

Coronary CT angiography (CTCA): current status

AngioTC coronario (ATCC): estado actual

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Summary
The evolution of CCTA has been remarkable in the last 20 years, becoming now the first-line test in numerous clinical scenarios in patients with coronary artery disease (CAD). New AHA/ACC, UK and European guidelines strongly advocate CCTA in patients with stable or chronic CAD. The addition of functional testing (FFR-CT/PCT) further expands the utility of CCTA by allowing simultaneous assessment of cardiac anatomy and function. The possibility of displaying non-obstructive coronary atherosclerosis in a noninvasive manner allows CCTA to diagnose CAD earlier, facilitating the implementation of timely preventive treatments with better performance in this field than functional stress tests, which usually require severe stenosis to detect the disease. The validation of CCTA following large-scale clinical trials, such as PROMISE and SCOT-HEART, continue to reinforce the clinical utility of this test. Technological advances in image quality, study acquisition, post-processing, and radiation dose reduction allow for wider and safer use of this diagnostic modality today, as recommended by current guidelines and as we see in our experience in this field.

Resumen
La evolución de la ATCC ha sido notable en los últimos 20 años, lo cual la ha convertido en la prueba de primera línea en numerosas situaciones clínicas de los pacientes con enfermedad arterial coronaria (EAC). Nuevas directrices de la AHA/ACC, del Reino Unido y de Europa abogan firmemente por la ATCC en pacientes con EAC estable o crónica. La adición de pruebas funcionales (FFR-TC/TC Perfusión) amplían aún más la utilidad de la ATCC para evaluar simultáneamente la anatomía y la función cardiaca. La posibilidad de visualizar la aterosclerosis coronaria no obstructiva de manera no invasiva hace que la ATCC permita el diagnóstico precoz de la EAC, lo cual facilita la implementación de tratamientos preventivos tempranos con mejor desempeño en este campo que las pruebas funcionales de estrés, que suelen requerir una estenosis grave para detectar la enfermedad. La validación de la ATCC posterior a los ensayos clínicos a gran escala, como PROMISE y SCOT-HEART, siguen reforzando la utilidad clínica de este examen. Los avances tecnológicos en la calidad de imagen, la adquisición de los estudios, en el posprocesamiento y en la reducción de la dosis de radiación permiten un uso más amplio y seguro de esta modalidad diagnóstica en la actualidad, como lo recomiendan las guías vigentes y como lo ven los autores de acuerdo con su experiencia en este campo.

Introduction
Coronary artery disease (CAD) remains the leading cause of death worldwide, and in the United States, one in seven deaths is attributable to this disease (1, 2). Angina pectoris is the most common symptom of ischemic heart disease and affects more than 100 million people worldwide (3).

Coronary CT angiography (CCTA) has become an important diagnostic tool that allows for the non-invasive evaluation of CAD. This review will describe the current state of CCTA, highlighting its major technological advances, the evolution of concepts in CAD, the evidence supporting its current clinical applications, the main indications and contraindications, and the standardized CAD-RADS 2.0 reporting system.

Technological Advances in CTCA
In the 1990s, the development of spiral or helical CT technology, along with subsequent advances in detector elements and the use of electrocardiographic synchronization, made it possible to perform non-invasive evaluation of the coronary tree using CCTA. In the decades that followed, the development of CT technology has led to significant advances, such as improved temporal and spatial resolution, iterative reconstruction algorithms, extensive longitudinal coverage, and multi-source technology.

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CCTA scans saw increased clinical use beginning in 2004 with the introduction of 64-detector-row CT scanners, which at that time had a spatial resolution of 0.625 mm, a temporal resolution of 250 ms, retrospective electrocardiographic synchronization, and radiation doses ranging from 12 to 22 mSv.

Spatial resolution

Spatial resolution is defined as the ability to distinguish two adjacent structures as separate structures. It is influenced by several factors: detectors, slice thickness, *pitch*, reconstruction parameters, filters, and artifacts. State-of-the-art CT scanners with 320 detector rows (640 slices) report a spatial resolution of 0.3 mm, and recently, photon-counting CT (PCCT) scanners have achieved a resolution of 0.2 mm (4). Due to the characteristics of their detectors, PCCT scanners measure the energy of X-ray photons and quantify them individually, which reduces electronic noise, beam hardening, and metallic artifacts while providing a higher signal-to-noise ratio and spatial resolution—features that make them potentially suitable for imaging patients with coronary stents (5).

Temporal resolution

Temporal resolution is the time required to acquire the data needed to generate an image. Temporal resolution is affected by the gantry rotation speed, image reconstruction—that is, prospective versus retrospective synchronization—pitch, the number of tubes (sources), and the post-processing algorithm. Current third-generation dual-source CT scanners (2 × 192 detector rows) can achieve a temporal resolution of up to 66 ms (6). A dual-source CT (DSCT) scanner contains two sets of tubes/detectors, arranged at angles of approximately 90 degrees to each other. The higher temporal resolution of the DSCT allows for diagnostic coronary angiography studies to be performed at heart rates higher than those required by other CT scanners (7).

Iterative Reconstructions (IR)

Iterative reconstructions (IR) have been developed to improve image quality and reduce noise (8, 9). IR techniques use images obtained from Filtered Back Projection (FBP) to generate new projection data, which are then compared with the originals, and noise corrections are applied. This process is repeated (i.e., iterated) several times. Reconstruction methods have the enormous advantage of reducing radiation dose while maintaining good image quality, as has been demonstrated in the literature (10).

Tomographs with wide longitudinal coverage

With 640-slice CT scanners (320 detector rows) that provide wide longitudinal coverage (16 cm), all images for a cardiac CT study can be acquired with a half-rotation of the gantry and within a single RR interval of the cardiac cycle in patients with a heart rate of less than 65 beats per minute, which significantly reduces the radiation dose (0.5–3.5 mSv) and eliminates staircase artifacts.

The latest advances in CCTA allow for the functional assessment of CAD, either through stress-induced myocardial perfusion imaging with CCTA (CT-P) or by calculating fractional flow reserve derived from CT (FFR-CT). Currently, applications based on artificial intelligence (AI) are significantly increasing the amount of information that can be extracted from CCTA data, including the automatic quantification of coronary atheromatous plaques (calcified and non-calcified), quantification of atherosclerotic burden, analysis of ventricular wall motion, analysis of peri-coronary fat density to identify active inflammatory processes in CAD, and analysis of deformation and volumetric function, among others.

In current clinical practice, a wide variety of CT scanners are used, ranging from first-generation systems with 64 detector rows to systems with wide longitudinal coverage (80, 128, 160, 192, 256, and 320 detector rows), dual-source systems (DSCT), and, more recently, photon-counting CT (PCCT). This results in significant variability in technical parameters, radiation dose, image quality, and the diagnostic information obtained from CT studies of the chest, depending on the equipment used—a factor that must be taken into account when analyzing the results of these exams. Higher spatial and temporal resolution, along with greater longitudinal coverage, improves image quality and consistency. Due to the wide variety of multi-slice CT scanners used in clinical practice for CCTA studies, it is impractical to describe the protocols for performing these examinations, as there would be virtually a different protocol for each CT scanner model.

Although numerous measures are available to quantify radiation in clinical images, the effective dose in mSv is the most useful for comparing radiation doses across modalities, and it is defined as the sum of the weighted organ absorbed doses. The effective dose is calculated by multiplying the dose-length product (DLP) by a factor k, which is 0.014 0,014 mSv.mGy-1.cm-1 for the heart, according to the guidelines of the European Commission and the American Association of Physicists in Medicine for chest CT in adults (11).

The PROTECTION series of studies illustrates the rapid evolution of technology and its adoption in clinical practice, with a 78% reduction in the median dose-length product (DLP) from 2007 to 2017 (885 [IQR 560–1,239] to 195 [IQR 110–338], $p < 0.001$) without a significant deterioration in image quality (12). Although these results can be attributed largely to increased awareness of dose-reduction protocols, scanner technology has improved enormously during this time, making it possible to perform CT scans at doses below 1 mSv, provided the appropriate equipment and training are available.

We briefly describe the technological evolution at the institution where the study was conducted over the past 18 years. CT studies began in 2006 using a 64-slice CT scanner with a z-axis coverage of 3.2 cm, a gantry rotation time of 400 ms (temporal resolution of 200 ms), a slice thickness of 0.5 mm, and retrospective electrocardiographic synchronization. Between 45 and 100 mL of IV contrast medium (370 mg/mL) was administered, and the exam was performed in 5 to 10 seconds (apnea time) with a radiation dose ranging from 11 to 22 mSv (13). At that time, with 64-detector-row CT scanners, 7% of coronary segments were not evaluated (14, 15).

Since 2021, a CT scanner with 320 detector rows (620 slices) has been in use, with a z-axis coverage of 16 cm, a gantry rotation time of 275 ms (temporal resolution of 137.5 ms), a slice thickness of 0.5 mm, spatial resolution of 0.3 mm, prospective electrocardiographic synchronization, and an examination time of 137.5 ms (apnea time), which utilizes high-resolution iterative deep learning reconstruction techniques such as AICE (Advanced Intelligent Clear-IQ Engine)

and, more recently, PIQE (Precise IQ Engine). Taking into account the technical characteristics of the new CT scanner and considering that the work is being conducted in an outpatient diagnostic center, a protocol has been established to perform CCTA studies following the ALARA (as low as reasonably achievable) principle, using the lowest possible radiation dose for the patient while evaluating the highest percentage of coronary segments with very good spatial resolution. With this in mind, the goal was set to perform all CCTA exams in a single heartbeat—within a single RR interval of the cardiac cycle during a half-rotation of the gantry. To achieve this, patients must have a stable heart rate of less than 65 beats per minute.

Therefore, the institution has a cardiovascular support physician responsible for administering beta-blockers when necessary; patients undergoing CCTA are evaluated prior to the exam and are comprehensively monitored during and after the studies. A retrospective review of all CCTA studies performed at the institution from June 2, 2023, to March 26, 2024, yielded the following results: 395 "single-beat CCTA" studies with prospective electrocardiographic synchronization using half-gantry rotation; patients had a mean age of 59.5 years (range 17–89 years), including 165 women with a mean age of 61.7 years (range 25–89 years) and 230 men with a mean age of 57.8 years (range 17–85 years). Intravenous beta-blockade was required prior to the exam in 37.4% of patients, with no secondary complications. The average heart rate during image acquisition was 54 beats per minute. All patients received sublingual nitrates (5 mg) and IV contrast (370 mg/mL) in an average volume of 69 mL (range 50–85 mL). In the cohort, the average total radiation dose[1] was 1.7 mSv (range 0.5–6.3 mSv); in women, it was 1.26 mSv (range 0.5–4.8 mSv); and in men, it was 2.1 mSv (range 0.6–6.3 mSv). To put this in perspective, the average annual radiation dose from natural environmental exposure in the United States is 3 mSv, and the dose from a whole-body PET-CT scan is 22.7 mSv (Radiation Dose to Adults From Common Imaging Examinations, American College of Radiology[2]).

The percentage of coronary segments evaluated by CCTA in patients with a calcium score less than 1,000 (388 patients) was 99.7% (5,804 segments evaluated out of a total of 5,820 segments), and the percentage of segments evaluated in patients with a calcium score greater than 1,000 (7 patients) was 92.3% (97 segments evaluated out of a total of 105 segments). The profile of CAD involvement in the cohort, according to the severity of coronary stenosis, is shown in Table 1, and the extent of calcified atherosclerotic burden is summarized in Table 2.

Table 1. CAD-RADS 2.0 Classification

CAD-RADS 2.0	#	%
0	99	25.06
0/E	34	8.61
1	96	24.30
2	70	17.72
3	58	14.68
4	28	7.09
5	10	2.53
Total	395	100.00

Table 2. Calcium Score

Total Calcium Score	#*	%
0	169	44.01
1 a 99	122	31.77
100-299	54	14.06
300-999	32	8.3
1000-2000	5	1.3
>2000	2	0.54
Total	384	100.00

* It is important to note that 11 patients in the cohort did not undergo a calcium score, as they had already had one performed.

Evolution of Concepts in CAD

The primary goals of therapeutic strategies in patients with angina due to obstructive CAD are to reduce the risk of major adverse cardiovascular events (MACE) and to relieve the symptoms of angina and exercise-induced ischemia. Historically, atherosclerotic obstructions limiting coronary blood flow were considered the primary cause of angina pectoris and the main determinants of future cardiovascular risk. Consequently, revascularization procedures, such as coronary artery bypass grafting and percutaneous coronary revascularization, were considered essential treatments (16). However, over the past two decades, a growing number of studies have challenged this approach, at least in part. In fact, although myocardial revascularization improves the prognosis of patients with left main disease and coronary artery bypass grafting in diabetic patients with three-vessel disease (17) and three-vessel disease in patients with reduced left ventricular ejection fraction (LVEF) (18), it has been reported that the role of percutaneous revascularization in patients with reduced LVEF remains controversial (19–22). It is important to note that data from randomized controlled trials have suggested that a strategy combining coronary revascularization with optimal medical therapy (OMT) may not always provide additional benefits compared with OMT alone, excluding from this comparison patients with left main disease and three-vessel disease (23).

The ISCHEMIA study (International Study of Comparative Health Effectiveness With Medical and Invasive Approaches) randomly as-

[1]This total dose includes the calcium score plus the contrast-enhanced volumetric acquisition of the CCTA.

[2]Available at: https://www.acr.org/Clinical-Resources/Clinical-Tools-andReference/radiology-safety/radiation-safety

signed 5,179 patients with moderate or severe inducible ischemia on non-invasive stress testing to either an initial invasive strategy—revascularization with a third-generation drug-eluting stent or coronary bypass surgery—and OMT, or an initial conservative strategy consisting of OMT alone (24). During a median follow-up of 3.2 years, an initial invasive strategy showed no benefits in the primary endpoints—cardiovascular (CV) death, myocardial infarction (MI), resuscitated sudden cardiac death, or hospitalization for unstable angina or heart failure—or in the secondary endpoints—CV death or MI. No incremental benefit was observed in the subset of diabetic patients based on the revascularization strategy (percutaneous or surgical) (24). Furthermore, in a long-term follow-up of 5.7 years, there were no differences in all-cause mortality between an initial invasive strategy and an initial conservative strategy, although there was a lower risk of CV mortality with the invasive strategy (25).

According to available studies and current clinical guidelines, OMT should be the initial treatment strategy for patients with stable angina. OMT is often an effective option for these patients, even though revascularization may lead to greater improvement in angina and quality of life compared to TMO alone. Myocardial revascularization should be considered as an adjunct to PMT, particularly in patients who remain symptomatic despite guideline-recommended OMT or in those for whom revascularization has a proven prognostic benefit—for example, left main disease or three-vessel disease with severely reduced LVEF—(20–22). The benefits and risks of the available therapeutic strategies should be discussed with the patient, as decisions in this regard may vary among patients depending on expectations for improvement, levels of physical activity and quality of life, and willingness to undergo intensified medical treatment.

Evidence Supporting the Current Clinical Applications of CCTA

In the outpatient setting, the efficacy of CCTA has been extensively studied in comparison with exercise testing or invasive coronary angiography. Trials such as PROMISE (26) and SCOT-HEART (27) challenged the exercise testing paradigm and highlighted the importance of anatomical findings in guiding treatment decisions.

CCTA allows for a comprehensive, anatomical assessment of the atherosclerotic disease burden, which plays a key role in improving risk stratification and can guide risk-based treatment decisions, such as the early initiation of preventive therapy or revascularization in cases of severe left main disease or three-vessel disease (16, 28). The SCOT-HEART study examined the diagnostic utility of CCTA compared with standard care in stable CAD—4,146 patients, with a median follow-up of 4.8 years. The premise of the study was to understand the effect of anatomical assessment using CCTA on clarifying the diagnosis of angina and its influence on subsequent treatment and clinical outcomes (29). SCOT-HEART demonstrated that adding CCTA to standard care with exercise testing resulted in nearly a twofold increase in the diagnostic certainty of angina—the primary endpoint—compared with standard care alone (27). At a 5-year follow-up, the SCOT-HEART study observed a significant reduction in the rate of mortality from coronary heart disease or nonfatal MI with the use of CCTA compared with routine testing (from 3.9% with standard management to 2.3% with the addition of CCTA [HR, 0.59; 95% CI, 0.41 to 0.84; p=0.004]) (30). The presumed mechanism behind the observed benefits was the initiation of evidence-based preventive medication in patients with non-obstructive disease detected by CCTA—atherosclerosis that does not cause ischemia and is therefore not detected by exercise or functional tests. In particular, patients in the CCTA group were more likely to start taking lipid-lowering drugs, antihypertensives, antiplatelet agents, and antianginal drugs (19.4% vs. 14.7%, HR 1.40, 95% CI: 1.19–1.65) (31). On the other hand, the PROMISE study compares the efficacy of ATCC with that of functional testing. Involving 10,003 patients with stable chest pain, it demonstrated the non-inferiority of CCTA compared with functional testing after a 25-month follow-up (26). Although no differences were found between the treatment strategies with regard to the primary outcome, the rate of MI and death at 12 months was significantly lower in patients who underwent CCTA (HR 0.66; p=0.049).

Studies such as DISCHARGE (32) and CONSERVE (33) demonstrated similar outcomes between CCTA and invasive angiography, with fewer complications and lower diagnostic costs associated with CCTA, supporting the view that CCTA is an appropriate substitute for invasive angiography in patients with stable chest pain.

Secondary analyses of trials such as PROMISE and SCOT-HEART highlight the superiority of CCAT in risk stratification and guiding preventive treatments compared with standard diagnostic methods such as functional or stress tests. CCTA-guided strategies showed significant reductions in cardiovascular events compared with stress testing and during longer-term follow-up, by focusing more intensive preventive care on patients with non-obstructive and obstructive CAD identified by CCTA. New evidence suggests that treatments such as statins and PCSK9 inhibitors may induce plaque regression or stabilization, as observed in CCTA studies. Although further research is needed to understand the mechanisms and long-term benefits of these treatments, the CCTA provides valuable insights into the progression of atherosclerosis and potential risk-reduction strategies.

Diagnostic testing for ischemic heart disease has evolved; initially, it was based on functional assessment focused on ischemia using various techniques such as exercise electrocardiography, nuclear imaging, echocardiography, and magnetic resonance imaging. For the anatomical evaluation of CAD, traditional invasive coronary angiography is currently supplemented by non-invasive CCTA, the latter supported by robust clinical studies and multinational guidelines (34, 35).

The prospective multinational PARADIGM study (Progression of Atherosclerotic Plaque Determined by Computed TomoGraphic Angiography Imaging) included 1,255 patients with suspected or known CAD who underwent CCTA with an interval between scans of ≥2 years (36). The results showed that statin therapy was associated with a slower progression of coronary atherosclerotic volume, with an increase in calcification and a reduction in high-risk plaque characteristics.

Fractional flow reserve (FFR) combined with CT angiography has recently emerged as a major innovation for defining the hemodynamic significance of stenoses and identifying potential candidates for revascularization (37, 38), using standard protocols and without additional radiation or medication. In this context, the PLATFORM study demonstrated that the use of FFR-CT was associated with a significantly lower rate of conventional coronary angiography procedures that revealed non-obstructive coronary arteries (39).

Another novel method for evaluating significant lesions is CT perfusion (CT-P). The applications of CT-P stem from the improved

spatial and temporal resolution of recent CT scanners. The basic principle involves visualizing areas of the myocardium with reduced or delayed contrast enhancement under stress conditions. In this context, dual-energy CT acquisition allows for the analysis of the iodine map of myocardial perfusion, with measurements of iodine concentration per voxel (40). CT-FFR and CT-P demonstrated similar results in the detection of flow-limiting stenoses, with conventional coronary angiography plus invasive FFR as the gold standard (41).

Diagnostic Accuracy of the CCTA

In the VERDICT study (42), CCTA was performed on 1,023 patients with suspected non-ST-segment elevation acute coronary syndrome prior to invasive coronary angiography to rule out coronary artery stenosis ≥50% (42). The population was high-risk: 24% had known atherosclerotic cardiovascular disease, 43% had a GRACE score >140, and 78% had elevated cardiac troponins. The CCTA performed well diagnostically, with a negative predictive value of 90.9% (95% CI: 86.8–94.1%), a positive predictive value of 87.9% (95% CI: 85.3–90.1%), a sensitivity of 96.5% (95% CI: 94.9–97.8%), and a specificity of 72.4% (95% CI: 67.2–77.1%) for obstructive CAD. In a 2018 meta-analysis that included nine studies and 2,078 patients who underwent both CCTA and invasive quantitative coronary angiography, the researchers found that the sensitivity and specificity of CCTA for stenosis were ≥50%: 97% (95% CI: 93–99%) and 78% (95% CI: 67–86%), respectively, using invasive coronary angiography as the gold standard (43). When using an invasive RFF of ≤0.80 (seven studies, 1,049 patients) instead of the percentage of stenosis as the reference standard, CCTA was found to have a sensitivity of 93% (95% CI: 89–96%) and a specificity of 53% (95% CI: 37–68%), respectively. These latter results were similar to those of the VERDICT study described above.

Main indications for CCTA in current clinical guidelines

CCTA is a well-validated, non-invasive test that is increasingly used to evaluate CAD in appropriately selected patients with suspected chronic or acute coronary syndromes. In addition, CCTA is the method of choice for evaluating congenital coronary anomalies.

The American College of Cardiology (ACC) and the American Heart Association (AHA) in their 2021 chest pain guidelines (34) and the European Society of Cardiology (ESC) in their 2024 guidelines for the management of chronic coronary syndromes (35), have recommended CCTA as the first-line test for evaluating patients with stable chest pain and no known CAD. CCTA received a Class 1 recommendation with Level A evidence in these guidelines[1]. These guidelines recommend CCTA with a Class 1 recommendation and Level A evidence for the following patient groups:

- In intermediate-to-high-risk patients (risk greater than 15%) with stable chest pain and no known CAD, CCTA is effective for diagnosing CAD, stratifying risk, and guiding treatment decisions according to American guidelines (34) (Figure 1).
- In individuals with suspected chronic coronary syndrome and a low or moderate pretest probability (pretest probability between 5% and 50%) of obstructive coronary artery disease, CCTA is recommended to diagnose obstructive coronary artery disease and estimate the risk of MACE, according to European guidelines (35).

The main indications and contraindications for CCTA:

- As an alternative to exercise testing as an initial test in patients with chronic (stable) symptoms suggestive of ischemic heart disease who do not have a prior diagnosis of CAD (Figure 1).
- As an alternative to invasive coronary angiography in patients with nondiagnostic or equivocal exercise test results and persistent symptoms in whom a diagnosis of CAD has not been established.
- In an emergency department without access to high-sensitivity troponins: as an alternative to stress tests or invasive coronary angiography in selected patients without known CAD who are diagnosed with acute coronary syndrome (ACS), without ST-segment elevation, with a low-risk clinical presentation—for example, without heart failure or refractory ischemic symptoms—and in whom the physician or patient wishes to avoid invasive coronary angiography, or when the cause of the troponin elevation is uncertain.
- In a setting where high-sensitivity troponin testing is available: in patients with suspected ACS, non-elevated (or uncertain) high-sensitivity troponin levels, no ECG changes, and no recurrence of pain, the CCTA may be considered as an initial test.
- When a congenital coronary anomaly is suspected (Figure 2).
- To assess the patency of coronary bypass grafts in patients who have undergone coronary artery bypass grafting (Figure 3).
- CCTA is appropriate for symptomatic patients with a history of coronary stent implantation with an orthogonal diameter greater than 3 mm (Figure 4).
- Asymptomatic patients with other abnormal test results (elevated calcium score and cardiovascular risk factors) or inconclusive results (stress tests) (Figures 2 and 5).
- When FFR-CT and CT-P are available, CCTA may be appropriate for the functional assessment of intermediate stenoses (30–90%) in multivessel disease, to guide decisions regarding invasive coronary angiography and revascularization.

[3]Class 1 is the strongest recommendation available for a medical test, and evidence level A indicates that there is high-quality evidence—derived from more than one randomized clinical trial or meta-analysis—that CCTA is beneficial, useful, and effective.

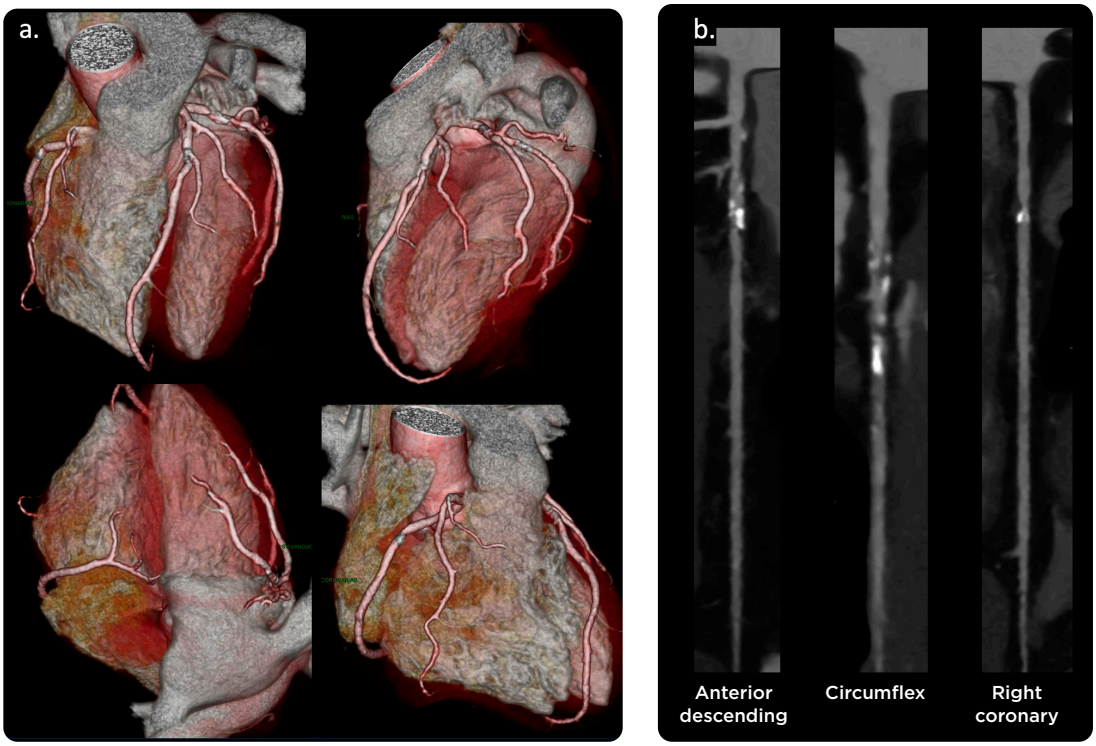


Figure 1. A 62-year-old man (weight 90 kg; height 169 cm). Indication: patient with atypical chest pain and multiple cardiovascular risk factors. Incidental coronary calcifications were identified on a routine chest CT scan performed due to a respiratory infection. Radiation dose: CCTA: 2 mSv. Volume of IV contrast medium: 80 cm^3. Results: short occlusion in the mid-segment of the circumflex artery; atheromatous plaques with stenosis ranging from 70 to 99% in the mid-segment of the left anterior descending artery, at the origin of the second diagonal branch of the left anterior descending artery, and in the proximal segment of the circumflex artery; and high-risk (HRP, for High-Risk Plaques) with stenosis between 50% and 69% in the proximal segments of the left anterior descending and right coronary arteries (CAD-RADS 2.0: 5/P4/HRP). a) 3D reconstructions of the heart. b) Straight reconstructions of the three main coronary arteries.

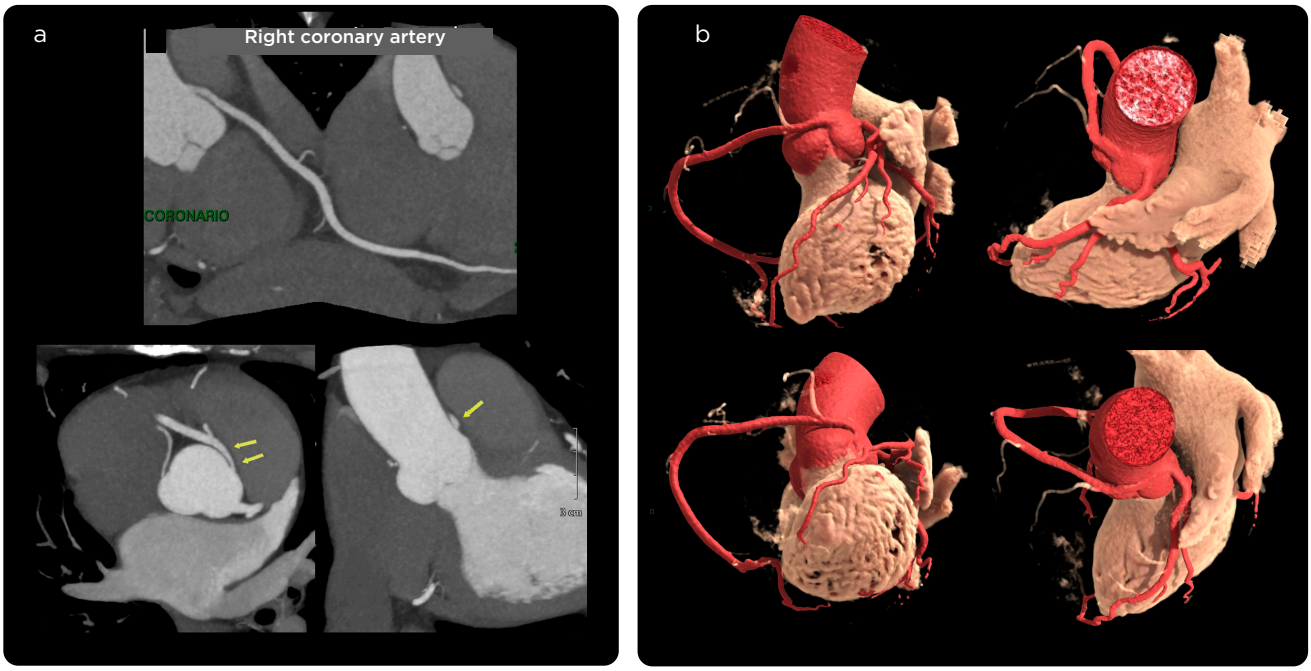


Figure 2. 62-year-old man (weight 70 kg; height 167 cm). Indication: asymptomatic patient with a recent abnormal stress test. Radiation dose: including cal-cium score and CCTA: 0.9 mSv. Volume of IV contrast medium: 65 cm^3. Result: Abnormal origin of the right coronary artery from the left sinus of Valsalva; its ostium is independent and located at the sinotubular junction very close to the junction between the left and right sinuses of Valsalva; its proximal course is interarterial (yellow arrows in a). A significant angulation at its origin is noted, with a cleft-like appearance of the ostium and the proximal 6 mm, consistent with a proximal segment with an intramural course within the aortic root wall. No atheromatous plaques or stenotic segments of the coronary tree are iden-tified (CAD-RADS 2.0: 0/E). a) Curved and multiplanar 2D reconstructions of the right coronary artery. b) 3D reconstructions of the heart with emphasis on the proximal segment of the right coronary artery.

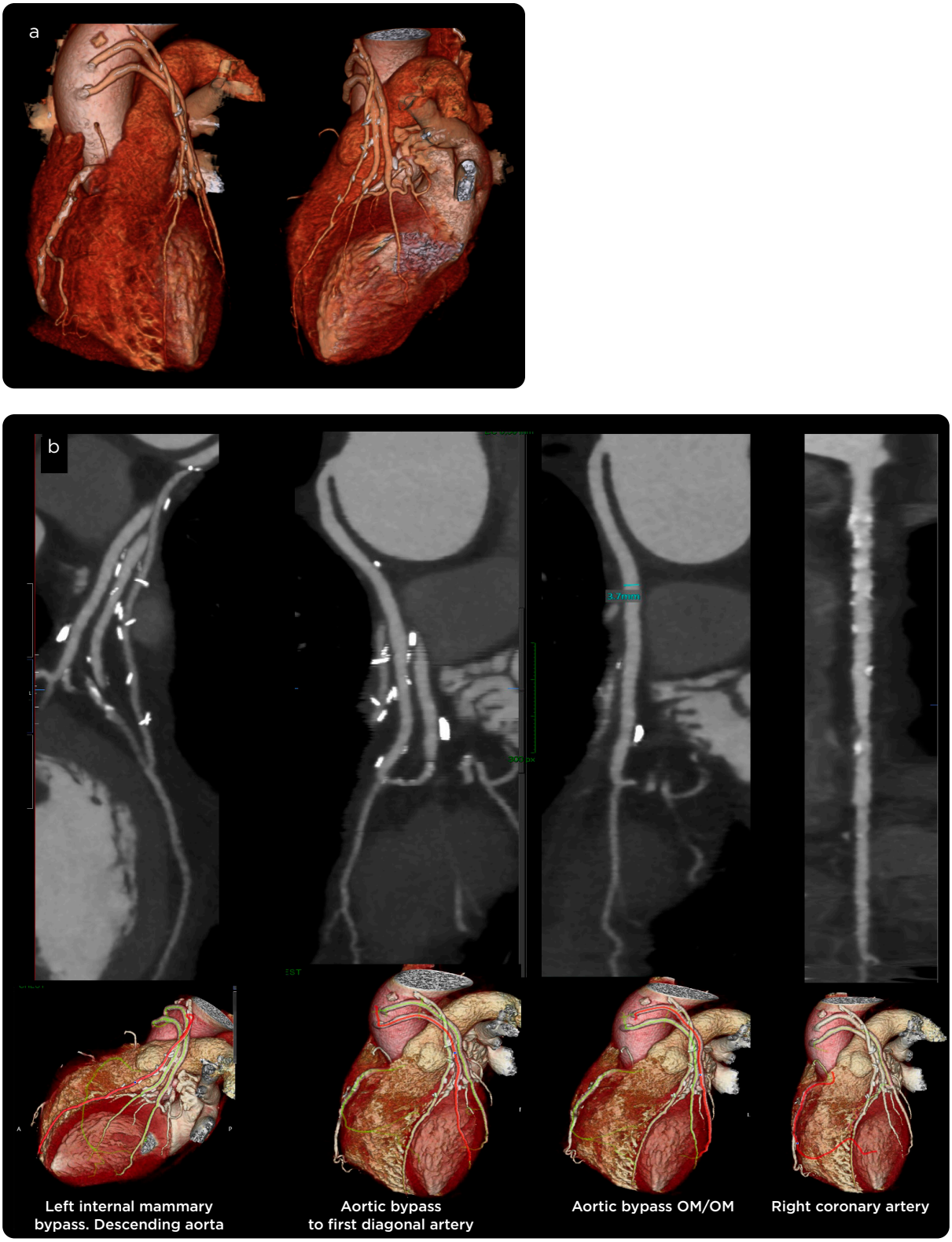


Figure 3. 65-year-old man (weight 85 kg; height 182 cm). Indication: patient with a history of coronary bypass surgery 3 years ago. Inconclusive stress test. Radiation dose: including the calcium score and CCTA, 2.6 mSv. Volume of IV contrast medium: 75 cm³. Result: a 2.2-mm-diameter left internal mammary artery graft was identified at the junction of the middle and distal segments of the left anterior descending artery; it was patent, with no stenotic lesions along its course or at the distal anastomosis, and two patent venous grafts without stenotic lesions, atheromatous plaques, or aneurysms—one from the ascending aorta to the first diagonal artery with a diameter of 3.5 mm, and another from the ascending aorta to the first obtuse-marginal artery with a diameter of 3.7 mm. The vascular beds distal to the bypass grafts appear patent, without stenosis. The right coronary artery shows calcified and mixed atheromatous plaques with stenosis less than 49% (CAD-RADS 2.0: 2/P4/G). a) 3D reconstructions of the heart. b) Curved and straight 2D reconstructions of the three bypass grafts and the right coronary artery.

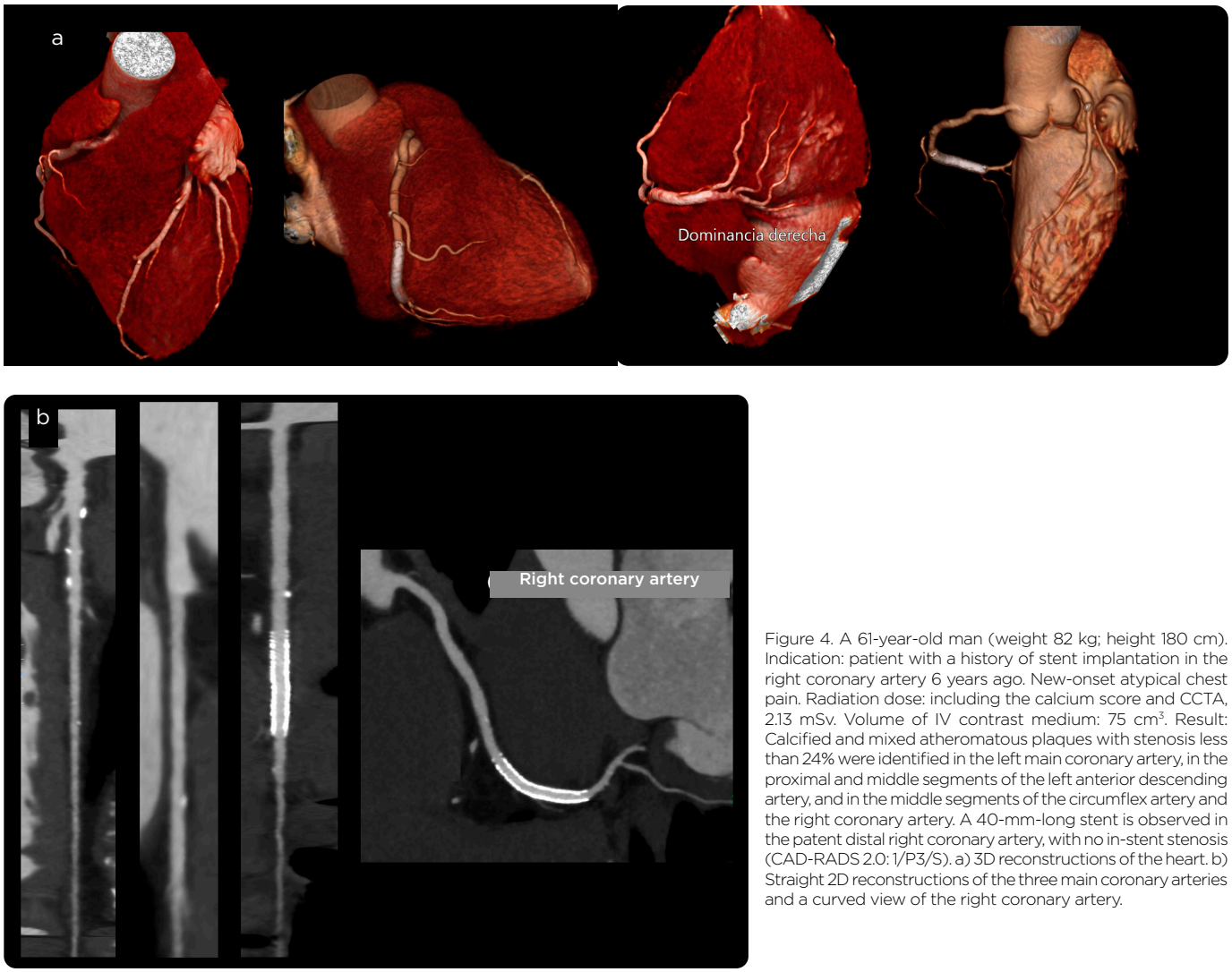


Figure 4. A 61-year-old man (weight 82 kg; height 180 cm). Indication: patient with a history of stent implantation in the right coronary artery 6 years ago. New-onset atypical chest pain. Radiation dose: including the calcium score and CCTA, 2.13 mSv. Volume of IV contrast medium: 75 cm^3. Result: Calcified and mixed atheromatous plaques with stenosis less than 24% were identified in the left main coronary artery, in the proximal and middle segments of the left anterior descending artery, and in the middle segments of the circumflex artery and the right coronary artery. A 40-mm-long stent is observed in the patent distal right coronary artery, with no in-stent stenosis (CAD-RADS 2.0: 1/P3/S). a) 3D reconstructions of the heart. b) Straight 2D reconstructions of the three main coronary arteries and a curved view of the right coronary artery.

Contraindications

Generally, there are no absolute contraindications for a CCTA scan. However, a history of a severe anaphylactic reaction to iodinated contrast media precludes the repeated administration of contrast media.

To obtain a CCTA with good image quality, the heart rate must be slow and regular, and the patient must follow instructions to hold their breath (apnea). This includes a willingness to receive premedication (oral or intravenous beta-blockers) when necessary. Renal function and allergy to contrast agents should be evaluated prior to the examination. Temporal and spatial resolution remain technical limitations and may hinder accuracy in determining the severity of coronary stenosis; this is particularly pronounced in patients with heavily calcified coronary arteries, in whom functional tests may be more appropriate than CCTA.

The relative contraindications for CCTA are as follows:

- Pregnancy
- Renal failure (creatinine clearance less than 30 mL/min/1.73 m^2).
- Inability to hold one's breath for more than 3–10 seconds, depending on the CT scanner's temporal resolution.
- Hemodynamic instability.
- Patient weight exceeding the recommended thresholds for the scanner.
- Depending on the technical specifications of the CT scanner, CT-guided cardiac catheterization is contraindicated in some machines for patients with atrial fibrillation, increased ventricular automaticity, or an inability to lower the heart rate to the levels required by the scanner.
- Some centers do not perform CCTA studies with calcium *scores* greater than 1,000 due to the low specificity and positive predictive value of CCTA under these circumstances.
- However, in centers where FFR-CT or CT-P is available, CCTA studies are generally performed even with calcium *scores* greater than 1,000.

The Society for Cardiovascular Computed Tomography recommends that, at a minimum, CT scanners with 64 detector rows be used for CCTA (44).



Figure 5. A 39-year-old woman (weight 56 kg; height 157 cm). Indication: asymptomatic patient with an inconclusive stress test and a family history of early coronary artery disease. Radiation dose: including calcium score and CCTA, 0.6 mSv. Volume of IV contrast medium: 60 cm^3. Result: normal study (CAD-RADS 2.0: 0). Curved and straight 2D reconstructions of the coronary arteries: a) Anterior descending. b) Circumflex. c) Right coronary.

The updated 2022 version of CAD-RADS (Coronary Artery Disease Reporting and Data System) 2.0 (45) improves the standardized reporting system for coronary CT angiography by incorporating data from recent large studies and new clinical guidelines, as well as adding features related to plaque burden and lesion physiology as determined by cardiac CT. Therefore, the updated CAD-RADS classification proposes evaluating the following categories: stenosis, plaque burden, and modifiers, and now also includes the assessment of ischemia using FFR-CT or CT-P, when available. CAD-RADS provides an important standardization framework that is expected to benefit education, research, peer review, the development of artificial intelligence, and quality assurance, with the goal of improving patient care.

Conclusions

The evolution of the CCTA has been remarkable over the past 20 years, making it the first-line test in numerous clinical situations for patients with CAD. New guidelines from the AHA/ACC, the United Kingdom, and Europe strongly recommend the CCTA for patients with stable or chronic CAD. The addition of functional tests (FFR-CT/CT-P) further expands the utility of CCTA for simultaneously assessing cardiac anatomy and function. The ability to visualize non-obstructive coronary atherosclerosis noninvasively allows CCTA to enable early diagnosis of CAD and facilitates the implementation of early preventive treatments with better outcomes in this field than functional stress tests, which typically require severe stenosis to detect the disease. Plaque analysis using CCTA will play an increasingly important role in the non-invasive detection of the disease, in evaluating treatment effects, and in providing information on disease progression. The validation of CCTA following large-scale clinical trials, such as PROMISE and SCOT-HEART, continues to reinforce the clinical utility of this examination. Technological advances in image quality, scan acquisition, post-processing, and radiation dose reduction now allow for a broader and safer use of this diagnostic modality, as recommended by current guidelines and as evidenced by the authors' experience in this field.

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