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CORONARY, PERIPHERAL, AND STRUCTURAL INTERVENTIONS

CLINICAL CASE SERIES

Coronary CTA-Guided Bifurcation PCI

Role of FFR_{CT} Virtual PCI and Myocardial Mass for Preprocedural Planning

Pedro E.P. Carvalho, MD,[a] João L. Cavalcante, MD,[a,b] John Lesser, MD,[a] Victor Cheng, MD,[a] Dimitrios Strepkos, MD,[a] Michaella Alexandrou, MD,[a] Deniz Mutlu, MD,[a] Emmanouil S. Brilakis, MD, PhD,[a,b] Yader Sandoval, MD[a,b]

ABSTRACT

Coronary computed tomography angiography (CTA) analysis can help in the planning of percutaneous coronary intervention (PCI). Fractional flow reserve derived from coronary CTA (FFR_{CT}), coronary CTA-derived regional myocardial mass, and FFR_{CT} virtual PCI planner can facilitate decisions concerning sheath and guide catheter selection, stent lengths on the basis of predicted post-PCI FFR_{CT}, optimal fluoroscopic angles, evaluation of provisional vs 2-stent bifurcation PCI techniques, and assessment of the magnitude of jeopardized myocardial mass in cases with side branch compromise. This case series illustrates the emerging opportunities for coronary CTA-based planning of bifurcation PCI. (JACC Case Rep. 2025;30:102814) © 2025 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Coronary computed tomography angiography (CTA) can facilitate preprocedural planning in patients with obstructive coronary artery disease (CAD) who are referred for percutaneous coronary intervention (PCI), especially patients who have complex lesions, including bifurcations.[1] In bifurcation PCI, coronary CTA can help inform vascular access site, including sheath and guide catheter size, plan PCI on the basis of the morphologic and physiologic assessment of the main vessel (MV) and side branch (SB), and determine the size of jeopardized myocardial mass in cases with SB compromise.[2]

TAKE-HOME MESSAGE

- Preprocedural planning with coronary CTA and FFR_{CT}-based applications including virtual PCI and myocardial mass can facilitate and optimize bifurcation PCI planning.

The present case series demonstrates coronary CTA-guided bifurcation PCI with the FFR_{CT} planner and highlights the emerging role of myocardial mass in preprocedural planning. Fractional flow reserve (FFR) derived from coronary CTA (FFR_{CT}, HeartFlow, Inc) is used for the diagnosis of vessel-specific ischemia. Our cases extend the use of coronary physiology for PCI guidance by using virtual FFR_{CT} pullbacks for CAD phenotyping. Moreover, the FFR_{CT} virtual PCI planner enables operators to select optimal fluoroscopic angles, the preferred PCI strategy, and stent lengths on the basis of the predicted post-PCI FFR_{CT}. Coronary CTA-based assessment of

From the [a]Center for Coronary Artery Disease, Minneapolis Heart Institute Foundation, Minneapolis, Minnesota, USA; and the [b]Allina Health Minneapolis Heart Institute, Abbott Northwestern Hospital, Minneapolis, Minnesota, USA.

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ABBREVIATIONS AND ACRONYMS

CAD = coronary artery disease

CRAN = cranial

CTA = computed tomography angiography

DES = drug-eluting stent

D1 = first diagonal

D2 = second diagonal

FFR = fractional flow reserve

FFR_{CT} = fractional flow reserve derived from coronary computed tomography angiography

IVUS = intravascular ultrasound

LAD = left anterior descending

MV = main vessel

NC = noncompliant

PCI = percutaneous coronary intervention

POT = proximal optimization technique

RAO = right anterior oblique

SB = side branch

the myocardium at risk in the MV and SB distribution may help determine the need for prophylactic SB wiring and optimal bifurcation stenting strategy.[2,3]

CASE 1

A 60-year-old man with type 2 diabetes mellitus presented with chronic exertional angina. Coronary CTA demonstrated a calcium score of 144 Agatston units (AU) and multivessel CAD with severe calcified stenosis (>70%) in the mid-left anterior descending (LAD) artery and first diagonal (D1) (Figure 1A). Lesion-specific and virtual FFR_{CT} pullbacks for the LAD-D1 bifurcation are shown in Figure 1A. The mid-LAD artery and D1 stenoses were hemodynamically significant, with FFR_{CT} values distal to the lesions of <0.50 and 0.54, respectively (Figure 1A). Following surgical consultation and a heart team-based approach, the patient chose PCI.

On the basis of the virtual PCI planner tool, the optimal fluoroscopic angles were anteroposterior cranial (CRAN) 40° and right anterior oblique (RAO) 30°, CRAN 30° (Figure 1B). We decided to use stent lengths of 30 mm in the LAD artery and 15 mm in D1 according to predicted post-PCI FFR_{CT} (Figure 1B). Post hoc vessel-specific myocardial mass assessment showed that the mid LAD artery (distal to D1) accounted for 11.5% of the myocardial mass, and D1 accounted for 8.85% (Figure 2). The patient underwent successful coronary CTA- and intravascular ultrasound (IVUS)-guided 2-stent bifurcation PCI using the minicrush technique, by placing a 2.75 mm × 30 mm drug-eluting stent (DES) in the LAD artery and a 2.5 mm × 15 mm DES in D1, with intravascular imaging used for post-PCI stent assessment. The proximal optimization technique (POT) was performed with a 3.5-mm noncompliant (NC) balloon with an excellent angiographic result without any procedural or in-hospital complications (Figures 3A to 3H).

CASE 2

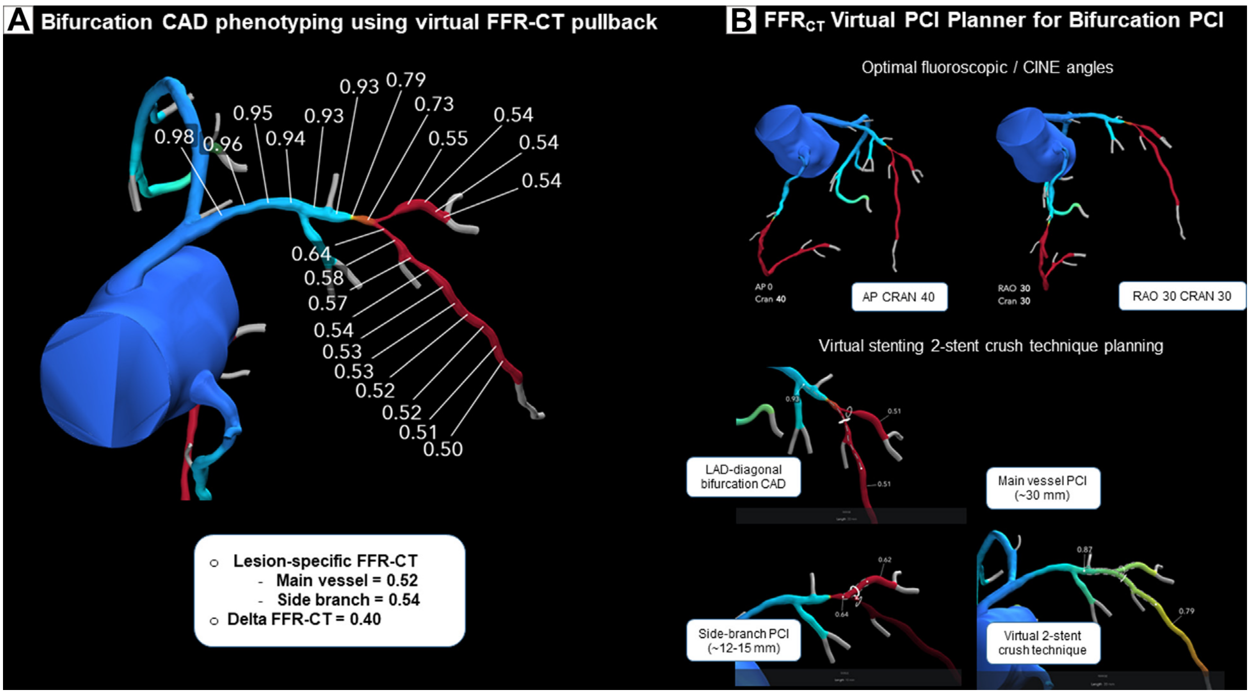
An 80-year-old woman with sinus node dysfunction and a dual-chamber permanent pacemaker underwent coronary CTA that demonstrated a calcium score of 3,319 AU and severe multivessel disease, with a proximal calcified 50% to 69% stenosis and a mid ≥70% stenosis in the LAD artery at the bifurcation into a large D1. The proximal LAD artery FFR_{CT} was 0.86, dropping to <0.50 in the distal vessel, and 0.70 in D1 (Figure 4A).

On the basis of the virtual PCI planner tool, the optimal fluoroscopic angle was RAO 30°, CRAN 30° (Figure 4B). Virtual PCI strategies, including a provisional technique and a 2-stent crush technique, are summarized in Figure 4B. A higher post-PCI FFR_{CT} value could be achieved with treatment of both the proximal and mid-LAD artery lesions as compared with treating the mid-LAD artery alone. A ~15 mm stent length was chosen for D1. D1 had a borderline abnormal FFR_{CT} (~0.74) beyond the D1 ostium, with results influenced by the proximal inflow LAD artery disease, and the lesion did not appear severe on assessments with coronary CTA, angiography, or IVUS. Post hoc vessel-specific myocardial mass assessment showed that the proximal LAD artery accounted for 36.8% of the myocardial mass, dropping to 16.2% after the bifurcation, whereas the D1 accounted for 14.2% (Figure 5). On the basis of these assessments, an initial provisional approach was favored. Given the severely calcified lesions, particularly at the proximal LAD artery (Figure 6A), rotational atherectomy with a 1.5-mm bur and intravascular lithotripsy were used. As a result of vessel mismatch, 2 stents (DES, 2.75 mm × 22 mm and 4.0 mm × 18 mm) were overlapped to cover the proximal and mid-LAD artery lesions, and a 4.0 NC balloon was used for POT. Following provisional stenting, however, the SB was jailed, and therefore the PCI strategy was converted to a reverse double kissing-crush technique with implantation of a 2.75 mm × 15 mm DES (length according to predicted post-PCI FFR_{CT}) in the D1 (Figures 6A to 6H).

CASE 3

A 72-year-old man with a history of previous PCI presented with chronic exertional angina and shortness of breath. Coronary CTA revealed a calcified ≥70% stenosis in the mid-LAD artery at the bifurcation into a large diagonal. The calcium score was 89 AU. The proximal LAD artery FFR_{CT} was 0.95, dropping to lesion-specific FFR_{CT} values of 0.75 and 0.83 in the distal LAD artery and distal D1 beyond the bifurcation lesion. Invasive coronary angiography confirmed a severe stenosis in the mid-

FIGURE 1 **Coronary Computed Tomography Angiography-Guided Bifurcation PCI Planning in Patient 1**



(A) Left anterior descending (LAD) artery and D1 bifurcation coronary artery disease (CAD) phenotyping using fractional flow reserve derived from coronary computed tomography angiography (FFR$_{CT}$) pullback. (B) Fractional flow reserve derived from coronary computed tomography angiography virtual percutaneous coronary intervention (PCI) planner analyzing optimal fluoroscopic angles and a virtual percutaneous coronary intervention planner analyzing post-percutaneous coronary intervention fractional flow reserve derived from coronary computed tomography angiography with a provisional vs 2-stent technique. CRAN = cranial; RAO = right anterior oblique.

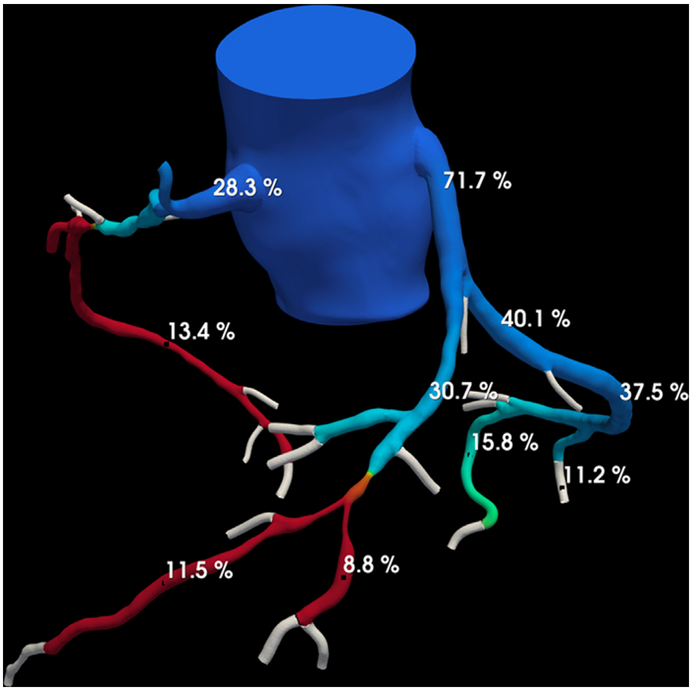
LAD artery. Pressure wire-based FFR assessments were 0.77 in the LAD artery and 0.88 in the D1. Lesion-specific and virtual FFR$_{CT}$ pullbacks are shown in **Figure 7A**.

On the basis of the virtual PCI planner tool, the optimal fluoroscopic angles were RAO 10°, CRAN 40° (**Figure 7B**). Virtual PCI strategies, including a provisional and a 2-stent crush technique, were evaluated and are summarized in **Figure 7B**. On the basis of the virtual PCI planner and predicted post-PCI FFR$_{CT}$ values, a ~30-mm stent was favored, with a provisional stenting technique preferred as the initial strategy. A post hoc vessel-specific myocardial mass distal to the LAD-D1 bifurcation was calculated as 16.0% in the LAD artery and as 14.4% in the D1 (**Figure 8**). The small D2 SB had a myocardial mass of 4.4%. Coronary CTA/IVUS-guided PCI was performed, with provisional 3.5 mm × 30 mm DES stenting in the mid-LAD followed by POT using a 4.0 NC ballon (**Figures 9A to 9E**). Given the presence of severe calcified stenosis, intravascular lithotripsy was performed with a 3.5-mm balloon for 70 pulses. Following provisional bifurcation PCI, a large D1 was partially jailed, and the small D2 was jeopardized (**Figure 9F**). The D1 was rescued through balloon angioplasty using a 2.5 NC balloon (**Figures 9G and 9H**). Given the small size of D2 and the absence of overt angina or electrocardiographic changes, as well as the risk associated with additional interventions to rescue D2, the patient was treated conservatively. Post-PCI, there was no worsening of the symptoms.

DISCUSSION

Our cases demonstrate the use of coronary CTA with FFR$_{CT}$ virtual PCI planning in bifurcation disease and

FIGURE 2 Coronary Computed Tomography Angiography-Based Myocardial Mass in Patient 1



Coronary computed tomography angiography-based vessel-specific myocardial mass.

inform about the emerging role of vessel-specific myocardial mass.[4,5]

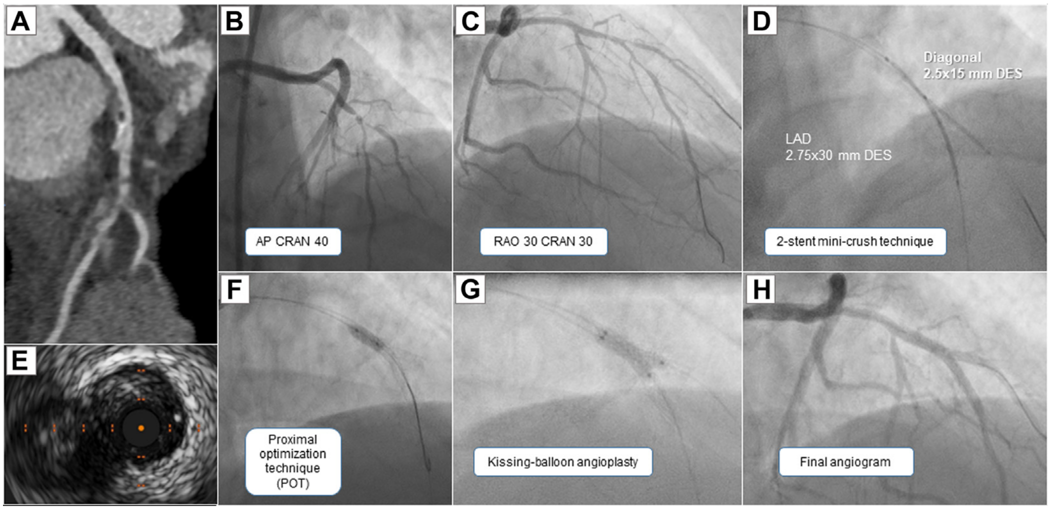
Bifurcation lesions represent 10% to 15% of lesions undergoing PCI and are associated with higher procedural complexity, for which novel methods to facilitate preprocedural planning may be beneficial.[6] Bifurcations have large anatomical variability, and disease phenotyping should take into account lesion location, SB involvement, bifurcation angulation, need to preserve SB, the likelihood of SB occlusion, MV and SB physiology, and the size of the MV relative to the SB. Despite the provisional technique being favored in most cases, SB compromise is not infrequent; hence upfront 2-stent techniques are favored for complex bifurcations such as those with large and diseased SB, left main coronary bifurcations, and when SB occlusion or reaccess is a concern.[7,8] Coronary CTA accurately provides anatomical characterization of bifurcations, including plaque and calcium characterization, and can inform the need for calcium modification strategies. The CT bifurcation score, a simple point score system that is based on coronary CTA data that incorporate plaque and vessel area, was validated to predict intraprocedural SB occlusion in bifurcation PCI with better performance compared with the angiographic Medina classification and the RESOLVE score, and it may guide the provisional vs 2-stent technique.[9]

In addition, computational fluid dynamics using coronary CTA images can provide a comprehensive physiological assessment and derive FFR_{CT}.[10] FFR_{CT} allows the noninvasive multivessel assessment of epicardial CAD, including lesion-specific FFR_{CT}, as well as virtual FFR_{CT} pullbacks and translesional pressure loss gradients or delta FFR_{CT} that can help characterize diffuse vs focal disease and help inform optimal revascularization strategies.

Beyond CAD phenotyping, there are emerging interventional applications such as the FFR_{CT} virtual PCI planner, a clinically available tool that facilitates preprocedural interventional planning, including 3-dimensional coronary models that allow assessment of vessel course and tortuosity, optimal angles for fluoroscopy, and stent length on the basis of predicted post-PCI FFR_{CT}. For bifurcation PCI, preprocedural planning with FFR_{CT}-based virtual PCI represents a promising approach that facilitates optimal fluoroscopic angle selection that reduces foreshortening and may also be associated with reduced contrast and radiation use and allows virtual comparison of provisional vs 2-stent techniques.[5] In our cases, virtual PCI was used prospectively to guide decision making and inform bifurcation technique and stent selection. The FFR_{CT}-based virtual PCI planner was validated against FFR-based pressure assessments in the prospective P3 (Precise Percutaneous Coronary Intervention Plan) trial involving 120 patients; however, bifurcations were excluded from this analysis.[5]

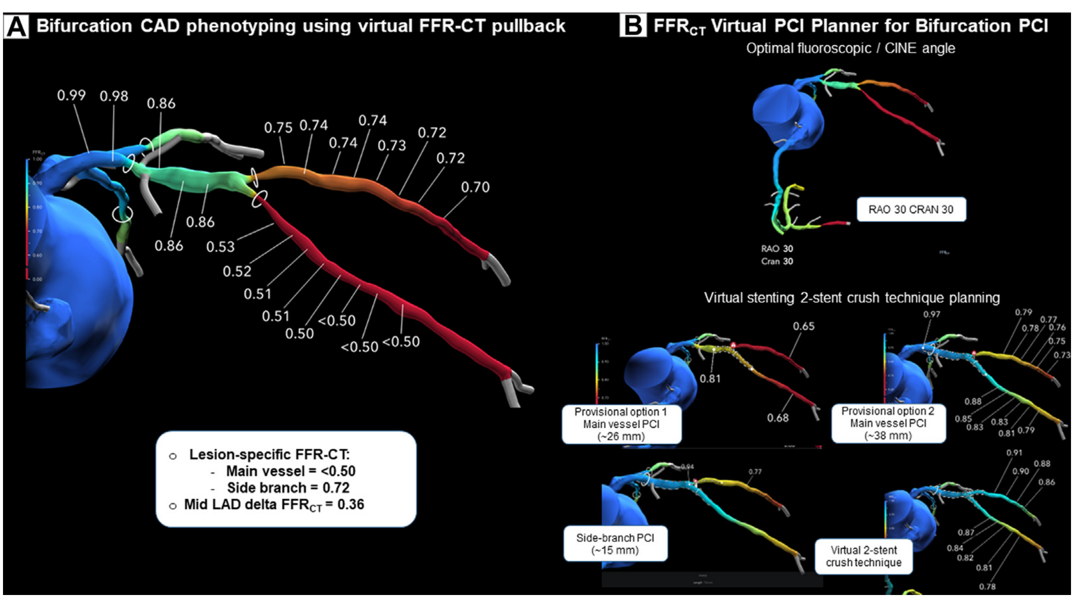
Vessel-specific myocardial mass has been validated in a study of 35 patients with normal coronary arteries who underwent coronary CTA and invasive myocardial perfusion assessed by 3-vessel continuous thermodilution measurements, in which a close relationship was observed between the relative mass of the perfusion territory calculated by the coronary

FIGURE 3 Coronary Computed Tomography Angiography, Pre-, and Post-Percutaneous Coronary Intervention Angiogram in Patient 1



(A) Curved multiplanar reconstruction of the left anterior descending (LAD) artery-first diagonal (D1) bifurcation. (B and C) Coronary computed tomography angiography–based optimal fluoroscopic angles. (D) Coronary computed tomography angiography–guided 2-stent bifurcation percutaneous coronary intervention using a minicrush technique. (E) Intravascular ultrasound of the left anterior descending artery-first diagonal bifurcation. (F) Proximal optimization technique in the left anterior descending artery. (G) Kissing-balloon angioplasty. (H) Left anterior descending artery-first diagonal post-percutaneous coronary intervention angiographic results. AP = anteroposterior; other abbreviations as in Figure 1.

FIGURE 4 Coronary Computed Tomography Angiography-Guided Bifurcation PCI Planning in Patient 2



(A) Left anterior descending (LAD) artery and first diagonal (D1) bifurcation coronary artery disease (CAD) phenotyping using fractional flow reserve derived from coronary computed tomography angiography (FFR_{CT}) pullback. (B) Fractional flow reserve derived from coronary computed tomography angiography virtual percutaneous coronary intervention (PCI) planner analyzing optimal fluoroscopic angles and virtual percutaneous coronary intervention planner analyzing post-percutaneous coronary intervention fractional flow reserve derived from coronary computed tomography angiography with a provisional vs 2-stent technique.

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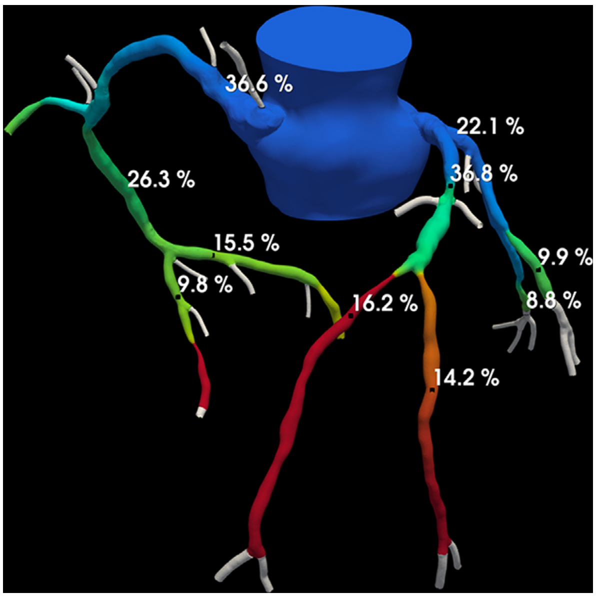
FIGURE 5 Coronary Computed Tomography Angiography-Based Myocardial Mass Estimation by Main Vessel and Side Branch in Patient 2

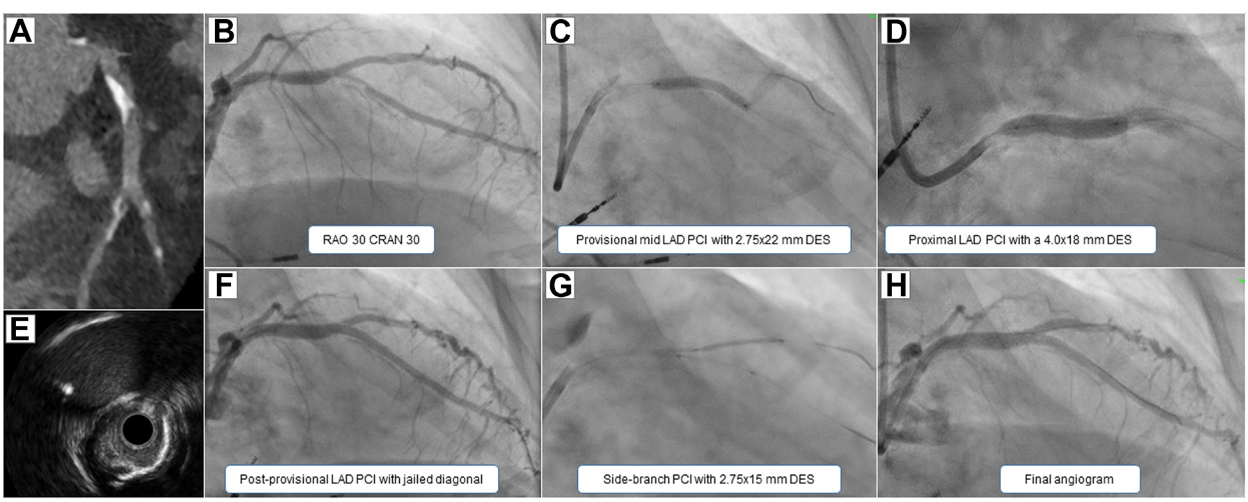


Patient 2 coronary computed tomography angiography-based vessel-specific myocardial mass subtended.

CTA algorithm and the invasively measured myocardial perfusion.[4] Myocardial mass assessments may help with clinical decision making on the need for SB stenting or protection and inform the potential risk and level of surveillance required when there is SB compromise. This concept is highlighted in our third example, in which D1 and D2 were jailed after provisional LAD PCI, and although the larger D1 representing 14.4% myocardial mass was rescued, the smaller D2 corresponding to 4.4% myocardial mass was not and was likely associated with mild postprocedural myocardial injury. On the basis of these observations, opportunities exist to better understand the risk for postprocedural myocardial injury and/or infarction and clinical outcomes that are based on the jeopardized myocardial mass. The role of CT-based myocardial mass subtended by MV and/or SB is being evaluated in the P4 (Precise Procedural and PCI Plan) randomized clinical trial, in which myocardial mass is assessed using an investigational approach that is based on the Voronoi's algorithm, with dedicated software and reporting for PCI planning in patients randomized to coronary CTA-guided PCI.

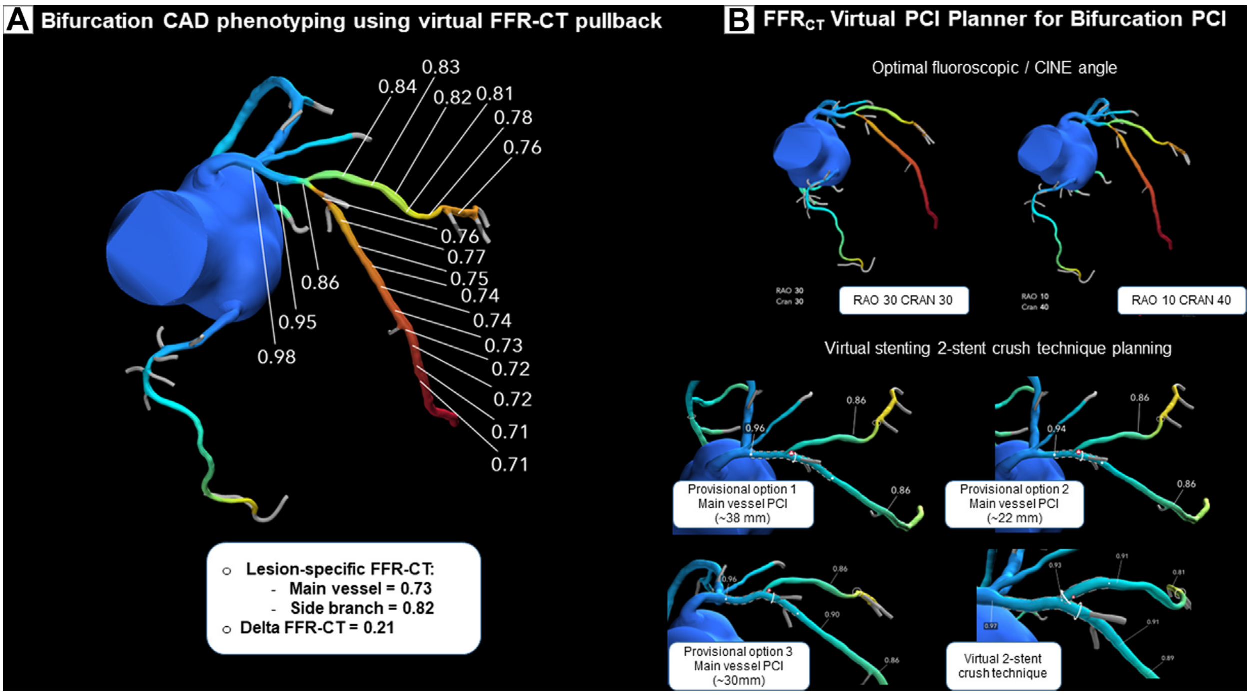
In our coronary CTA-guided PCI experience, intravascular imaging modalities such as IVUS or

FIGURE 6 Coronary Computed Tomography Angiography, Pre-, and Post-PCI Angiogram in Patient 2



(A) Multiplanar reconstruction of the left anterior descending (LAD) artery-first diagonal (D1) bifurcation. (B) Coronary computed tomography angiography-based optimal fluoroscopic angle. (C) Provisional bifurcation percutaneous coronary intervention (PCI) using a 2.75 mm × 22 mm in the left anterior descending artery. (D) proximal left anterior descending artery percutaneous coronary intervention with a 4.0 mm × 18 mm drug-eluting stent (DES). (E) Intravascular ultrasound of the left anterior descending artery-first diagonal bifurcation. (F) Post-provisional bifurcation -percutaneous coronary intervention jailing the first diagonal. (G) First diagonal bifurcation percutaneous coronary intervention. (H) Left anterior descending artery-first diagonal post-percutaneous coronary intervention angiographic results. Abbreviations as in Figure 3.

FIGURE 7 **Coronary Computed Tomography Angiography-Guided Bifurcation PCI Planning in Patient 3**



(A) Left anterior descending (LAD) artery and first diagonal (D1) bifurcation coronary artery disease (CAD) phenotyping using fractional flow reserve derived from coronary computed tomography angiography (FFR$_{CT}$) pullback. (B) The fractional flow reserve derived from coronary computed tomography angiography virtual percutaneous coronary intervention (PCI) planner analyzing optimal fluoroscopic angles, and the virtual percutaneous coronary intervention planner analyzing post-percutaneous coronary intervention fractional flow reserve derived from coronary computed tomography angiography with a provisional vs 2-stent technique.

optical coherence tomography are routinely used to complement decisions about stent sizing and post-PCI assessments (ie, distal dissection, stent expansion, and apposition). Although coronary CTA is excellent for disease length and luminal dimensions, there is recognized variability in nitroglycerin use for coronary CTA acquisition that can influence vessel size. Coronary CTA-based lumen assessments often underestimate stent size selection as compared with established intravascular imaging stent selection approaches that are based on external elastic lamina. Similarly, despite comprehensive coronary CTA-guided preprocedural planning, SB occlusion occurred in 2 of our cases, and this illustrates the need for novel coronary CTA-based approaches to predict SB occlusion, as well as future studies that inform a prognostically relevant myocardial mass threshold.

CONCLUSIONS

Bifurcation lesions represent ~15% to 20% of PCIs and often require complex stenting techniques. Preprocedural planning with coronary CTA and FFR$_{CT}$-based applications including virtual PCI and myocardial mass can facilitate and optimize bifurcation planning.

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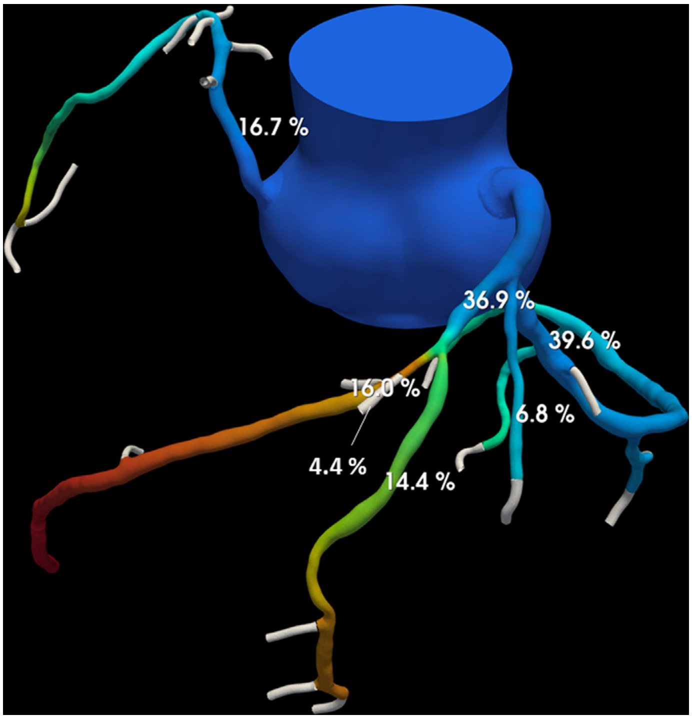
FIGURE 8 **Coronary Computed Tomography Angiography-Based Myocardial Mass in Patient 3**



Patient 3 coronary computed tomography angiography–based vessel-specific myocardial mass.

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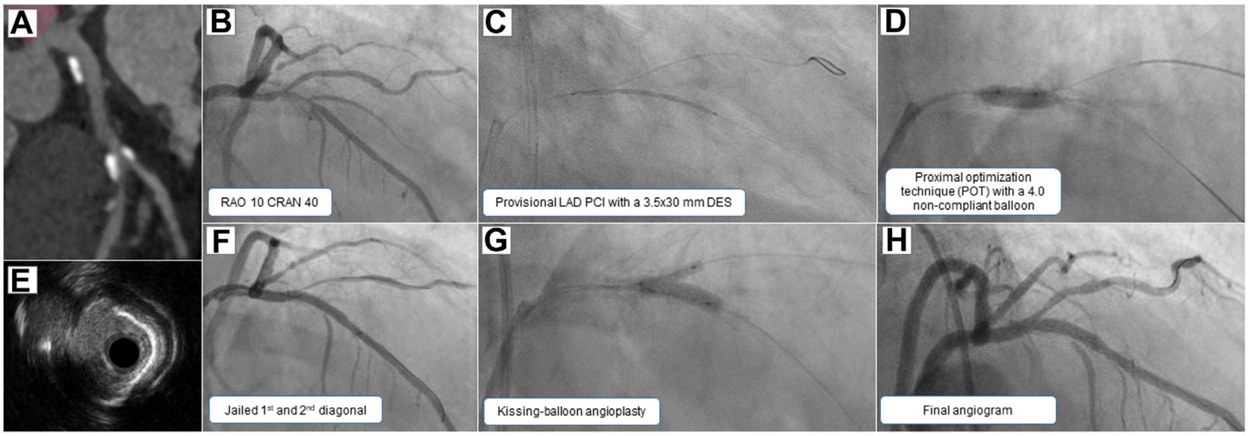
ADDRESS FOR CORRESPONDENCE: Dr Yader Sandoval, Minneapolis Heart Institute, Abbott Northwestern Hospital and Center for Coronary Artery Disease, 920 East 28th Street, Suite 300, Minneapolis, Minnesota 55407, USA. E-mail: yader.sandoval@allina.com.

FIGURE 9 **Coronary Computed Tomography Angiography, Pre-, and Post-PCI Angiogram in Patient 3**



(A) Multiplanar reconstruction of the left anterior descending (LAD) artery-first diagonal (D1) bifurcation. (B) Coronary computed tomography angiography-based optimal fluoroscopic angle. (C) Provisional bifurcation percutaneous coronary intervention (PCI) using a 3.5 mm × 30 mm in the left anterior descending artery. (D) Proximal optimization technique with a 4.0 NC balloon in the left anterior descending artery. (E) Intravascular ultrasound of the left anterior descending artery-first diagonal bifurcation. (F) Post-provisional bifurcation percutaneous coronary intervention jailing the first and second diagonals. (G) Rescue of the side branch and kissing-balloon angioplasty. (H) Left anterior descending artery-first diagonal post-percutaneous coronary intervention angiographic results with a second diagonal jailed. Abbreviations as in Figures 1 and 3.

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KEY WORDS bifurcation percutaneous coronary artery disease, coronary computed tomography angiography, fractional flow reserve, myocardial mass