Journal of the Society for Cardiovascular Angiography & Interventions 3 (2024) 101301

JSCAI

The official journal of the Society for
Cardiovascular Angiography & Interventions

Comprehensive Review

Cardiac Computed Tomography Angiography in the Evaluation of Coronary Artery Disease: An Interventional Perspective

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ABSTRACT

Cardiac computed tomography angiography (CCTA) has become the gold standard for noninvasive anatomic assessment of the coronary arteries. With high positive predictive value and even higher negative predictive value, CCTA allows for rapid determination of the presence or absence of coronary plaque and triage of patients' need for further invasive evaluation and treatment. From an interventional cardiologist's perspective, CCTA (more so than stress testing) is helpful in determining the need for invasive therapy. In conjunction with functional assessments, the anatomic evaluation from CCTA mirrors the anatomical assessment of a coronary angiogram more than any other noninvasive assessment. This allows for catheter selection, percutaneous coronary intervention preplanning, as well as additional decision making before the patient has entered the catheterization laboratory. This manuscript explores some of the more recent developments in noninvasive coronary angiography and discusses the use and utility of CCTA from an interventional cardiologist's perspective.

Cardiac computed tomography angiography is a better triage tool for the catheterization laboratory in stable patients with chest pain

More than 1,000,000 invasive coronary angiograms occur in the US annually. Although this has been a standard means to evaluate a patient's coronary anatomy, there is an inherent risk (typically quoted approximately 0.1%) including death, stroke, and vascular complications.[1] The percentage of cardiac catheterizations performed for chest pain which results in no revascularization can be up to 40%.[2]

Compared to invasive coronary angiography (ICA), cardiac computed tomography angiography (CCTA) represents a noninvasive alternative to evaluate coronary anatomy. It has been available to cardiologists and their patients for the better part of 2 decades and has become a guideline-directed alternative to ICA for the evaluation of patients with chest pain.[3]

The diagnostic accuracy for noninvasive functional (stress) testing is good, with most sensitivities and specificities in the 70% to 80% range.[4] In the most recent chest pain guidelines, CCTA is shown to be more accurate in delineating the presence of coronary disease, with higher positive and negative predictive values in the triage of patients than noninvasive testing.[5]

Low-to-moderate risk chest pain patients derive less benefit from invasive testing and therapies but derive significant benefit from identification of coronary artery disease (CAD) as it leads to higher utilization of medications that reduce cardiac events.[6] Additionally, those patients who undergo CCTA prior to ICA are less likely to have nonobstructive CAD on diagnostic coronary angiography.[7]

Higher acuity patients with chest pain may be better served by ICA than CCTA

Chest pain is the second most common reason for visits to the emergency department (ED), and accounts for more than 7 million visits annually.[8] Use of CCTA for the evaluation of chest pain in emergency room patients is increasing as well, with escalating use of this modality to triage patients and aid in early discharge. Early papers regarding the use of CCTA in performing "triple rule outs" for coronary disease, aortic dissection, and pulmonary embolus, were tempered with realistic concerns related to image quality, and use in the disposition of these

Abbreviations: ACS, acute coronary syndrome; AI, artificial intelligence; CABG, coronary artery bypass graft; CCTA, cardiac computed tomography angiography; ED, emergency department; FFrCT, fractional flow reserve computed tomography; ICA, invasive coronary angiography; PCI, percutaneous coronary intervention; RCA, right coronary artery.

Keywords: cardiac computed tomography angiography; chest pain; computed tomography; computed tomography coronary angiography; heart catheterization; interventional cardiology.

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https://doi.org/10.1016/j.jscai.2024.101301
Received 18 November 2023; Received in revised form 8 January 2024; Accepted 9 January 2024
Available online 26 March 2024

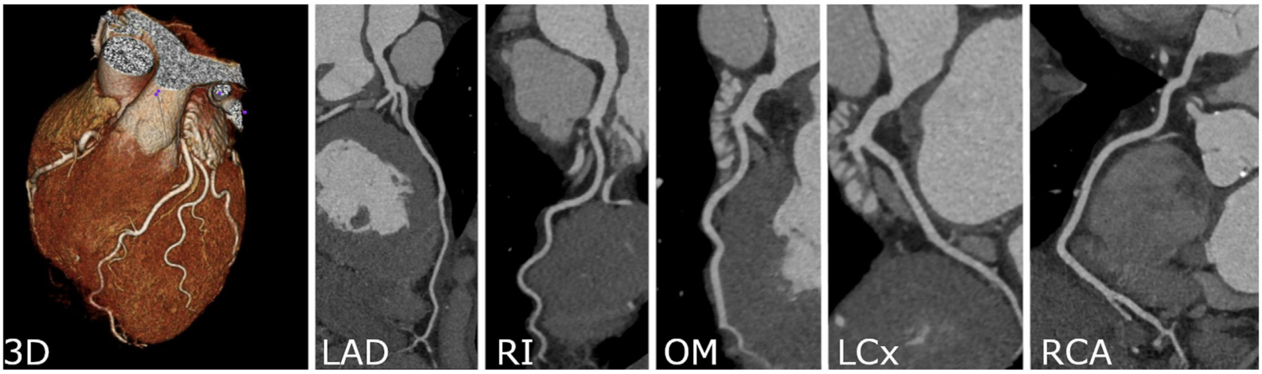


Figure 1.
Chest pain rule out in the emergency department: A patient with multiple risk factors for coronary disease and multiple visits to the emergency department for acute chest pain. The patient presented with a negative electrocardiogram and cardiac enzymes, with a self-reported history significant for myocardial infarction. Cardiac computed tomography angiography demonstrated normal coronary arteries, no pericardial effusion, no pulmonary emboli, or aortic dissection. Other than "minimal" aortic plaque, this study allowed safe discharge, as it did not suggest a cardiac or life-threatening etiology of the symptoms. LAD, left anterior descending (coronary artery); LCx, left circumflex (coronary artery); OM, obtuse marginal (coronary artery); RCA, right coronary artery.

higher-risk patients.[9] Appropriate use criteria have suggested CCTA is reasonable to be used for patients in low-to-intermediate risk groups, or in clinically stable patients with markers for non–ST-segment elevation myocardial infarction, but clearly recommend invasive evaluation for higher-risk non–ST-segment elevation myocardial infarction and ST-segment elevation myocardial infarction (Figure 1).[10]

Patient selection can aid in obtaining better CCTA image quality, which is important when the goal is to "rule out" coronary disease. In an

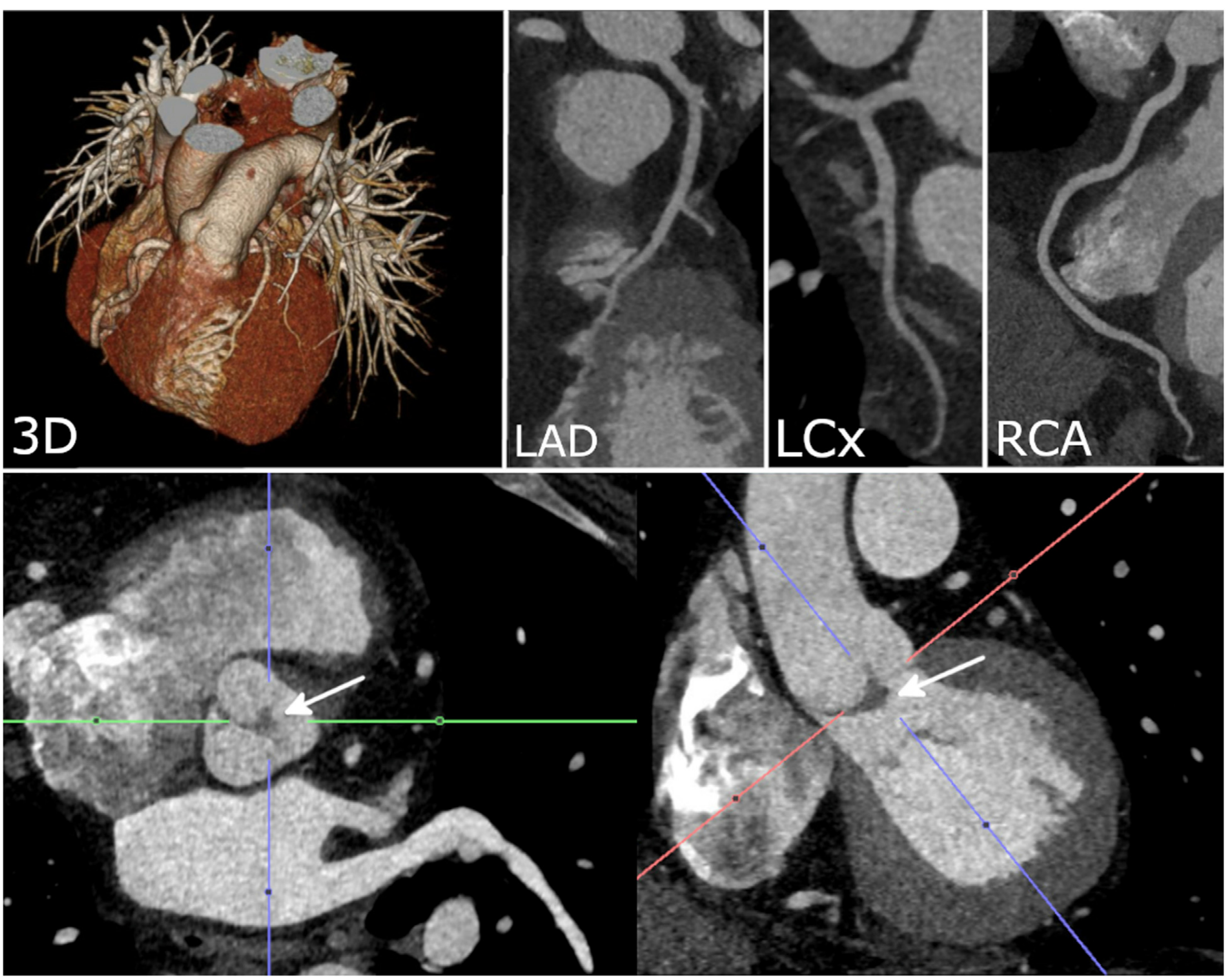


Figure 2.
Preoperative CCTA for a patient with endocarditis: The left anterior descending (LAD), left circumflex (LCx) and right coronary artery (RCA) are all free of disease. Aortic valve endocarditic lesions (arrows–bottom panels) are noted on the aortic valve. This patient went on to have valvular surgery, without the need for preoperative invasive coronary angiography.

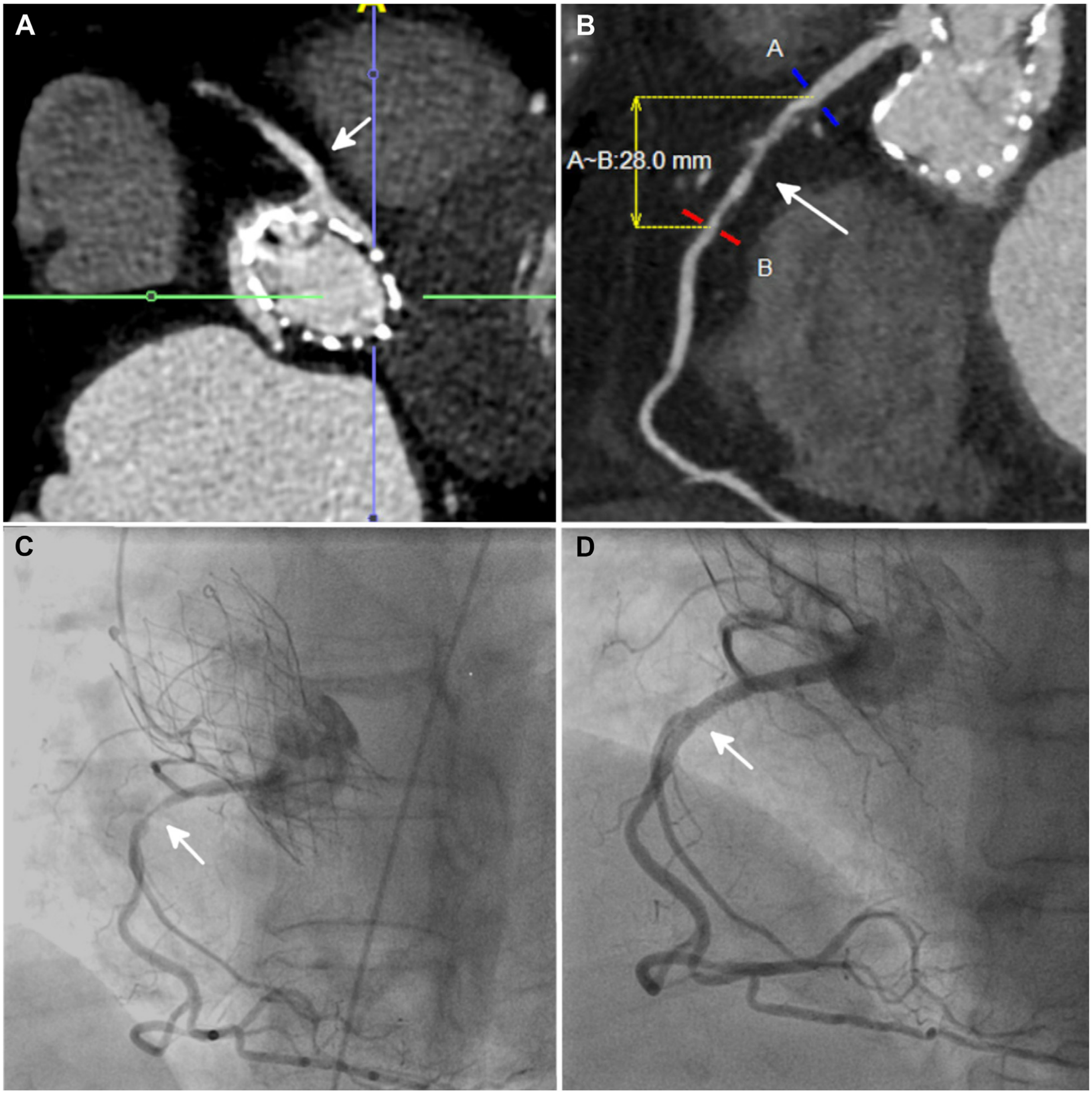


Figure 3.
Cardiac computed tomography angiography (CCTA) in a patient with prior transcatheter aortic valve replacement (TAVR): This patient received TAVR 4 years prior, now presenting with unstable angina. Cath at the time of TAVR placement showed mild disease. CCTA now indicates an anterior takeoff of the right coronary artery (RCA) (**A**–arrow) as evidenced by the "12 o'clock" orientation of the RCA ostium at the level of the sinus of Valsalva. Curved reformatted image showing lesion length and coronary sizing of a high-grade stenosis (**B**–arrow) in the proximal RCA. CCTA allowed the determination of stenosis, lesion length, and takeoff of the coronary ostia. Diagnostic invasive coronary angiography of the RCA, using an Amplatzer catheter, shows a high-grade stenosis (**C**–arrow) which was stented using a 2.5 × 28 mm drug-eluting stent (**D**–arrow), optimized to 3.0 mm.

ED population, it can be harder to select for ideal heart rate, body mass index, and ability to comply with breath holds, which impact CCTA image quality.[11,12] Additionally, due to the obligate contrast use, potential downstream complications such as contrast-associated nephropathy may impact the decision to utilize CCTA.

Although in some studies, CCTA may facilitate more direct discharges from the ED, studies have shown no change in downstream cardiac events, at the cost of more downstream testing and higher radiation exposure for patients.[13,14] In patients with low-risk chest pain in the ED, as defined by a low HEART Score and exclusion of acute coronary syndrome (ACS), there is little clinical benefit in the use of CCTA as a triage tool.[15] When admitted with true ACS, CCTA as a part of the up-front evaluation does not reduce the incidence of death or subsequent myocardial infarction and tends to increase the length of hospitalization.[16]

In higher-risk patients (eg, with active chest pain or ACS) up-front CCTA can delay definitive evaluation with ICA. With its extremely high specificity, CCTA is most helpful in allowing deferral of ICA in chest pain patients when the study shows completely normal coronaries or non–flow-limiting coronary disease. In hospitalized patients with chest pain, if coronary plaque is found, invasive evaluation is often the next step. Up-front CCTA with its obligatory need for contrast material may require additional time to allow contrast to "wash out," and typically will result in extended hospitalization. In general, low-to-moderate risk

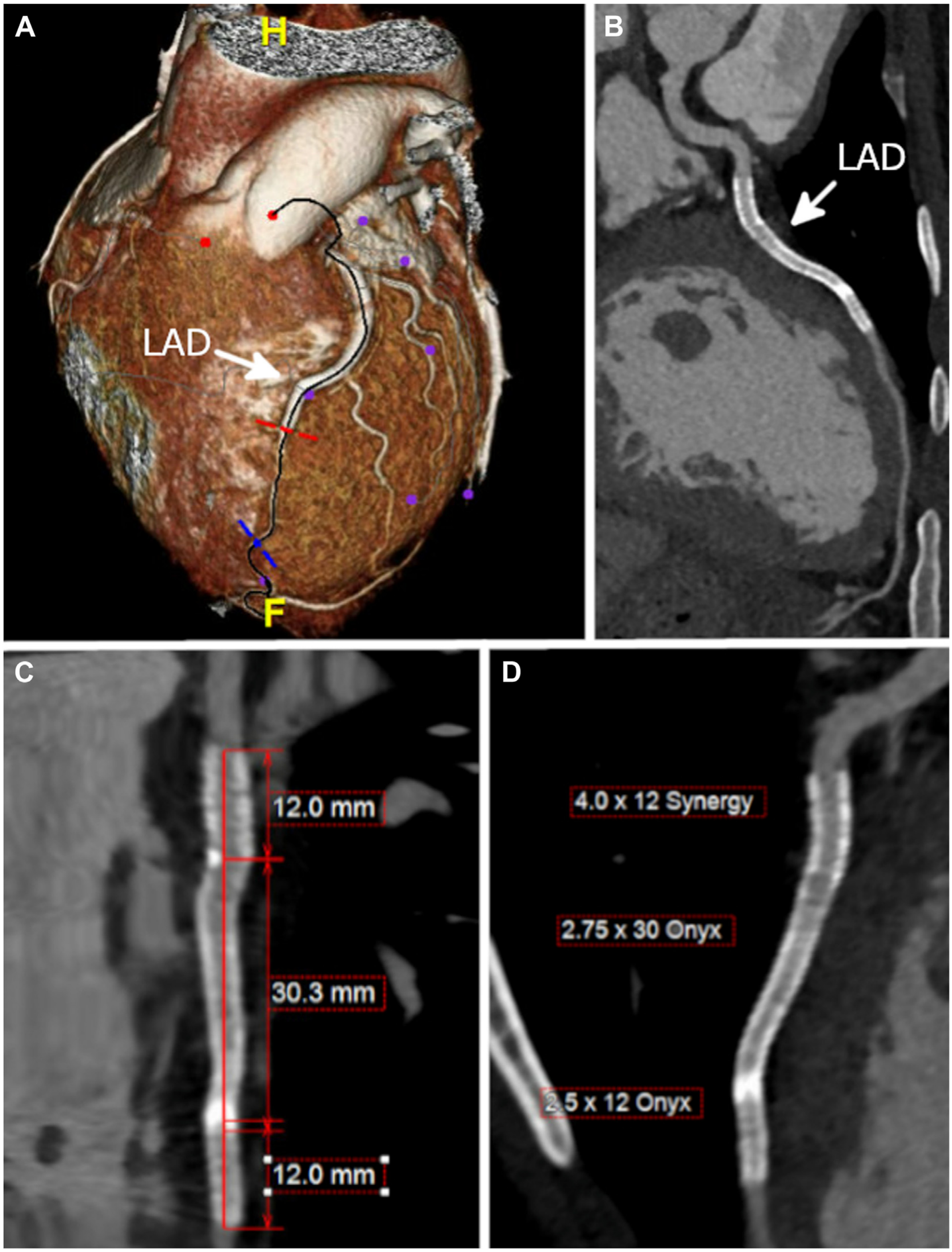


Figure 4.

Cardiac computed tomography angiography (CCTA) in a chest pain patient with a history of spontaneous coronary artery dissection (SCAD): CCTA is used to follow the patient with prior coronary stents placed after acute infarct due to SCAD. Three-dimensional coronary reconstruction (**A**) and curved reformat evaluation (**B**) show no new or residual coronary dissection, and absence of coronary atherosclerosis. Evaluation of the stents themselves shows patency of 3 overlapping stents (**C** and **D**). LAD, left anterior descending (coronary artery).

patients without ACS who present to the ED can be triaged clinically and neither stress testing nor CCTA (as a gatekeeper for catheterization) is clinically helpful in preventing future MI.[17]

Inpatient chest pain evaluation with CCTA

Similarly, in patients who have been admitted to the hospital for chest pain, there is good diagnostic accuracy and association between patients with plaque seen on CCTA and worse cardiac outcomes.[18,19] However, there is scarce data on the broader use of CCTA in the acute evaluation of chest pain patients, particularly in those with increased cardiac troponin concentrations or evidence of myocardial injury.[20] Although able to accurately determine the presence and severity of coronary disease, and obviate the need for invasive testing, CCTA: (1) may add to the delay of obtaining a definitive diagnosis, (2) may cause delay of ICA due to the need to reduce a patient's exposure to contrast, and (3) may not be able to exclude significant coronary plaque due to

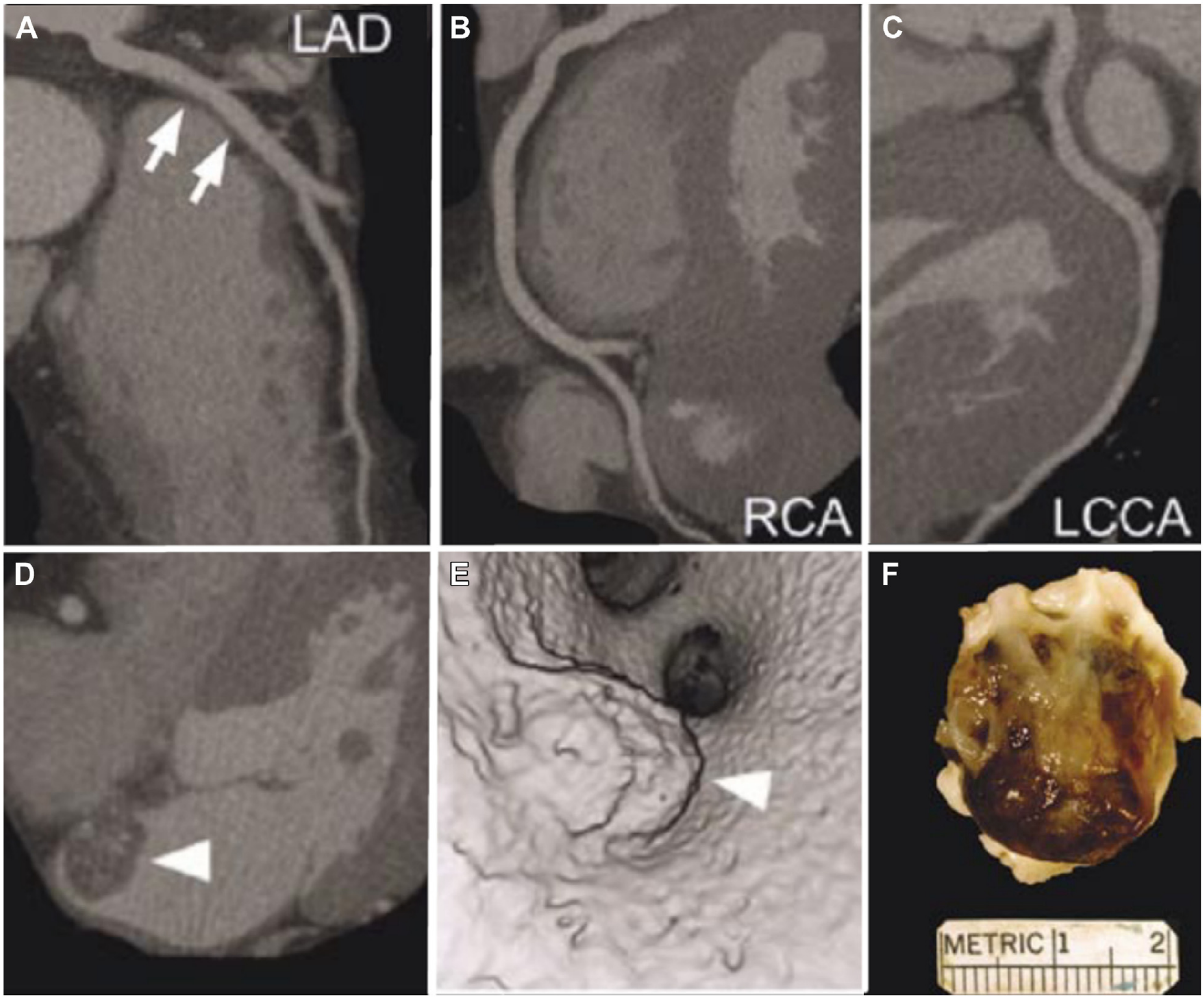


Figure 5.

Preoperative coronary evaluation for noncoronary surgery: Cardiac computed tomography angiography used for surgical preoperative evaluation of a patient with a left atrial myxoma. Curved reformatted images of the coronaries show minimal plaque in the proximal left anterior descending (**A**–double arrows). Normal right coronary artery (**B**) and left circumflex coronary artery (**C**). The mass is seen in the left atrium as a large flow void (**D**–arrowhead) and using 3D "navigator" view (**E**–arrowhead) which shows the relationship of the mass to the pulmonary arteries. The excised 2 × 2 cm myxoma is shown post removal (**F**). Reprinted with permission.[31] LAD, left anterior descending (coronary artery); LCCA, left coronary circumflex artery; RCA, right coronary artery.

body habitus or high heart rate. In studies looking at "emergency" CCTA, its use did not result in the reduction of length of stay or cost.[21]

CCTA to reduce the need for "high-risk" ICA

There are situations where ICA is felt to be necessary but may be associated with a high procedural risk. Surgery for infectious endocarditis (particularly involving the aortic valve) and prior to surgery for aortic dissection are situations in which obtaining angiographic information can be associated with embolic events.[22] CCTA can be used as an alternative to evaluate for coronary disease, and at the same time gain information about the aortic root (Figure 2).[23–25] Invasive catheterization in patients with mechanical valves is of higher risk due to bleeding or the need to stop anticoagulation prior to the procedure. In such cases, CCTA may be a safer choice than either performing an invasive evaluation while on anticoagulation or stopping anticoagulation temporarily. Additionally, CCTA gives information (similar to cinefluoroscopic modality) related to valve function, similar to or even superior to fluoroscopy at the time of ICA.[26] Likewise, in patients with transcatheter aortic valve replacement, CCTA can both determine the need for further invasive evaluation, as well as guide the choice of catheters prior to ICA (Figure 3).

Patients with prior ICA and intervention for spontaneous coronary artery dissection may be at high risk for ICA. CCTA as a subsequent test for recurrent chest pain allows for visualization of arteries to check for healing, new dissection, and even patency of previously placed stents (Figure 4).[27,28]

Preoperative coronary angiography for noncoronary cardiac surgery (such as valve surgery) or transcatheter aortic valve replacement is still recommended by guidelines but may no longer be necessary.[29] In situations where the pretest probability is low-to-moderate, it is reasonable (and in some cases such as in preoperative evaluation for aortic valve surgery, preferable) to get information related to both the coronary anatomy as well as the ascending aorta with CCTA.[30] Similarly, there are data suggesting that this type of noninvasive coronary imaging is useful in the preoperative assessment for other types of noncoronary, cardiac surgery (Figure 5).[31–33]

Post bypass surgery, in patients with chest pain, most of the information that is needed is related to the patency of grafts.[34] From a

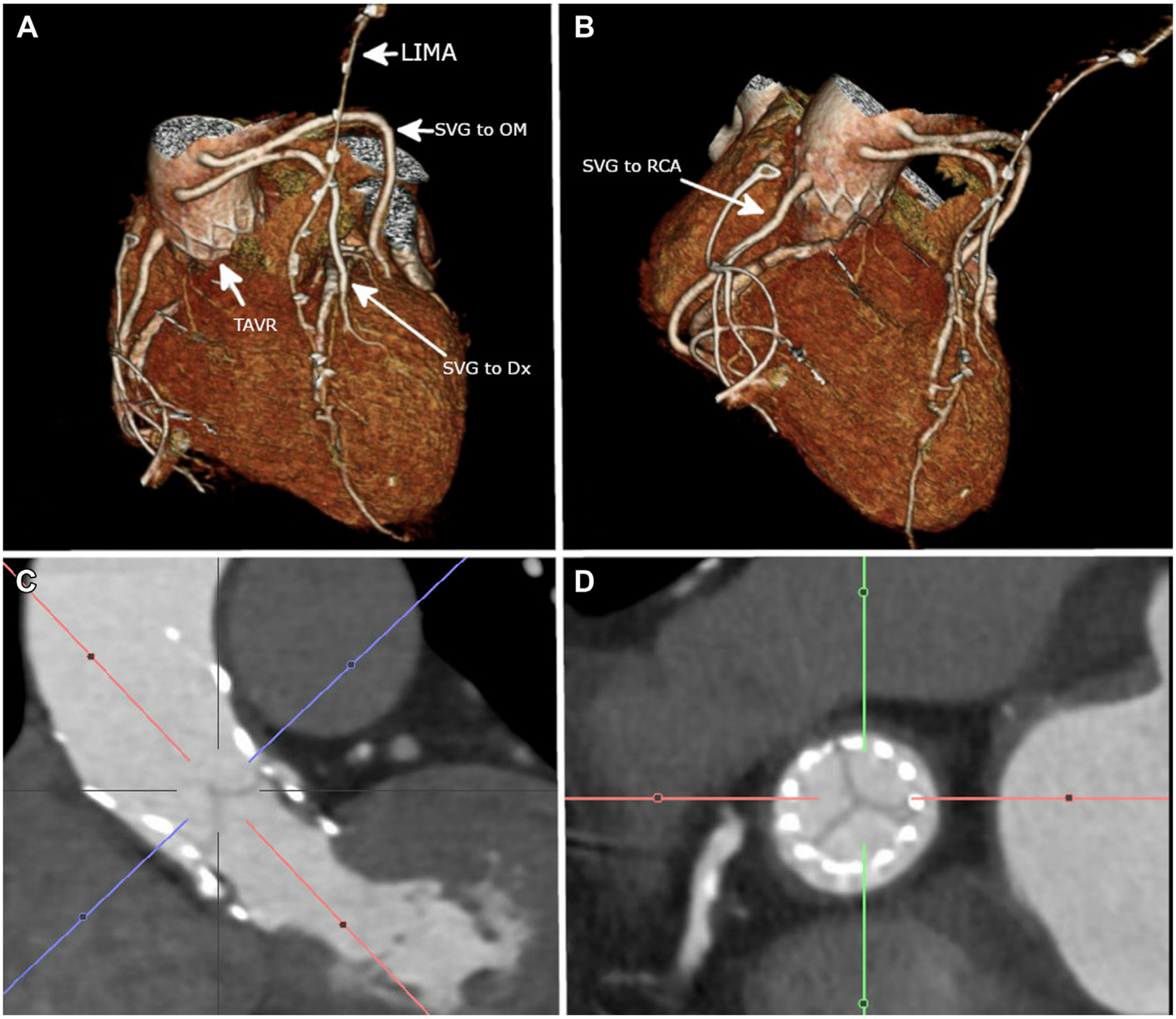


Figure 6.
Post coronary artery bypass graft (CABG) evaluation of graft patency: Cardiac computed tomography angiography (CCTA) of a patient post transcatheter aortic valve replacement (TAVR) and CABG × 4. Patency of grafts (LIMA to LAD, SVG to Dx, SVG to OM, SVG to RCA) are all identified. CCTA allows the additional benefit of evaluating the bioprosthetic valve for thrombosis, which was ruled out on this exam. Dx, diagonal branch (coronary artery); LAD, left anterior descending (coronary artery); LIMA, left internal mammary artery; OM, obtuse marginal (coronary artery); RCA, right coronary artery; SVG, saphenous vein graft.

technical standpoint, CCTA for determining graft patency is excellent and can guide the need for further (ie, invasive) testing or continued medical management (Figures 6 and 7).[35] When invasive evaluation is needed, particularly when an operative note is not available, pre-catheterization CCTA may save radiation, contrast, and time in allowing the operator to know where grafts are located as well as patency (Figure 8).[34]

Information for the interventionalist at the time of catheterization

In addition to the ability of CCTA to aid in the determination of the need for catheterization, there is information obtained that can assist the interventional cardiologist before invasive testing. A large portion of coronary angiography access is now through the transradial approach. Although safer from a complication standpoint, there are specific anatomic subsets such as subclavian tortuosity or arteria lusoria which make this approach more difficult. These anatomic variants can be discovered prior to entering the catheterization lab using CCTA (Figure 9).[36,37]

Determination of the presence of high-risk subsets of coronary disease (left main and multivessel coronary disease) can be identified prior to ICA, which can alter the method in which coronaries are engaged. Diagnostic and guide catheter choices can be made, and there can be preplanning for the need for hemodynamic support if the patient decompensates (Figure 10).[38,39]

Knowing the location and orientation of the coronary ostia can facilitate invasive catheterization, as can knowing whether the arteries are a normal variant or truly anomalous (Figure 11).[40] The axial images through the sinus of Valsalva and the ascending aorta can clearly show the location and orientation of the coronary ostia. In normal coronary anatomy, the right coronary artery (RCA) is typically located around "11 o'clock," whereas the left main coronary ostium is usually located around "4 o'clock." The RCA is typically felt to be more anterior at the "12 o'clock" location, whereas the posterior left main ostium is around "6 o'clock."[39] Noting that an RCA ostium is anterior would suggest the use of a different type of catheter, such as an Amplatzer-type catheter,

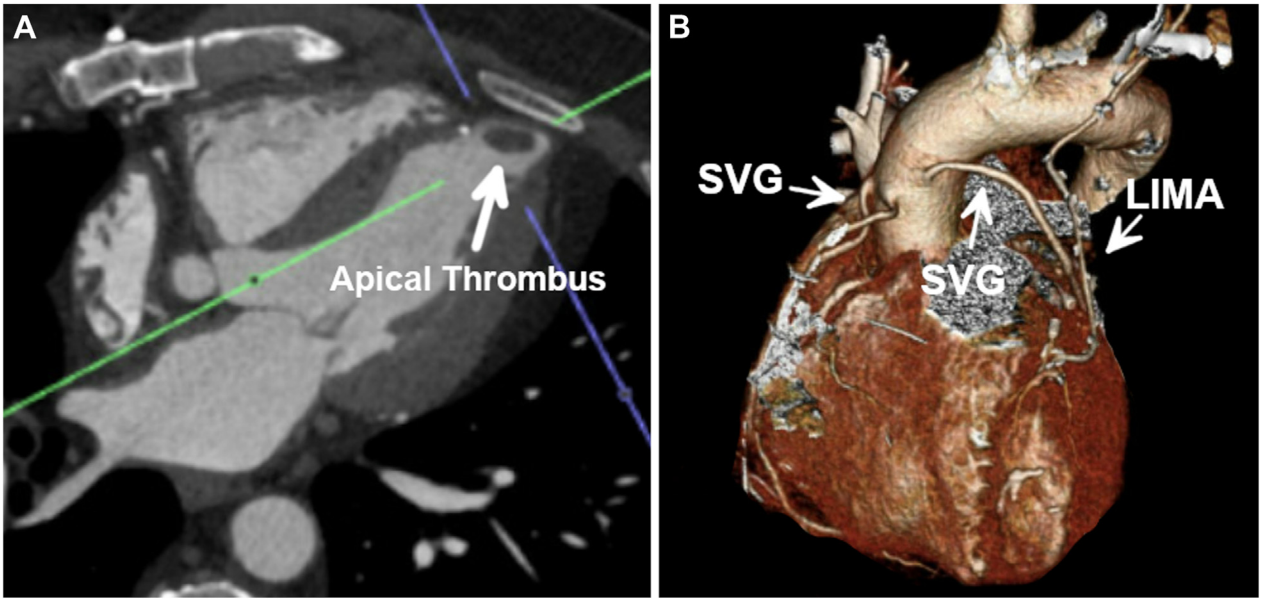


Figure 7.

High risk for invasive coronary angiography (ICA) post coronary artery bypass graft (CABG). Cardiac computed tomography angiography (CCTA) to evaluate for graft patency in a patient with known (severe) native coronary artery disease and left ventricular thrombus (**A**–arrow). CCTA, rather than ICA, was done preferentially to evaluate the patient's grafts without having to instrument the heart or hold oral anticoagulation, reducing the risk for embolic stroke. Patency of all grafts is noted, including a LIMA to the LAD, SVG to the Dx branch, and SVG to the RCA (**B**). Dx, diagonal branch (coronary artery); LAD, left anterior descending (coronary artery); LIMA, left internal mammary artery; RCA, right coronary artery; SVG, saphenous vein graft.

which facilitates engagement of the coronary artery and improves support during percutaneous coronary intervention (PCI) (Figure 12). A very posterior takeoff left main requires additional counter-clockwise torque (particularly from the right radial approach) to effectively engage.

Coronary anomalies (when discovered during an invasive heart catheterization) represent a scenario where a CCTA performed after the invasive procedure may be helpful in fully determining the true course and potential danger of a coronary anomaly.[41,42] Determining whether the left or right coronary arteries course between the aorta and pulmonary artery can assist diagnostic efforts and aid in surgical planning for correction (Figure 13).

Preplanning for PCI

Once significant CAD is found, there is additional information that CCTA can provide the interventional cardiologist when planning PCI. The presence of significant side branches at the location of coronary stenosis can alter stent length or type, whereas the presence and severity of plaque at a bifurcation can aid in the prediction of successful bifurcation stenting.[43] The use of CCTA to evaluate coronary distributions with regard to myocardial mass may be useful for both assessing the benefit of revascularization as well as potential negative outcomes should branch vessel occlusion occur. [44,45] Tortuosity and angulation of the arteries themselves can alter the timing of a case or the need for hemodynamic support. Lesion length and artery diameter can be measured prior to the invasive procedure, which can alter planned stent length and diameter (Figure 14). The composition of plaque and the presence of severe coronary calcification can change planning with regard to the need for plaque modification prior to stent placement.[46] With an increasing array of vessel preparation options including atherectomy, high-pressure balloons, intravascular lithotripsy, and drug-coated balloons, CCTA planning can increase efficiency and proper strategy to optimize PCI.

Recent data suggest that CCTA may aid in facilitating PCI in chronic total occlusions (Figure 15).[47,48] Understanding the course of the vessel can aid in both antegrade and retrograde approaches as well as understanding crossing strategies after carefully studying the characteristics of the proximal and distal atherosclerotic caps.

Use of functional assessment with fractional flow reserve computed tomography in the context of the COURAGE and ISCHEMIA trials

Invasive functional assessment of coronary stenosis is the standard of care in stenoses that are intermediate in severity, and there is good data supporting the benefit of intervening in those subsets that demonstrate functional flow limitation.[49] Fractional flow reserve computed tomography (FFrCT) utilizes mathematical algorithms to estimate coronary blood flow and thereby evaluate the functional significance of coronary stenosis. There are data demonstrating that in patients with nonsignificant stenoses diagnosed by FFrCT, deferring invasive evaluation has no negative sequelae given the high negative predictive value of this test.[50] However, these studies are in the setting of stable ischemic coronary disease, and it has been noted that the additional use of this modality tends to have a lower positive predictive value, can add significantly to the expense, and there is a known mismatch in higher severity stenoses when compared with ICA.[51–53]

In a higher acuity population, the use of FFrCT has been shown to have potential issues with both false negative and false positive results, and may not be as applicable in this population.[54,55] In the era of the COURAGE and ISCHEMIA trials, it has become clear that even in moderate subsets of ischemic coronary disease, deferring invasive evaluation is safe, and so additional functional assessment may be of less value.[56] Functional assessment of coronary flow, as an adjunct to anatomic evaluation using CCTA is becoming more robust, and multiple studies are being done expanding the use in the evaluation of patients for coronary disease. That being said, the accuracy is not 100%,

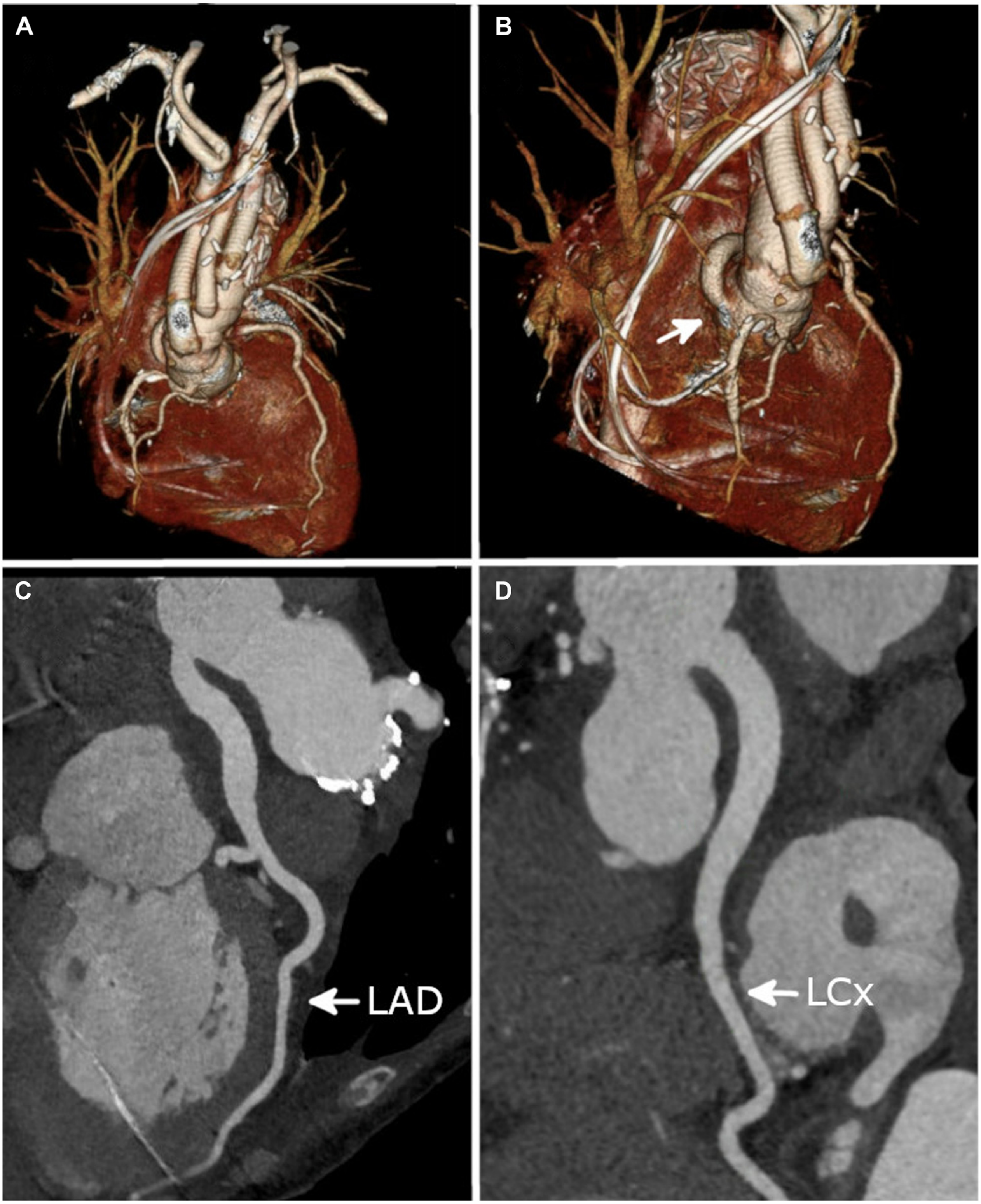


Figure 8.

Postaortic dissection and coronary artery bypass graft (CABG): Cardiac computed tomography angiography of a patient with prior surgery for ascending aortic dissection, which included CABG, the details of which were not known. CCTA demonstrates the replacement of the ascending aortic arch and reimplantation of the great vessels (**A**) with a modified "Cabrol" procedure including the posterior location of the bypass conduit to the left system (**B**–arrow). Patency of the conduit to the LAD and LCx is noted (**C**, **D**). It is noted that engagement of the coronaries during invasive coronary angiography may have been difficult, even if the ostia locations had been known. LAD, left anterior descending (coronary artery); LCx, left circumflex (coronary artery).

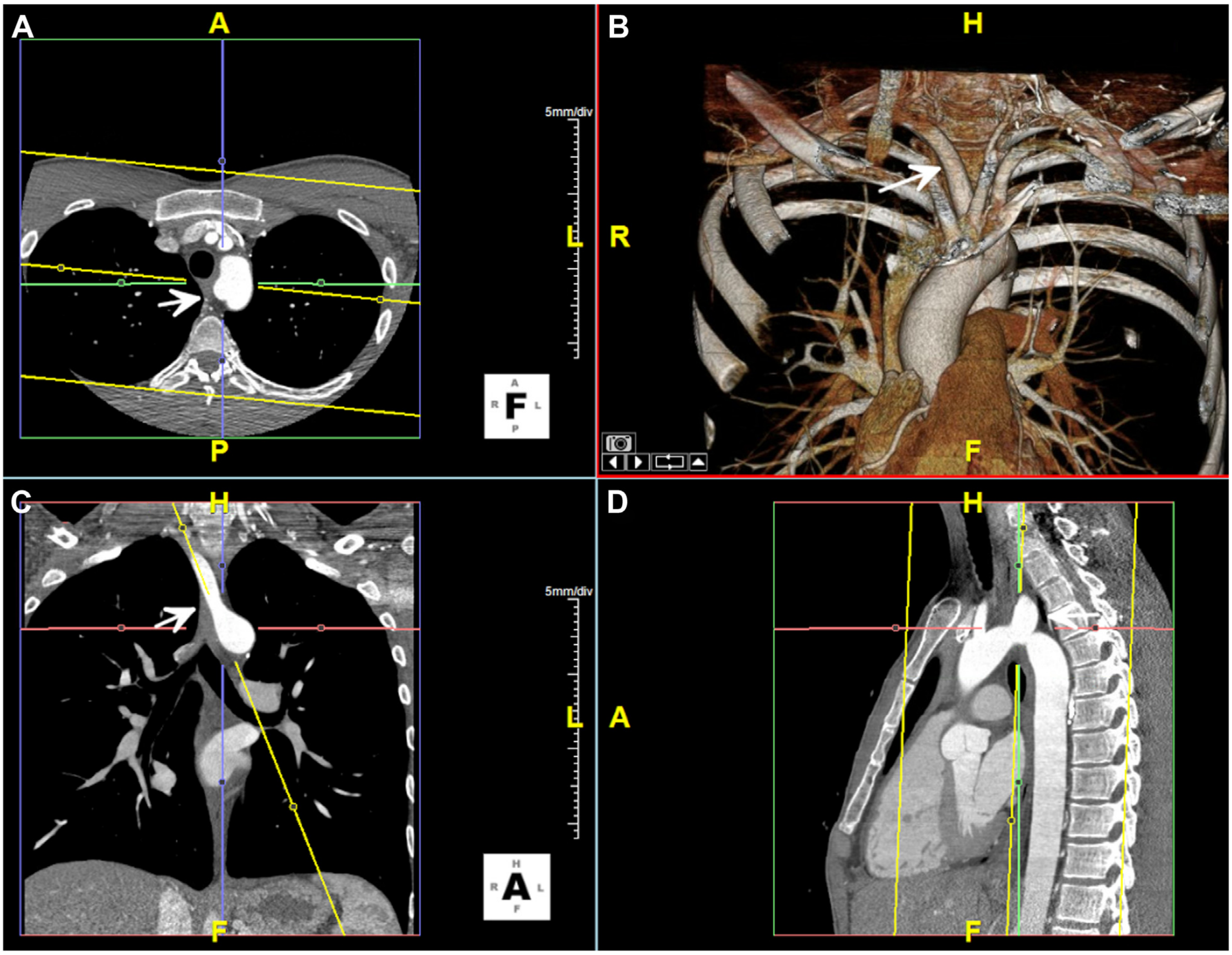


Figure 9.

Arteria lusoria: Cardiac computed tomography angiography of a patient demonstrating aberrant right subclavian artery (so-called "arteria lusoria") which can be challenging to navigate during a coronary angiogram performed through the right radial artery approach. Aberrant origin of this most-distal great vessel seen in axial (**A**–arrow), 3D (**B**–arrow), coronary (**C**–arrow) and saggital (**D**–arrow) views.

and there are still situations in which the clinical scenario and the CT results are discordant with angiographic findings. It is up to the interventional cardiologist to use those additional invasive tools to fully evaluate those patients in the catheterization laboratory (Figure 16).

Additionally, the pattern of coronary disease, and whether stenoses are focal or diffuse, can be determined angiographically by CT as well as functionally by FFrCT. These patterns of coronary disease, focal or diffuse, can impact both procedural as well as clinical outcomes, and so

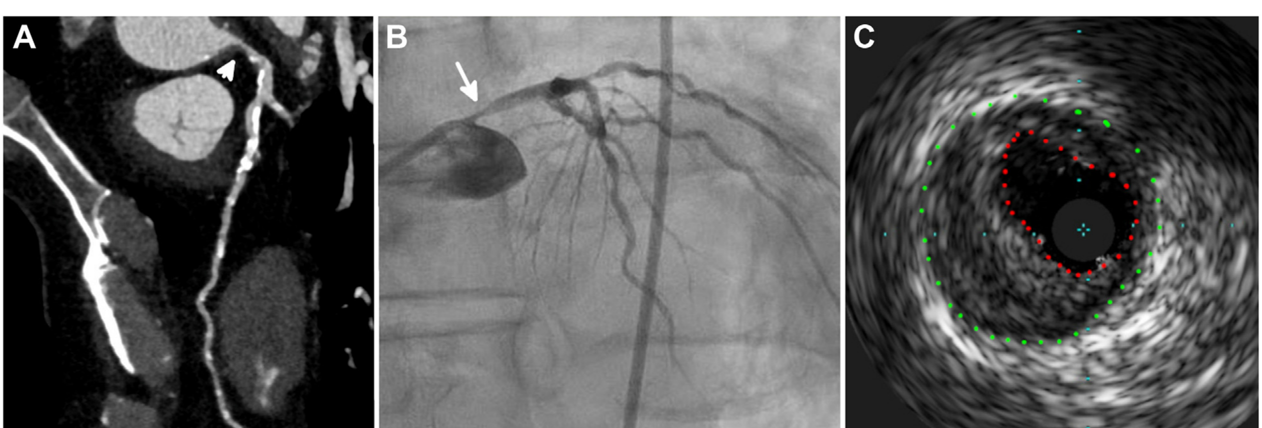


Figure 10.

Left main disease: Patient with chest pain–left main disease seen on cardiac computed tomography angiography (A–arrow), invasive angiogram (B–arrow), and confirmed by intravascular ultrasound (C-red dots indicating lumen, green dots indicating media of artery).

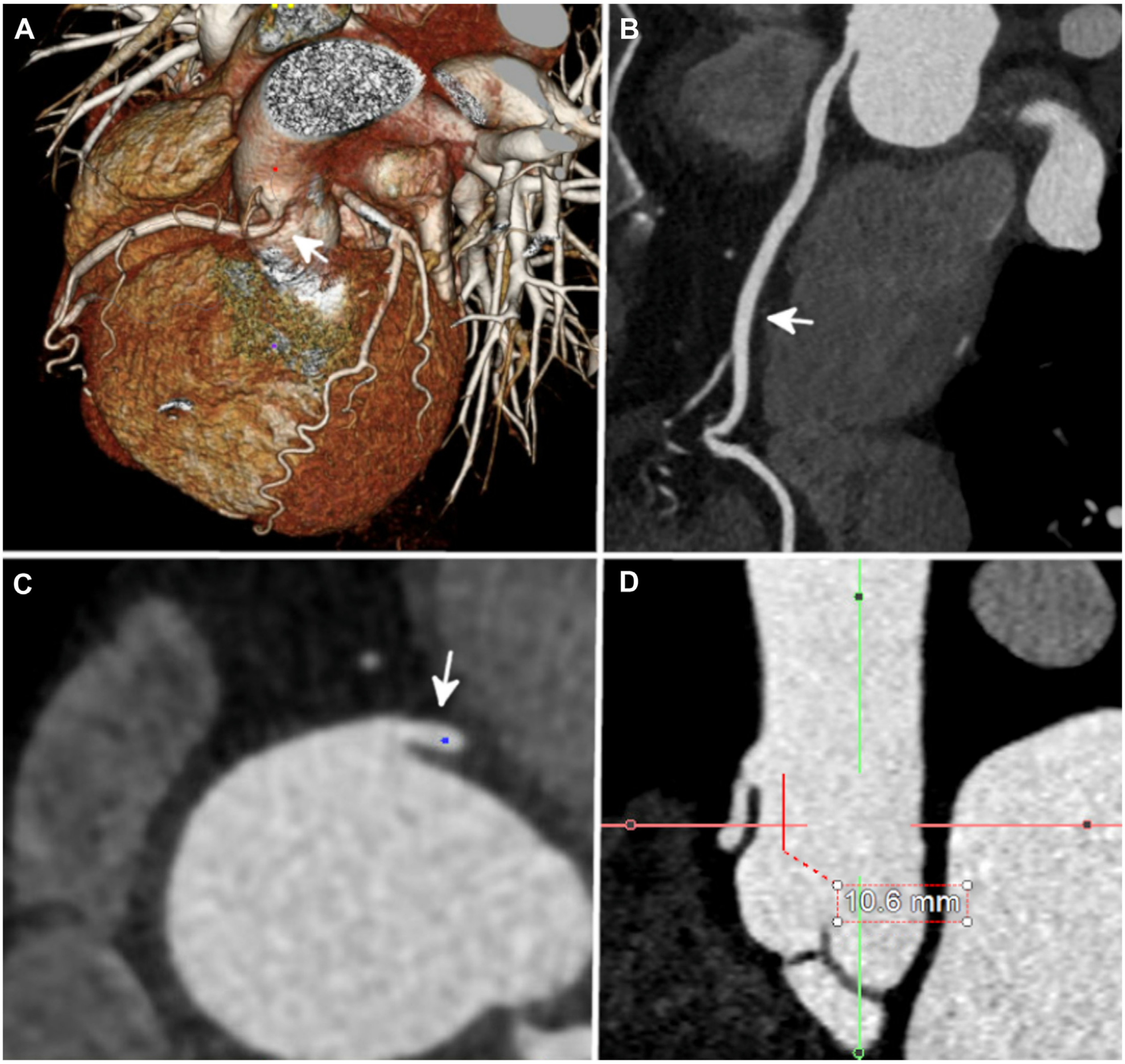


Figure 11.
Ostia orientation and location. Cardiac computed tomography angiography demonstrating an anterior takeoff of the right coronary artery shown on 3D reconstruction (**A**–arrow) without significant coronary disease in the body of the artery (**B**–arrow). Axial images (**C**–arrow) show the anterior origin and takeoff of the proximal portion of the artery. The origin is approximately 10 mm above the sinus of Valsalva (**D**).

are pertinent pieces of information to know prior to PCI.[57,58] Patients with nonobstructive, diffuse CAD found on CCTA might still be considered for further evaluation with PET or invasive coronary testing to ascertain coronary flow reserve, microvascular function, and vasospasm.

Future directions for CCTA: Artificial intelligence and CCTA for coronary artery bypass graft

Future directions for CCTA will focus on increasing the accuracy of the diagnosis of coronary disease severity and predicting future events. The characterization of "vulnerable plaque" by CCTA is now being looked at to predict (and in some cases prevent) future cardiac events with PCI.[59]

There is the potential for obviating the need for confirmative ICA in patients discovered to have surgical coronary disease by CCTA. Studies, such as FastTrack coronary artery bypass graft (CABG), are underway evaluating the outcomes of CCTA-directed surgical bypass compared to ICA-guided referral, without the need for invasive diagnostics prior to CABG.[60]

Artificial intelligence (AI) is being leveraged to support CCTA readers and improve accuracy in the evaluation of coronary stenoses.[61] AI may also become helpful in determining the potential for successful PCI related to calcium burden, the complexity of anatomy, as well as the myocardial volume subtended by a particular coronary distribution.[62] Future directions of the use of AI may include the ability to highlight areas of concern in the coronary tree, and "pre-plan" coronary interventions using a combination of anatomic and functional imaging.[63]

Ultra-high resolution CT, utilizing photon counting, will likely be the next major improvement in coronary imaging. This technology allows for higher spatial resolution, lower noise, less radiation, and improved ability to identify plaque characteristics.[64] It also improves

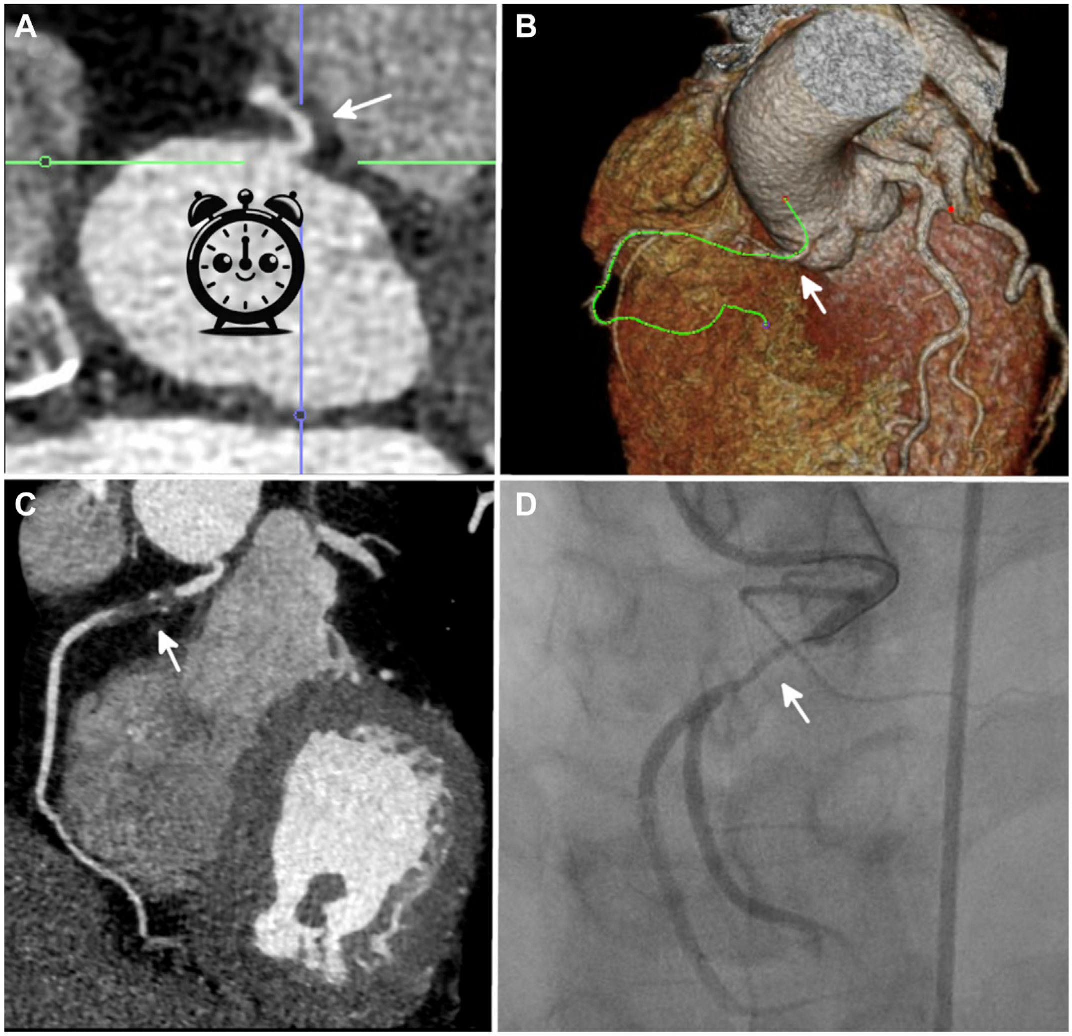


Figure 12.

Choosing appropriate guiding catheters: Cardiac computed tomography angiography of a 52-year-old man with chest pain. The ostium of the right coronary artery (RCA) is at "12 o'clock" in the axial images of the aortic root (**A**) suggesting a very anterior takeoff. This is also confirmed with 3D reconstruction (**B**). Curved reformat images suggest a high-grade stenosis (**C**) of the proximal RCA. Engagement of the artery is performed using an Amplatzer Left 0.75 guide, providing support for wiring (**D**) and ultimately percutaneous coronary intervention of this stenosis. As the origin of the RCA was from the right coronary cusp, it was not truly "anomalous," but its location increases the difficulty in engaging using standard catheters.

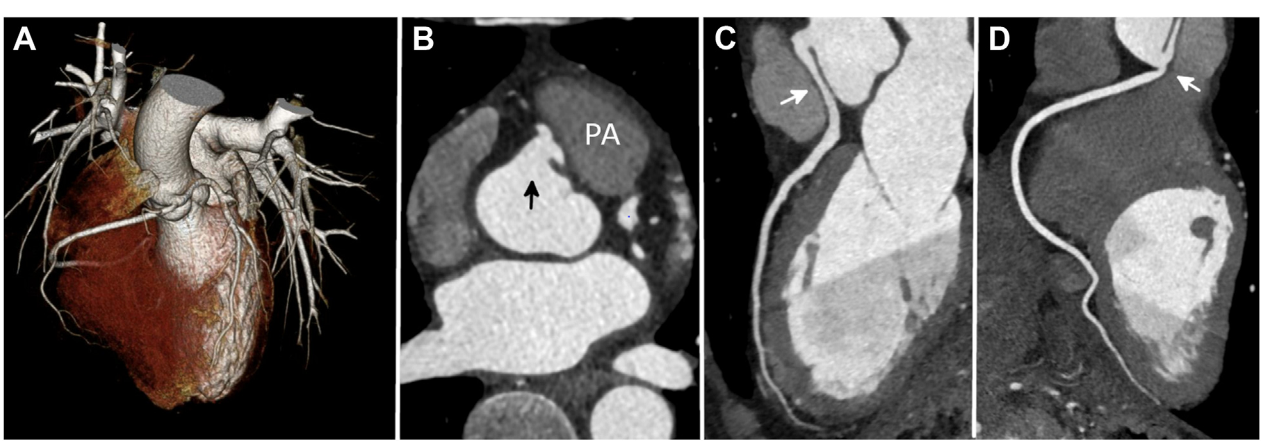


Figure 13.

Coronary anomaly with high-risk anatomy in a patient with chest pain. Single coronary (R-IIB subtype) showing an anterior takeoff of the coronary from the right coronary cusp in 3D (**A**) and axial (**B**–arrow) imaging. The interarterial portion of the coronary is free of disease but has a significant caliber change as it passes between the pulmonary artery (PA) and the sinus of Valsalva (**C**–arrow). The right coronary artery is likewise free of disease (**D**–arrow). No further invasive imaging is needed to determine the course of this anomalous coronary.

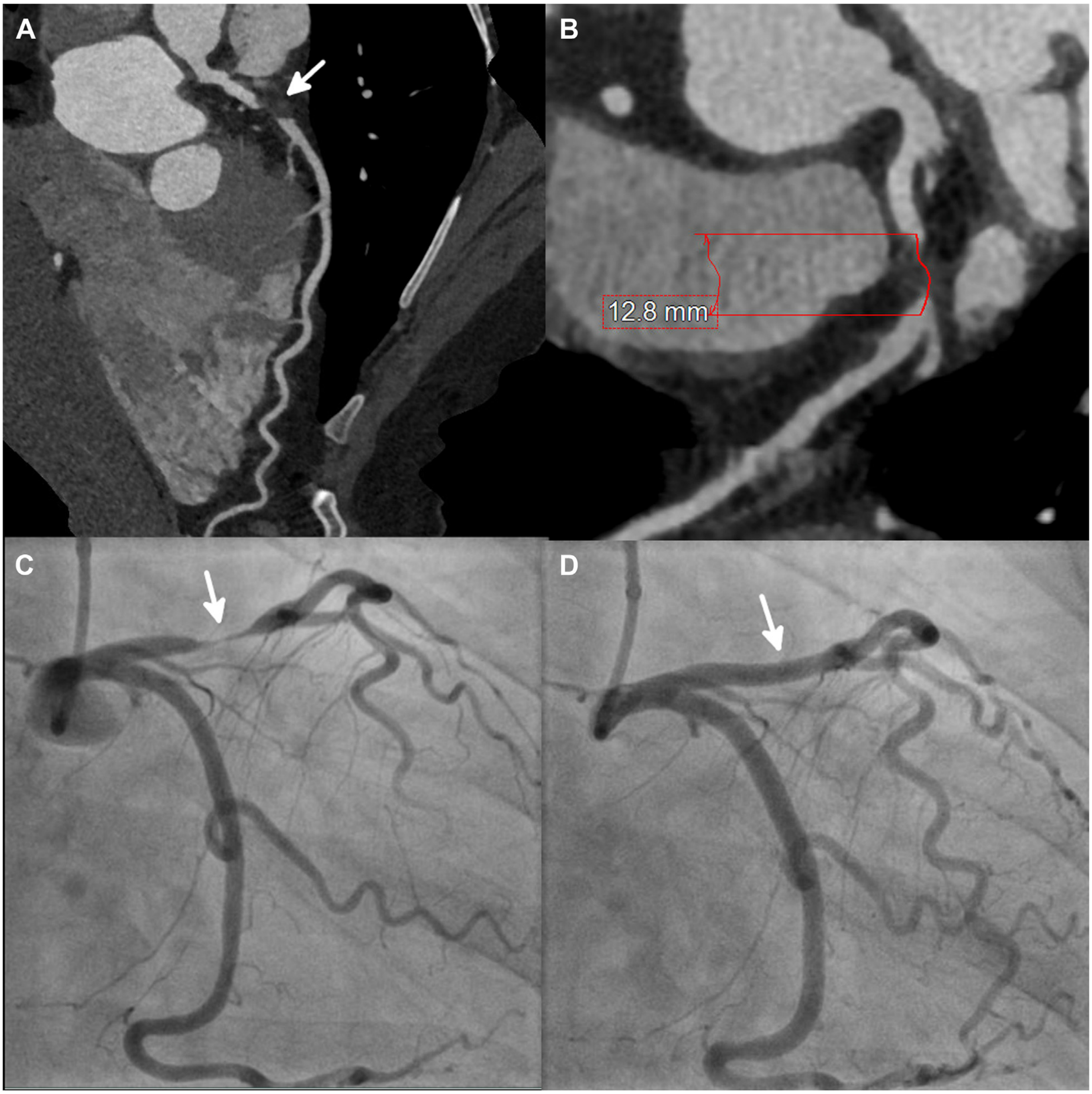


Figure 14.
Pre-percutaneous coronary intervention stent planning. Cardiac computed tomography angiography showing high-grade stenosis in the proximal left anterior descending (coronary artery) (**A**–arrow), with measurement of the stenosis approximately 13 mm (**B**). Angiographic evaluation of the coronary arteries confirmed location and severity (**C**–arrow). A 3.5 × 15 mm drug-eluting stent (optimized to 4.0 mm) was placed successfully (**D**–arrow).

upon current CT technology with regard to imaging of arteries with previously placed stents.[65] Integration of imaging modalities in a catheterization laboratory setting holds the potential to give on-demand, real-time analysis to the interventionalist at the time of ICA. Fusion of noninvasive, functional as well as anatomic imaging can potentially be available as another tool to complement angiography, intravascular ultrasound, and optical coherence tomography.[66]

Conclusion

Cardiac computed tomography angiography is an excellent tool for the evaluation of patients with low-to-moderate risk, stable ischemic cardiac disease. It allows for decisions to be made as to whether a patient may benefit from further invasive evaluation or therapy, and at the same time can definitively show who would benefit from lipid-lowering and antiplatelet therapy. It can obviate the need for coronary angiography in some patients who need cardiac surgery, can help with PCI planning, and is the gold standard for the evaluation of coronary anomalies. In patients with active chest pain, CCTA does not add significant additional benefit and may delay needed invasive testing, add to cost, and delay discharge. There is a need for further research to study the benefits of CCTA as a counterpart to, and in conjunction with ICA, as it may facilitate interventional cardiologists' workflow and invasive coronary procedures (Central Illustration).

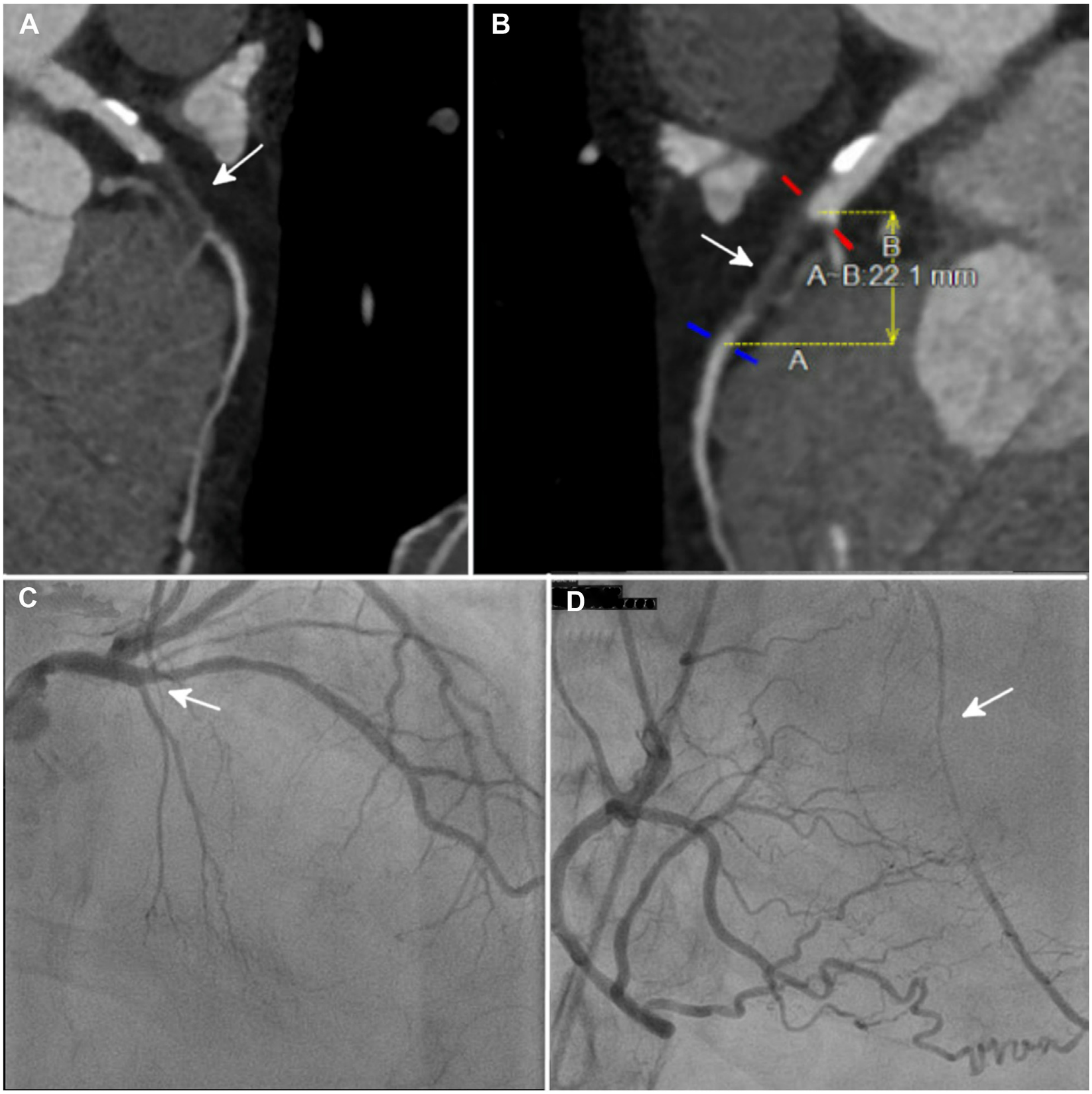


Figure 15.

Chronic total occlusion (CTO). Cardiac computed tomography angiography (CCTA) showing CTO of the proximal LAD (**A**, **B**–arrow). The length of the CTO, presence of side branches, and degree of calcification of the occlusion could be evaluated prior to invasive catheterization and assisted in preprocedural planning. Invasive catheterization demonstrated the CTO with an antegrade injection of the left coronary system (**C**–arrow) and retrograde filling through collaterals from the RCA (**D**–arrow). Note: In an occluded artery, it is not possible to determine by CCTA whether the distal filling of the artery is from antegrade or retrograde flow. LAD, left anterior descending (coronary artery); RCA, right coronary artery.

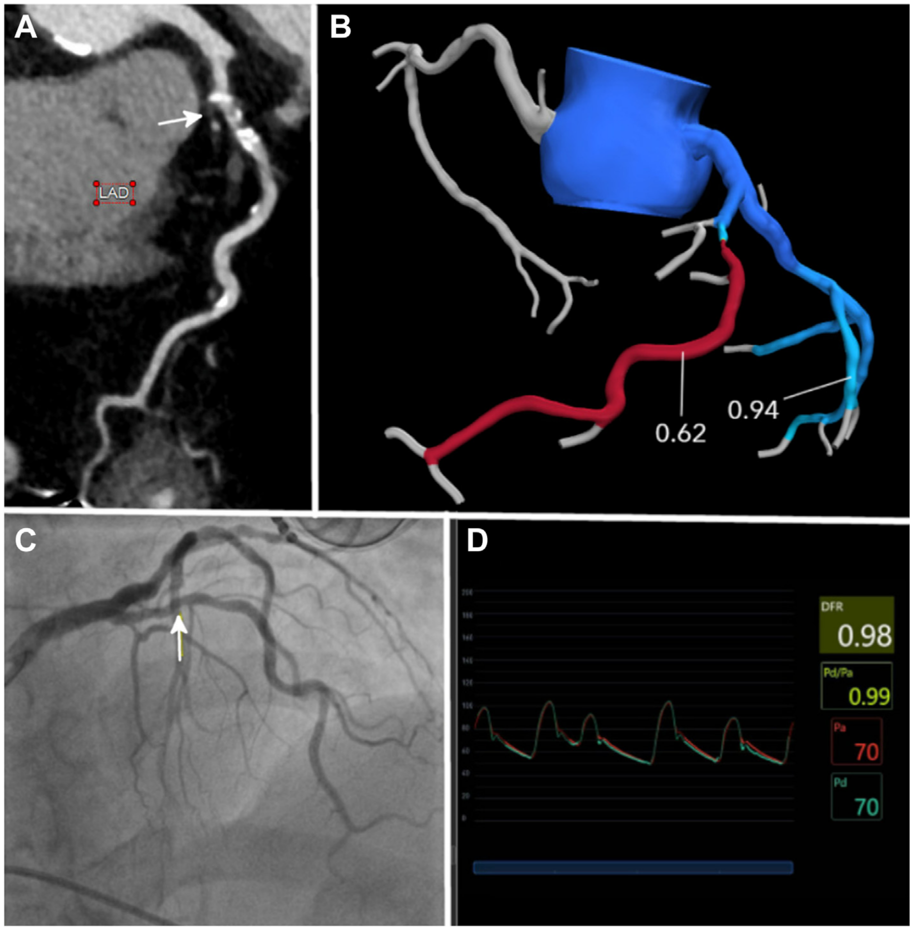
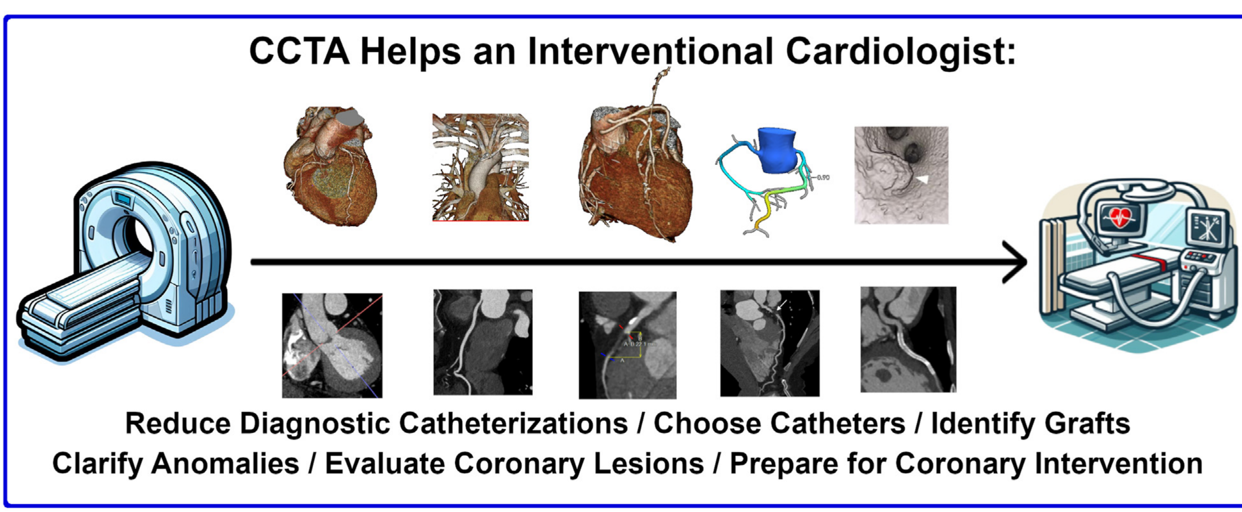


Figure 16.
Functional testing using fractional flow reserve computed tomography (FFrCT)–false positive. Cardiac computed tomography angiography demonstrating plaque in the proximal LAD (**A**–arrow) with FFrCT suggesting significant flow reduction past the stenosis (**B**). Invasive angiogram shows less-impressive visual estimation of stenosis (**C**–arrow) with invasive physiologic evaluation (**D**) suggesting nonsignificant flow reduction. LAD, left anterior descending (coronary artery).



Central Illustration.
Cardiac computed tomography angiography (CCTA) is useful to an interventional cardiologist in many situations, assisting in the evaluation of patients prior to their invasive cardiac procedure.

Declaration of competing interest

Robert J. Widmer is an advisor for Abbott, Philips, Gore, and Medtronic and a speaker for Gore and Abbott. Yader Sandoval reports the following: Abbott Diagnostics (advisory board), Roche Diagnostics (advisory board, speaker), Philips (advisory board), Zoll (advisory board), Patent #20210401347 (machine learning models for ECG-based troponin level detection), Member, IFCC Committee on Clinical Applications of Cardiac Bio-Markers (IFCC C-CB), Member, ACC Interventional Section Leadership Council, Associate Editor, *JACC: Advances*. Zachary P. Rosol, Subhash Banerjee, and Jeffrey M. Schussler reported no financial interests.

Funding sources

This work was not supported by funding agencies in the public, commercial, or not-for-profit sectors.

Ethics statement and patient consent

This article was written in accordance with appropriate ethical guidelines.

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