

Estimating Left Main Bifurcation Geometry: Are Geometric Models Reliable in Diseased Arteries?

Stefano Garzon,^{1,2} Lucas Pilotto,¹ José Mariani,¹ Felipe Bezerra,¹  Guy Prado,^{1,2}  Willterson Bandeira,¹ Breno Almeida,¹ Pedro Lemos¹

Hospital Israelita Albert Einstein,¹ São Paulo, SP – Brazil

Department of Clinical and Molecular Medicine - Sapienza University,² Roma – Italy

Abstract

Background: Accurate characterization of coronary bifurcation geometry is essential for planning and optimizing percutaneous coronary interventions. Although several geometric models have been proposed to predict coronary bifurcation dimensions, their performance in diseased vessels remains insufficiently explored.

Objective: To assess the accuracy and precision of three geometric prediction models (Murray, Finet, and Huo–Kassab) in estimating left main coronary artery (LMCA) bifurcation diameters, using quantitative coronary angiography (QCA) and intravascular ultrasound (IVUS) as reference standards.

Methods: This retrospective, single-center study included 13 patients undergoing IVUS evaluation of the LMCA, left anterior descending artery, and left circumflex artery. Bifurcation diameters predicted by each geometric model were compared with measurements obtained by QCA and IVUS. Accuracy, precision, and model ratios were calculated for each comparison. Agreement between predicted and measured values was further assessed using Bland–Altman analysis.

Results: When compared with QCA, the Murray and Huo–Kassab models demonstrated higher accuracy (0.06 mm and –0.03 mm, respectively) and similar precision (0.95 mm for both) than the Finet model (accuracy –0.35 mm, precision 0.96 mm). In comparisons with IVUS, the Murray model showed the best performance, with an accuracy of –0.49 mm and a precision of 0.84 mm. Bland–Altman analysis indicated superior agreement for the Murray model, particularly when IVUS was used as the reference standard.

Conclusions: In this population of patients with moderately diseased LMCA bifurcations, the Murray and Huo–Kassab models provided more accurate geometric predictions than the Finet model. Overall, the Murray model demonstrated the best performance, especially in IVUS-based assessments.

Keywords: Coronary Vessels; Coronary Artery Disease; Coronary Angiography.

Introduction

The geometric configuration of coronary artery bifurcations plays a central role in coronary physiology and the progression of atherosclerotic disease. The left main coronary artery (LMCA) bifurcation is particularly relevant, not only because of its critical contribution to myocardial perfusion of the left ventricle, but also due to its susceptibility to plaque accumulation and flow-related disturbances.¹

Several geometric models have been proposed to describe the relationship among vessel diameters at

coronary bifurcations, including those developed by Murray, Finet, and Huo–Kassab.^{2–4} These models differ in their theoretical foundations. The Murray and Huo–Kassab models are based on principles of fluid dynamics and energy optimization, whereas the Finet model relies on a linear relationship derived from the fractal geometry of epicardial coronary arteries.

Accurate characterization of bifurcation geometry is essential for both diagnostic evaluation and procedural planning, particularly in percutaneous coronary interventions involving the LMCA. In this context, intravascular ultrasound (IVUS) provides more precise quantification of lumen and vessel dimensions than conventional angiographic techniques such as quantitative coronary angiography (QCA).^{5–8}

Despite the advantages of IVUS imaging, its availability is not universal. As a result, angiography-based geometric models often represent the only practical tool available to interventional cardiologists for estimating vessel dimensions. Although these models have been extensively

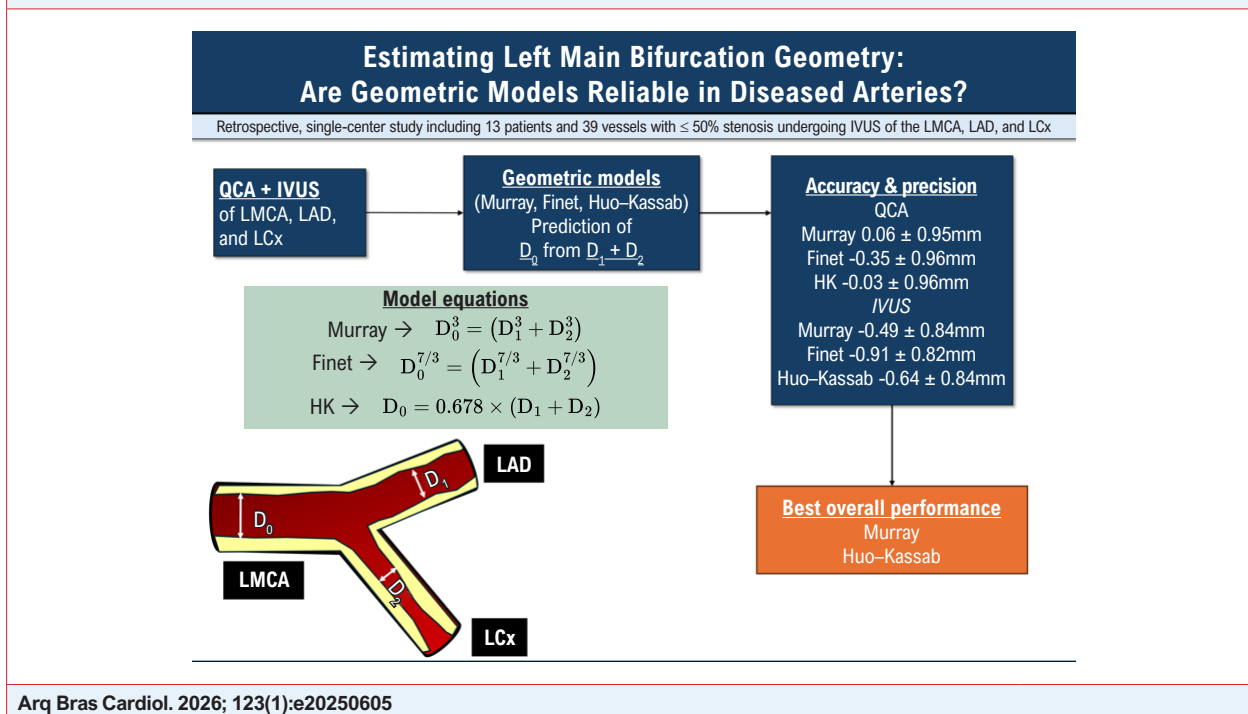
Mailing Address: Stefano Garzon •

Hospital Israelita Albert Einstein - Cardiologia Intervencionista - Av. Albert Einstein, 627. Postal Code 05652-900, São Paulo, SP – Brazil
E-mail: stefano.lemos@einstein.br

Manuscript received September 01, 2025, revised manuscript October 15, 2025, accepted November 12, 2025

Editor responsible for the review: Henrique Ribeiro

DOI: <https://doi.org/10.36660/abc.20250605>

Central Illustration: Estimating Left Main Bifurcation Geometry: Are Geometric Models Reliable in Diseased Arteries?ABC Cardiol
Arquivos Brasileiros de Cardiologia

IVUS: intravascular ultrasound; LAD: left anterior descending artery; LCx: left circumflex artery; LMCA: left main coronary artery; QCA: quantitative coronary angiography.

studied, including comparisons among them, their accuracy in diseased vessels, which directly affects their applicability in real-world clinical practice, remains incompletely defined.⁹⁻¹¹

This study aimed to assess the accuracy and precision of the Murray, Finet, and Huo-Kassab models in estimating LMCA bifurcation geometry using both angiography and IVUS in atherosclerotic LMCA bifurcations.

Methods

Study design

This retrospective, single-center study was designed to compare three coronary bifurcation geometric prediction models with QCA and IVUS measurements of LMCA bifurcation. The study protocol was approved by the local ethics committee, and written informed consent was obtained from all participants.

Patient selection

The institutional database was screened for patients who underwent IVUS evaluation of the left coronary artery. Patients were included according to predefined angiographic and IVUS criteria.

QCA inclusion criteria were i) the LMCA and the proximal segments of the left anterior descending artery (LAD) and

left circumflex artery (LCx), including the distal bifurcation, had to be clearly visible in at least one projection suitable for QCA analysis; ii) a proximal segment of at least 5 mm in length, defined as the segment proximal to the emergence of any side branches and without significant stenosis ($< 50\%$ by visual assessment), had to be available for analysis in all three vessels; and iii) selected segments must not have undergone any prior manipulation, including balloon dilatation or stent implantation.

IVUS inclusion criteria were i) IVUS evaluation of the LMCA, LAD, and LCx performed during the same procedure; ii) use of automated pullback in all vessels; iii) image quality adequate for analysis; and iv) availability of a proximal segment, prior to the emergence of side branches, that had not undergone any previous manipulation, including balloon dilatation or stent implantation.

Quantitative coronary angiography and intravascular ultrasound

QCA and IVUS were performed according to standard clinical practice. Angiographic images were acquired in multiple projections following intracoronary administration of nitrates. IVUS imaging was performed using either the OptiCross 40 MHz catheter (Boston Scientific, USA) or the Eagle Eye 20 MHz catheter (Philips Volcano, USA), with automated pullback after full heparinization and intracoronary nitrate administration.

Imaging analyses

QCA analyses were performed using QAngio XA version 7.3 (Medis Medical Imaging System BV, the Netherlands). Measurements were obtained using the dedicated bifurcation module, in accordance with recommendations from the European Bifurcation Club consensus document.¹² The T-shape model, which is the default and recommended option for most coronary bifurcations, was used in the majority of cases, whereas the Y-shape model was applied only when both distal branches had similar diameters. After bifurcation contour tracing, reference diameters were obtained for each vessel. For the LMCA, reference diameters were not measured within the distal bifurcation. For the LAD and LCx, reference diameters were confined to the proximal segments, prior to the emergence of side branches, as defined by the inclusion criteria.

IVUS analyses were performed using QIvus Research Edition version 3.1 (Medis Medical Imaging System BV, the Netherlands). Measurements were conducted according to previously published IVUS consensus documents.^{13,14} The region of interest (ROI) for each vessel was defined based on the inclusion criteria and corresponded to the same segment used for QCA reference diameter measurements (Figure 1). Semi-automated contour detection was used to delineate vessel and lumen borders, with manual adjustments when necessary. The software automatically generated the following parameters for each selected ROI: i) minimum, maximum, and mean lumen and vessel areas; ii) minimum, maximum, and mean plaque burden; iii) minimum, maximum, and mean lumen- and vessel area-derived diameters; and iv) minimum, maximum, and mean area and diameter stenosis.

QCA and IVUS analyses were performed by two experienced operators who were blinded to each other's results and to all clinical data. Repeat analyses were performed by one of the operators 30 days after the initial measurements.

Geometric prediction models

The Murray, Finet, and Huo–Kassab models were used to estimate coronary bifurcation geometry. The diameter of the main vessel (D_0) was calculated from the diameters of the daughter branches (D_1 and D_2) using the following equations:

Murray:

$$D_0^3 = (D_1^3 + D_2^3)$$

Finet:

$$D_0 = 0.678 \times (D_1 + D_2)$$

Huo–Kassab:

$$D_0^{7/3} = (D_1^{7/3} + D_2^{7/3})$$

In this study, D_0 , D_1 and D_2 corresponded to the diameters of the LMCA, LAD, and LCx, respectively. For comparisons with QCA, reference diameters were used. For comparisons with IVUS, average area-derived lumen diameters were used.

Statistical analysis

Statistical analyses were performed using R software version 4.5.0 (R Foundation for Statistical Computing, Vienna, Austria). Categorical variables are presented as counts and percentages, and continuous variables are expressed as mean $\pm$ standard deviation. A p value < 0.05 was considered statistically significant.

Accuracy, precision, and model ratio were calculated for each geometric model. Accuracy was defined as the mean difference between observed and predicted LMCA diameters, expressed in millimeters. Precision was defined as the standard deviation of this difference. The model ratio was defined as the ratio between observed and predicted LMCA diameters, with values closer to 1 indicating better model performance.

Agreement between observed and predicted measurements was evaluated using Bland–Altman analysis. For each comparison, the mean difference and 95% limits of agreement were calculated.

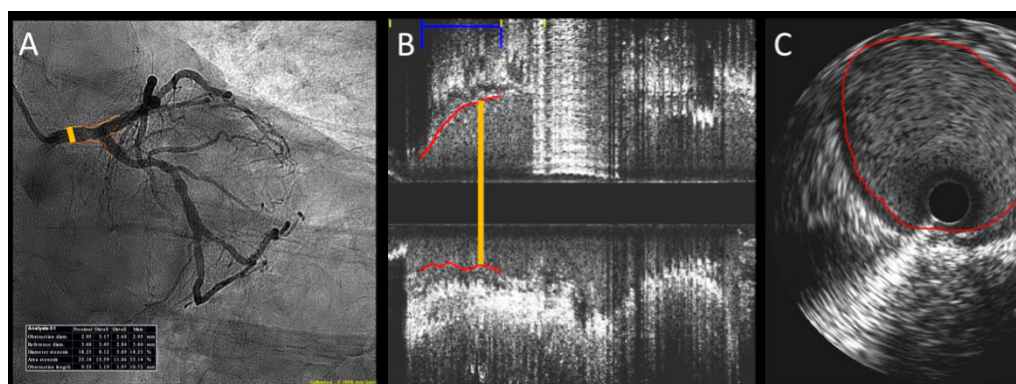


Figure 1 – QCA and IVUS measurements performed in the same region of interest. A) QCA analysis of the left main coronary artery bifurcation, with the reference diameter ROI highlighted in yellow; B) IVUS longitudinal view showing the same ROI as in the QCA analysis, with lumen contours outlined in red; blue markers delimit the segment containing the largest lumen area, highlighted in yellow; C) IVUS cross-sectional view at the site of the largest lumen area, with lumen contours outlined in red. QCA: quantitative coronary angiography. IVUS: intravascular ultrasound. ROI: region of interest.

Results

A total of 81 patients who underwent IVUS evaluation of the LMCA, LAD, and LCx during the same procedure between September 2017 and January 2022 were identified in the institutional database. Of these, 13 patients met all inclusion criteria. The main findings are summarized in Central Illustration. Most patients were excluded because of severe vessel disease without an analyzable proximal segment or because of previously implanted stents in the segment of interest, which precluded reliable analysis. Baseline characteristics of the study population are presented in Table 1.

Intra- and inter-observer measurement reproducibility

For QCA, intra-observer accuracy and precision were -0.01 mm and 0.38 mm, respectively ($p = 0.92$). For IVUS, intra-observer accuracy and precision were -0.02 mm and 0.26 mm, respectively ($p = 0.79$). Inter-observer accuracy and precision were 0.06 mm and 0.67 mm for QCA ($p = 0.75$) and 0.02 mm and 0.45 mm for IVUS ($p = 0.87$).

Table 1 – Baseline characteristics of the included patients (n = 13)

Variable	Value
Male sex	9 (69.2%)
Age, years	64 ± 13
Ethnicity (White)	13 (100.0%)
Height, cm	172 ± 12
Weight, kg	83 ± 14
BMI, kg/m ²	27.8 ± 2.5
BSA, m ²	1.97 ± 0.24
Hypertension	10 (76.9%)
Diabetes mellitus	6 (46.2%)
Hyperlipidemia	12 (92.3%)
Previous CAD	4 (30.8%)
Previous stroke	2 (15.4%)
Previous PAD	3 (23.1%)
Previous CABG	2 (15.4%)
Smoker	
Never	7 (53.8%)
Previous	5 (38.5%)
Active	1 (7.7%)
Clinical presentation	
Stable angina	10 (76.9%)
Unstable angina	2 (15.4%)
Myocardial infarction	1 (7.7%)

QCA measurements

Mean reference diameter, mm

LMCA	4.13 ± 1.09
LAD	3.10 ± 0.56
LCx	3.08 ± 0.59

Mean obstruction diameter, mm

LMCA	3.07 ± 0.81
LAD	2.60 ± 0.63
LCx	2.24 ± 0.59

Mean stenosis, %

LMCA	7.92 ± 17.84
LAD	11.59 ± 14.02
LCx	24.55 ± 14.45

IVUS measurements

Mean diameter, mm

LMCA	4.05 ± 0.68
LAD	3.42 ± 0.56
LCx	3.64 ± 0.62

Mean CSA, mm²

LMCA	12.89 ± 3.72
LAD	9.46 ± 3.12
LCx	10.25 ± 3.38

Mean PB, %

LMCA	43.41 ± 13.42
LAD	44.69 ± 9.33
LCx	41.13 ± 13.33

BMI: body mass index; BSA: body surface area; CAD: coronary artery disease; PAD: peripheral artery disease; CABG: coronary artery bypass grafting; CSA: cross-sectional area; QCA: quantitative coronary angiography; LMCA: left main coronary artery; LAD: left anterior descending artery; LCx: left circumflex artery; IVUS: intravascular ultrasound; PB: plaque burden.

Comparison between quantitative coronary angiography and intravascular ultrasound

A total of 39 paired measurements comparing IVUS and QCA diameters of the LMCA, LAD, and LCx were analyzed. When IVUS was compared with QCA, accuracy and precision were 0.27 mm and 0.71 mm, respectively, with a positive bias of 11.4% observed for IVUS-derived measurements. Bland–Altman analysis demonstrated a consistent positive bias of IVUS measurements relative to QCA (Figure 2).

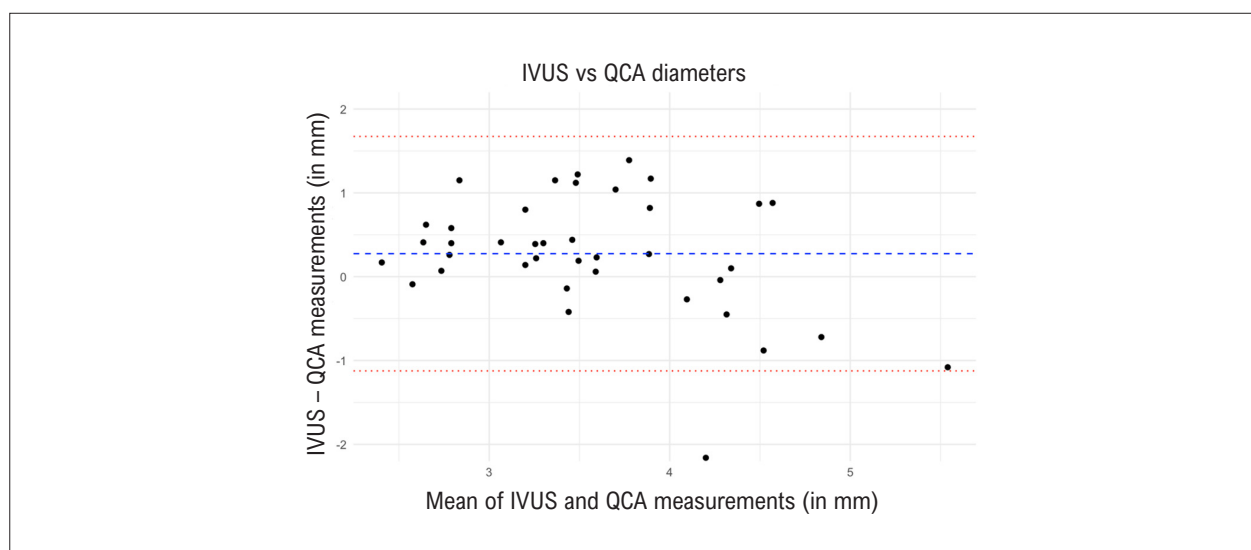


Figure 2 – Bland–Altman plot comparing IVUS and QCA diameter measurements. Comparison of IVUS and QCA diameter measurements obtained from the left main coronary artery, left anterior descending artery, and left circumflex artery. The blue solid line represents the mean difference between IVUS and QCA measurements, and the red dashed lines indicate the 95% limits of agreement. IVUS: intravascular ultrasound; QCA: quantitative coronary angiography.

Geometric models compared with quantitative coronary angiography

A total of 13 LMCA diameters predicted by the Murray, Finet, and Huo–Kassab models were compared with QCA measurements. The Murray and Huo–Kassab models showed similar performance, with accuracy and precision values of 0.06 mm and 0.95 mm, and -0.03 mm and 0.95 mm, respectively. The Finet model demonstrated the lowest performance, with an accuracy of -0.35 mm and a precision of 0.96 mm. Among the three models, the Huo–Kassab model showed the model ratio closest to 1 (Table 2).

Geometric models compared with intravascular ultrasound

A total of 13 IVUS-based LMCA measurements were analyzed. Comparisons between IVUS measurements and predictions derived from the three geometric models are summarized in Table 3. The Murray model demonstrated the highest accuracy and precision (-0.49 mm and 0.84 mm, respectively). Bland–Altman analysis confirmed superior performance of the Murray model compared with the other models, characterized by a small bias, a mean difference close to 0, and narrower limits of agreement (Figure 3).

Discussion

In this study, we compared three geometric models of coronary bifurcation geometry with measurements obtained by QCA and IVUS. Although all models demonstrated reasonable agreement with observed diameters, their performance varied according to the imaging modality used. When evaluated against both QCA and IVUS, the Murray and Huo–Kassab models showed higher accuracy and precision than the Finet model. Notably, the Murray model demonstrated the highest accuracy when IVUS was

used as the reference standard, with a smaller negative bias and narrower limits of agreement.

The superior performance of the Murray and Huo–Kassab models may be explained by their stronger theoretical foundations. Both models are derived from principles of fluid dynamics, whereas the Finet model is empirically based on angiographic measurements, which may not accurately reflect true vessel dimensions, particularly in the presence of atherosclerotic disease.^{2–4} In addition, our finding that IVUS systematically yielded larger vessel diameters than QCA, although consistent with previous reports, further highlights the importance of imaging modality selection when validating predictive geometric models.^{15,16}

Interestingly, the Murray model demonstrated slightly better agreement with IVUS-derived measurements than the Huo–Kassab model in our study population. One possible explanation is that the simplicity of Murray’s cubic relationship may render it more mathematically robust to small variations in input measurements. In contrast, the more complex exponent used in the Huo–Kassab model may amplify minor discrepancies in branch diameter measurements. This effect may be particularly relevant in a population composed of vessels with moderate plaque burden, as was the case in our study. Our findings are partially consistent with those reported by Blanco et al., who observed that although the Huo–Kassab model provided better geometric matching in angiographically normal coronary arteries, the Murray model was statistically closer to observed values.¹⁷ Their simulations also demonstrated that no universal scaling law could fully balance wall shear stress at the bifurcation, reinforcing the concept that geometric models, while useful approximations, cannot fully capture the complex interaction between anatomy and flow in individual patients.

These considerations emphasize that geometric prediction models represent an imperfect translation of theoretical principles

Table 2 – Comparison of predicted and observed quantitative coronary analysis measurements of the left main coronary artery bifurcation using different geometric models

Model	Accuracy (mm)	Precision (mm)	Model ratio
Murray	0.06	0.95	1.03
Finet	−0.35	0.96	0.92
Huo–Kassab	−0.03	0.95	1.00

Table 3 – Comparison of predicted and observed intravascular ultrasound measurements of the left main coronary artery bifurcation using different geometric models

Model	Accuracy (mm)	Precision (mm)	Model ratio
Murray	−0.49	0.84	0.91
Finet	−0.91	0.82	0.85
Huo–Kassab	−0.64	0.84	0.89

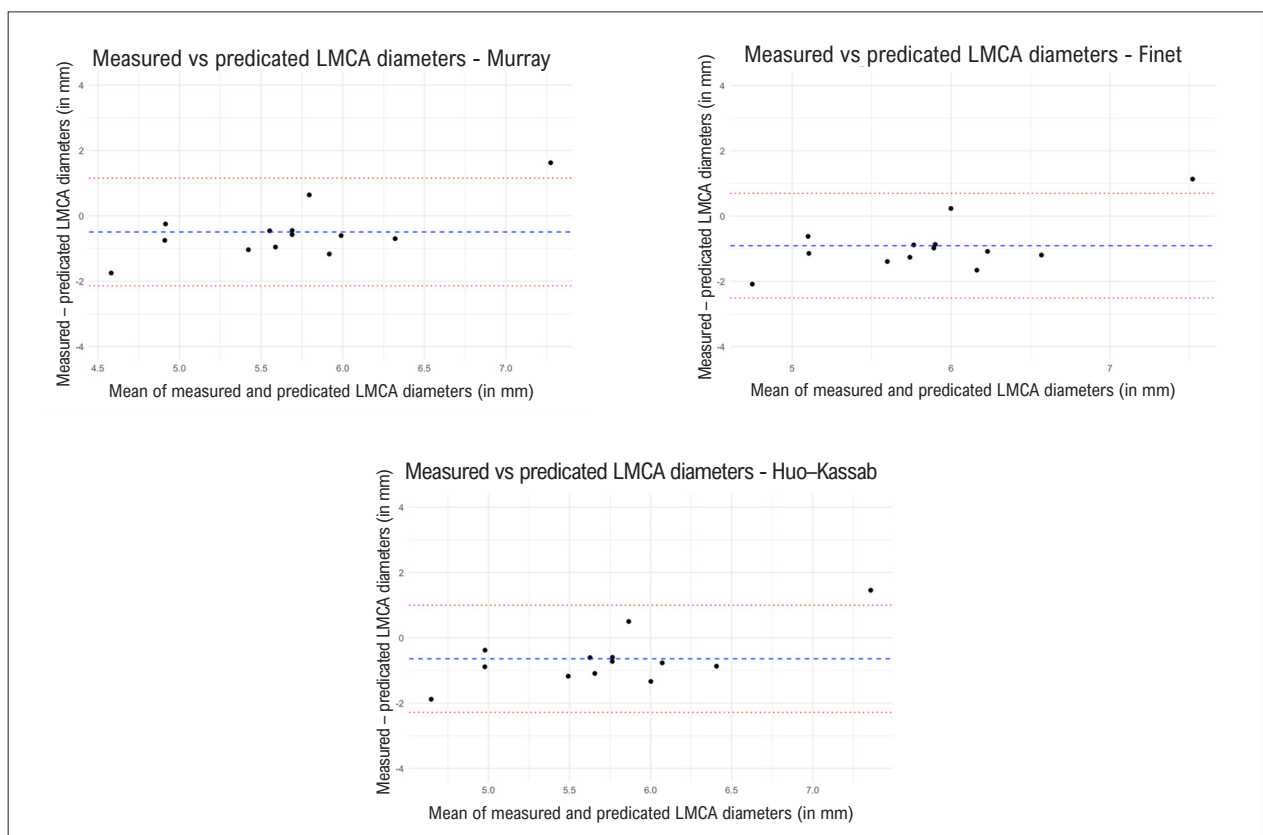


Figure 3 – Bland–Altman plots comparing measured and predicted diameters in the LMCA bifurcation. Bland–Altman analysis comparing intravascular ultrasound–measured diameters with diameters predicted by the three geometric models in the LMCA bifurcation. The blue solid line represents the mean difference, and the red dashed lines indicate the 95% limits of agreement. LMCA: left main coronary artery.

into clinical practice. Although they may help identify non-normal coronary segments,¹¹ they did not provide a reliable substitute for direct vessel sizing in our study. In clinical practice, even small discrepancies in vessel diameter estimation may have significant consequences, and differences on the order of 1 mm, whether

underestimating or overestimating vessel size, can lead to adverse procedural outcomes. Therefore, despite their mathematical robustness, geometric prediction models should be regarded strictly as adjunctive tools rather than definitive sizing methods.

This study has several limitations. Its retrospective design and small sample size introduce the potential for selection bias. Although analyses were restricted to arterial segments without severe disease, these vessels were not free of atherosclerosis. Consequently, our findings cannot be extrapolated to either angiographically normal or severely diseased coronary arteries. Nevertheless, the study also has notable strengths, including the use of IVUS with automated pullback and standardized segment selection, which enhance measurement reproducibility. In addition, both linear and area-derived mean vessel diameters were evaluated, providing a representative assessment of coronary geometry. Importantly, the study reflects real-world clinical practice, in which accurate prediction of bifurcation diameters is more relevant in diseased arteries than in normal vessels. Overall, the results should be considered exploratory and hypothesis-generating, and further studies with larger populations are needed to confirm these findings and assess their implications for stent sizing and procedural planning.

Conclusion

In this study, the Murray and Huo–Kassab models outperformed the Finet model in predicting LMCA bifurcation diameters, particularly when IVUS measurements were used as the reference standard. These findings support the preferential use of these geometric models in clinical and computational applications involving coronary bifurcations. However, geometric prediction models do not replace IVUS imaging for vessel sizing in LMCA interventions.

Author Contributions

Conception and design of the research and Analysis and interpretation of the data: Garzon S, Lemos P; Acquisition

of data and Writing of the manuscript: Garzon S, Pilotto L; Statistical analysis: Garzon S; Critical revision of the manuscript for content: Garzon S, Mariani J, Bezerra F, Prado G, Bandeira W, Almeida B, Lemos P.

Potential conflict of interest

No potential conflict of interest relevant to this article was reported.

Sources of funding

There were no external funding sources for this study.

Study association

This study is not associated with any thesis or dissertation work.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Data Availability Statement

All datasets supporting the results of this study are available upon request from the corresponding author.

References

- Kimura BJ, Russo RJ, Bhargava V, McDaniel MB, Peterson KL, DeMaria AN. Atheroma Morphology and Distribution in Proximal Left Anterior Descending Coronary Artery: In Vivo Observations. *J Am Coll Cardiol*. 1996;27(4):825-31. doi: 10.1016/0735-1097(95)00551-x.
- Murray CD. The Physiological Principle of Minimum Work Applied to the Angle of Branching of Arteries. *J Gen Physiol*. 1926;9(6):835-41. doi: 10.1085/jgp.9.6.835.
- Finet G, Gilard M, Perrenot B, Rioufol G, Motreff P, Gavit L, et al. Fractal Geometry of Arterial Coronary Bifurcations: A Quantitative Coronary Angiography and Intravascular Ultrasound Analysis. *EuroIntervention*. 2008;3(4):490-8. doi: 10.4244/eijv3i4a87.
- Huo Y, Kassab GS. A Scaling Law of Vascular Volume. *Biophys J*. 2009;96(2):347-53. doi: 10.1016/j.bpj.2008.09.039.
- Park SJ, Kim YH, Park DW, Lee SW, Kim WJ, Suh J, et al. Impact of Intravascular Ultrasound Guidance on Long-Term Mortality in Stenting for Unprotected Left Main Coronary Artery Stenosis. *Circ Cardiovasc Interv*. 2009;2(3):167-77. doi: 10.1161/CIRCINTERVENTIONS.108.799494.
- Hernandez JMT, Alonso JAB, Hospital JAC, Manterola FA, Camarero TG, Carlos FG, et al. Clinical Impact of Intravascular Ultrasound Guidance in Drug-Eluting Stent Implantation for Unprotected Left Main Coronary Disease: Pooled Analysis at the Patient-Level of 4 Registries. *JACC Cardiovasc Interv*. 2014;7(3):244-54. doi: 10.1016/j.jcin.2013.09.014.
- Kwon W, Lee JM, Yun KH, Choi KH, Lee SJ, Lee JY, et al. Clinical Benefit of Intravascular Imaging Compared with Conventional Angiography in Left Main Coronary Artery Intervention. *Circ Cardiovasc Interv*. 2023;16(12):e013359. doi: 10.1161/CIRCINTERVENTIONS.123.013359.
- Park SJ, Ahn JM, Kang SJ, Yoon SH, Koo BK, Lee JY, et al. Intravascular Ultrasound-Derived Minimal Lumen Area Criteria for Functionally Significant Left Main Coronary Artery Stenosis. *JACC Cardiovasc Interv*. 2014;7(8):868-74. doi: 10.1016/j.jcin.2014.02.015.
- Huo Y, Finet G, Lefevre T, Louvard Y, Moussa I, Kassab GS. Which Diameter and Angle Rule Provides Optimal Flow Patterns in a Coronary Bifurcation? *J Biomech*. 2012;45(7):1273-9. doi: 10.1016/j.jbiomech.2012.01.033.
- Huo Y, Finet G, Lefèvre T, Louvard Y, Moussa I, Kassab GS. Optimal Diameter of Diseased Bifurcation Segment: A Practical Rule for Percutaneous Coronary Intervention. *EuroIntervention*. 2012;7(11):1310-6. doi: 10.4244/EIJV7I11A206.
- Huo Y, Kassab GS. Scaling Laws of Coronary Circulation in Health and Disease. *J Biomech*. 2016;49(12):2531-9. doi: 10.1016/j.jbiomech.2016.01.044.
- Collet C, Onuma Y, Cavalcante R, Grundeken M, Gènéreux P, Popma J, et al. Quantitative Angiography Methods for Bifurcation Lesions: A Consensus Statement Update from the European Bifurcation Club. *EuroIntervention*. 2017;13(1):115-23. doi: 10.4244/EIJ-D-16-00932.

13. Mintz GS, Nissen SE, Anderson WD, Bailey SR, Erbel R, Fitzgerald PJ, et al. American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, Measurement and Reporting of Intravascular Ultrasound Studies (IVUS). A Report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents. *J Am Coll Cardiol*. 2001;37(5):1478-92. doi: 10.1016/s0735-1097(01)01175-5.
14. Mintz GS, Garcia-Garcia HM, Nicholls SJ, Weissman NJ, Bruining N, Crowe T, et al. Clinical Expert Consensus Document on Standards for Acquisition, Measurement and Reporting of Intravascular Ultrasound Regression/Progression Studies. *EuroIntervention*. 2011;6(9):1123-30. doi: 10.4244/EIJV6I9A195.
15. Kubo T, Akasaka T, Shite J, Suzuki T, Uemura S, Yu B, et al. OCT Compared with IVUS in a Coronary Lesion Assessment: The OPUS-CLASS Study. *JACC Cardiovasc Imaging*. 2013;6(10):1095-104. doi: 10.1016/j.jcmg.2013.04.014.
16. Goto K, Mintz GS, Litherland C, Lansky AJ, Weisz G, McPherson JA, et al. Lumen Measurements from Quantitative Coronary Angiography and IVUS: A PROSPECT Substudy. *JACC Cardiovasc Imaging*. 2016;9(8):1011-3. doi: 10.1016/j.jcmg.2015.07.006.
17. Blanco PJ, Santos GHV, Bulant CA, Alvarez AM, Oliveira FAP, Cunha-Lima G, et al. Scaling Laws and the Left Main Coronary Artery Bifurcation. A Combination of Geometric and Simulation Analyses. *Med Eng Phys*. 2022;99:103701. doi: 10.1016/j.medengphys.2021.08.011.



This is an open-access article distributed under the terms of the Creative Commons Attribution License