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Impact of bifurcation angle and other anatomical characteristics on blood flow – A computational study of non-stented and stented coronary arteries

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ABSTRACT

The hemodynamic influence of vessel shape such as bifurcation angle is not fully understood with clinical and quantitative observations being equivocal. The aim of this study is to use computational modeling to study the hemodynamic effect of shape characteristics, in particular bifurcation angle (BA), for non-stented and stented coronary arteries.

Nine bifurcations with angles of 40°, 60° and 80°, representative of ± 1 SD of 101 asymptomatic computed tomography angiogram cases (average age 54 ± 8 years; 57 females), were generated for (1) a non-stented idealized, (2) stented idealized, and (3) non-stented patient-specific geometry. Only the bifurcation angle was changed while the geometries were constant to eliminate flow effects induced by other vessel shape characteristics. The commercially available Biomatrix stent was used as a template and virtually inserted into each branch, simulating the T-stenting technique. Three patient-specific geometries with additional shape variation and ± 2 SD BA variation (33°, 42° and 117°) were also computed. Computational fluid dynamics (CFD) analysis was performed for all 12 geometries to simulate physiological conditions, enabling the quantification of the hemodynamic stress distributions, including a threshold analysis of adversely low and high wall shear stress (WSS), low time-averaged WSS (TAWSS), high spatial WSS gradient (WSSG) and high Oscillatory Shear Index (OSI) area.

The bifurcation angle had a minor impact on the areas of adverse hemodynamics in the idealized non-stented geometries, which fully disappeared once stented and was not apparent for patient geometries. High WSS regions were located close to the carina around peak-flow, and WSSG increased significantly after stenting for the idealized bifurcations. Additional shape variations affected the hemodynamic profiles, suggesting that BA alone has little effect on a patient's hemodynamic profile. Incoming flow angle, diameter and tortuosity appear to have stronger effects.

This suggests that other bifurcation shape characteristics and stent placement/strategy may be more important than bifurcation angle in atherosclerotic disease development, progression, and stent outcome.

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1. Introduction

Coronary arterial bifurcations are prone to atherosclerosis development, and 20–30% of all percutaneous coronary interventions (PCI) involve bifurcations. They are also vulnerable to stent thrombosis and restenosis, with a 3–10 fold higher risk compared to non-bifurcation lesions (Lakovou et al., 2005).

The bifurcation angle (BA), the angle between the daughter vessels after branching (angle B using European Bifurcation Club nomenclature), has been suggested as risk predictor in clinical

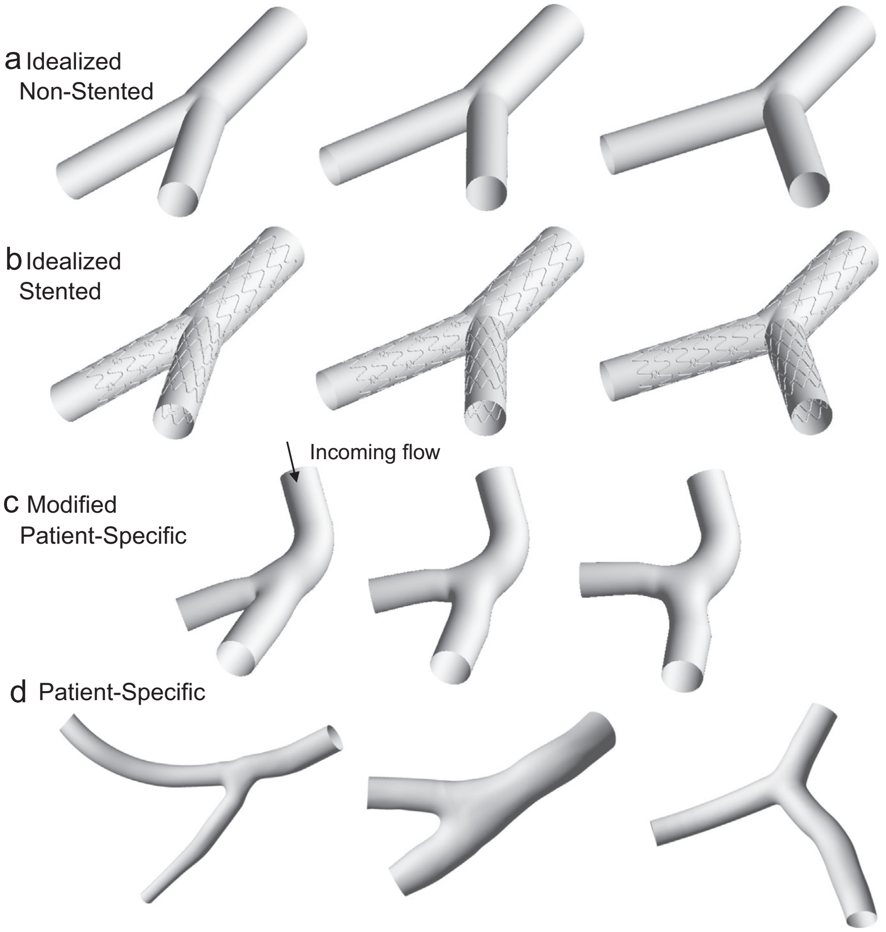

Fig. 1. Bifurcation geometries investigated: (a) idealized non-stented, (b) idealized stented, (c) modified patient-specific geometries, all with 40°, 60° and 80° bifurcation angle (left to right), and (d) patient-specific geometries with 33°, 42° and 117° bifurcation angles (left to right).

Table 1
Shape measurements for all patient-specific geometries studied.

		Patient modified	P1	P2	P3
Bifurcation angle LM–LCX (deg)	α_{LM-LCX}	109.80	163.16	142.24	102.02
Bifurcation angle LM–LAD (deg)	α_{LM-LAD}	158.70	163.11	171.62	139.84
Bifurcation angle LAD–LCX (deg)	$\alpha_{LAD-LCX}$	40/60/80	32.85	41.73	116.76
Incoming angle (deg)	α_{In}	34.25	8.14	6.65	−0.61
Diameter LM (mm)	d_{LM}	2.18	3.59	3.71	4.78
Diameter LAD (mm)	d_{LAD}	3.11	2.53	3.41	4.41
Diameter LCX (mm)	d_{LCX}	2.64	3.08	2.81	4.80
Tortuosity LM (dimensionless)	T_{LM}	1.59	1.01	1.08	1.03
Tortuosity LAD (dimensionless)	T_{LAD}	1.01	1.03	1.05	0.96
Tortuosity LCX (dimensionless)	T_{LCX}	1.07	1.02	1.01	1.04
Eccentricity	Ecc	1.65	1.02	1.50	1.06
Area ratio	AR	0.38	0.64	0.60	0.52
Principal component analysis #1	PCA1	−1.12	−0.43	−0.03	2.22
Principal component analysis #2	PCA2	−0.09	−0.94	−0.62	1.47

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