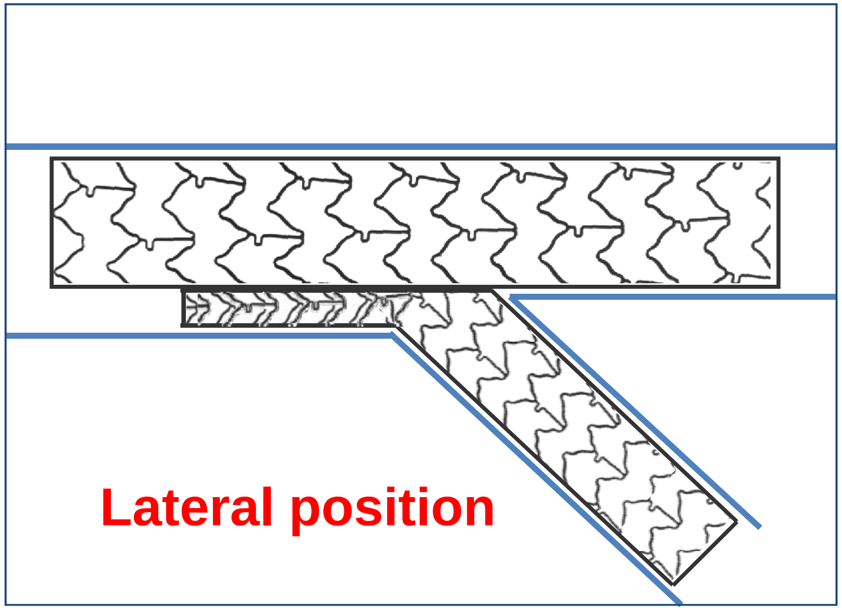
- Fibroatheroma was mainly observed in myocardium and lateral wall.
- Pathological intimal thickening was dominant in pericardium.

Three-Dimensional Modeling of Double-Stent Techniques at the Left Main Coronary Artery Bifurcation Using Micro-Focus X-Ray Computed Tomography

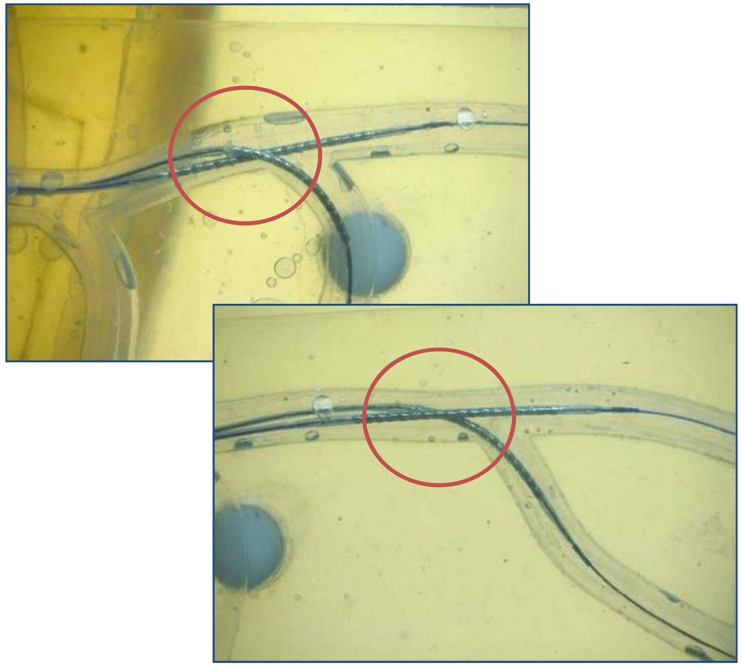


Murasato Y, Catheter Cardiovasc Interv. 2007;70:211-20.

Effect of 3-D structure on stent overlapping



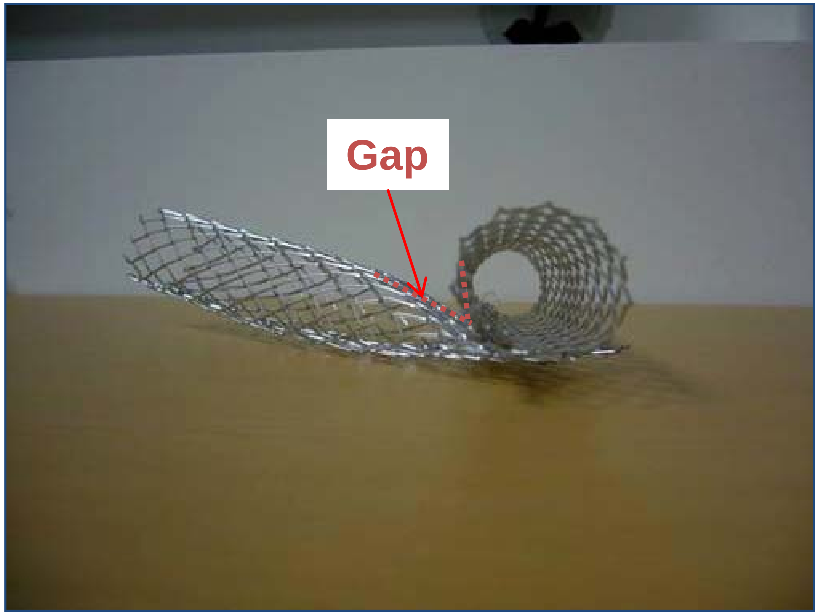
Ideal Image



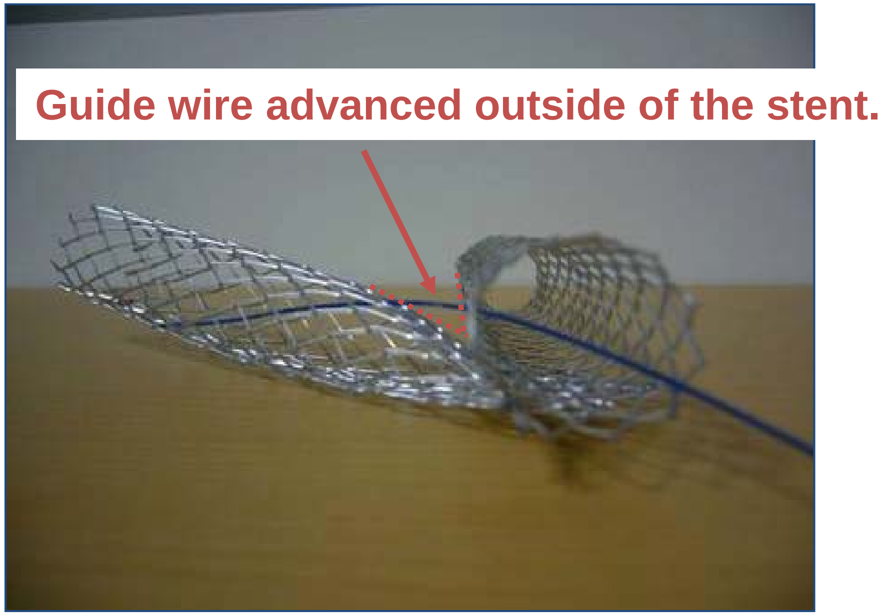
In the actual situation…

Stent overlap or crossing is observed. Two stents are not positioned laterally.

Issues of Crush stenting: Stent overlapping

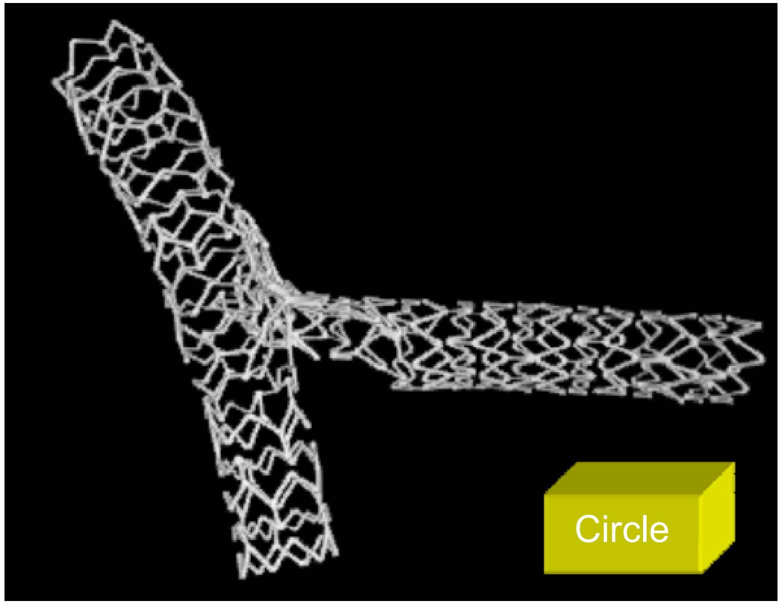


Stent overlapping produces some gap formation at the opposite side of the overlapping.

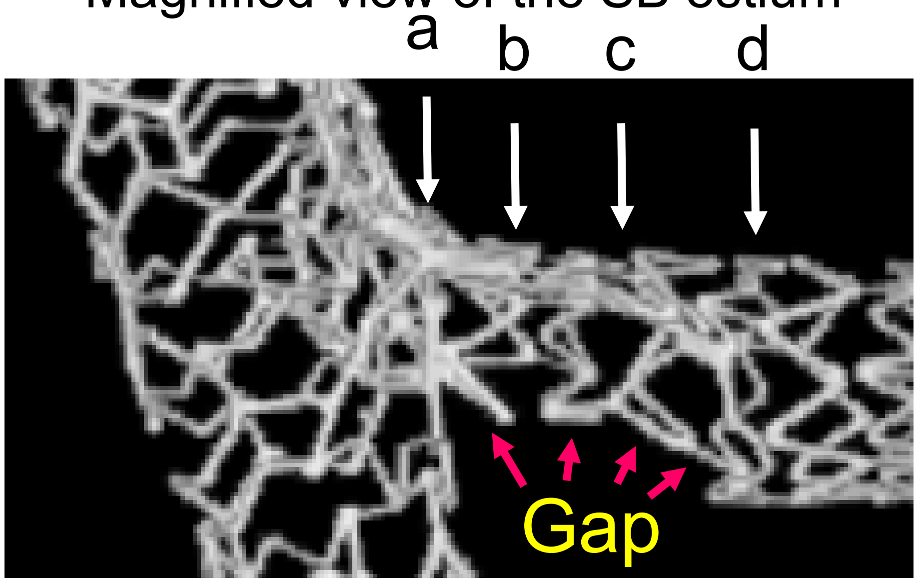


When the GW is advanced outside of the SB stent, the gap would be increased.

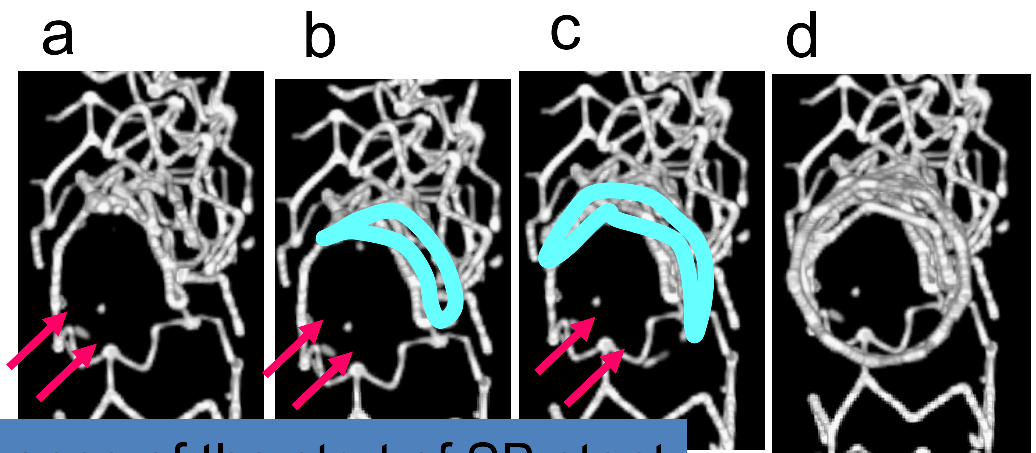
Crush stenting
Worse case



Magnified view of the SB ostium



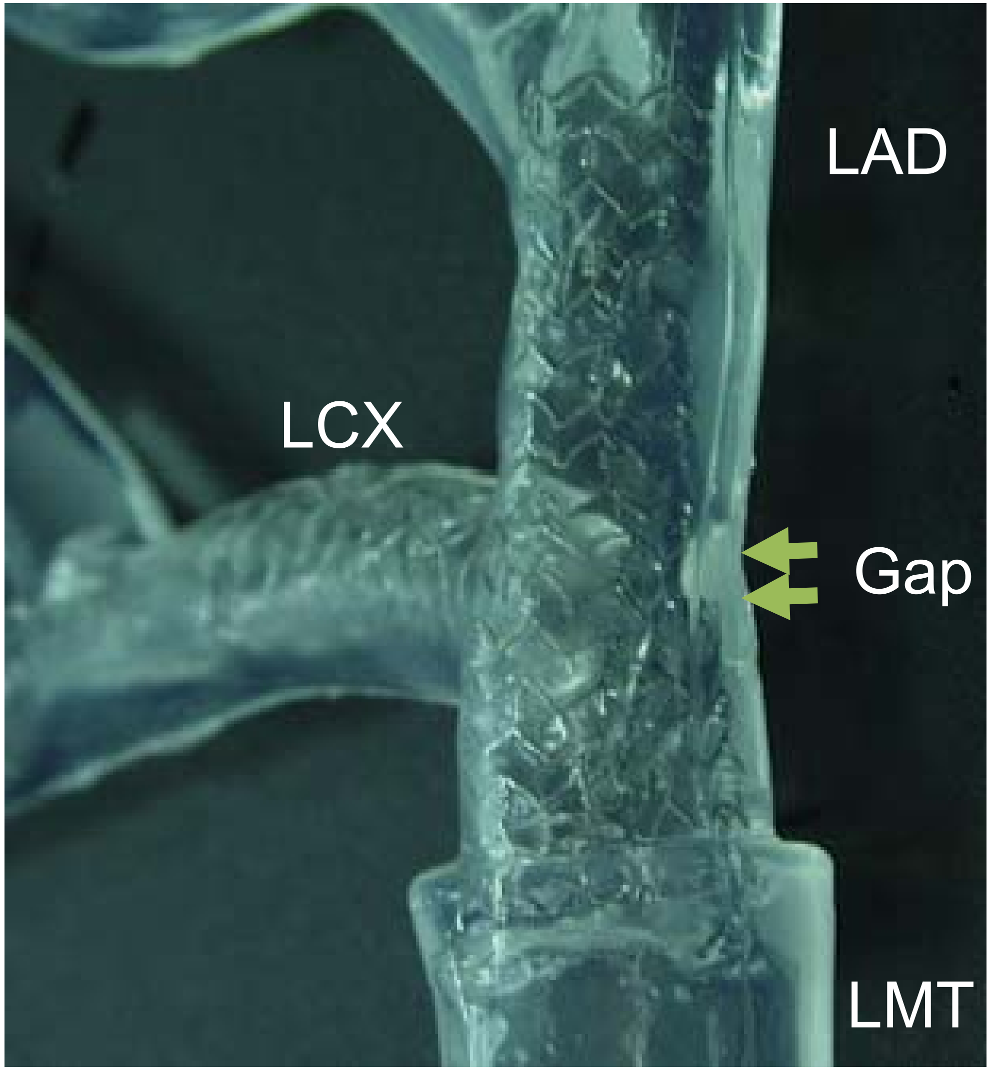
Cross sectional view

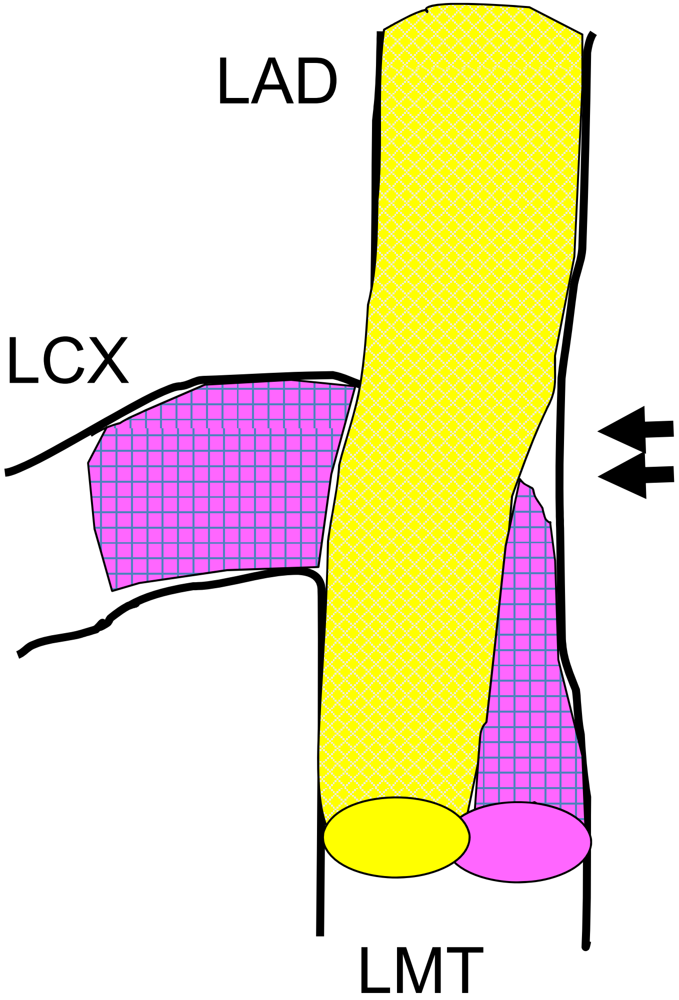


Absence of the strut of SB stent

Murasato Y, J Interv Cardiol, 22:135,2009

Stent overlapping created a gap beneath the overlapped portion of the stent.

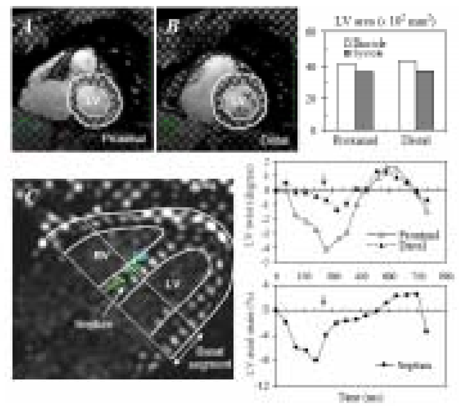




Murasato Y. J Invasive Cardiol. 2006, 18 :E279

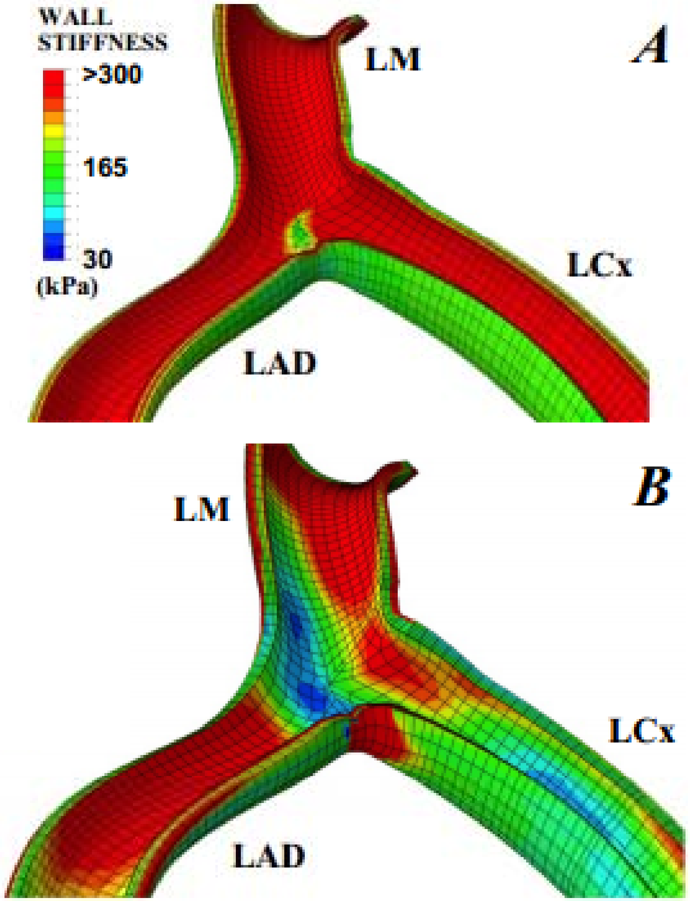
Endothelial shear stress and wall stiffness

Influence of heart motion



Dynamic MRI tagging technique

Torsion – Radial strain – Axial strain



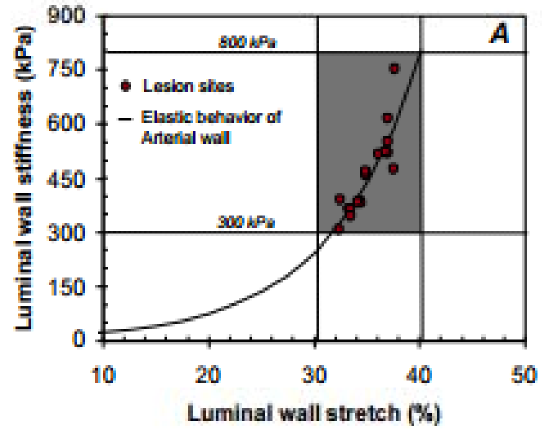
Without LV motion

Quasi-UNIFORM distributions

With LV motion

HETEROGENEOUS distributions

Correlation between plaque location and wall stiffness



Ohayon et al. Am J Physiol Heart Circ Physiol 2011

Take home messages

- Revascularization should be performed according to the vascular branching law.
- Rheological assessment or consideration will be more necessary to complete ideal revascularization.
- High bifurcation angle leads to frequent restenosis and TLR, especially in crush and culotte stenting.
- 3-dimentional structure affects rheological disturbance which results in vulnerable atherosclerosis.
- LV wall motion leads to various strain strength which results in heterogeneous vessel wall stiffness in the bifurcation.

Thank you for your attention!