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Practice guidelines

CAD-RADS™ 2.0 - 2022 Coronary Artery Disease-Reporting and Data System

An Expert Consensus Document of the Society of Cardiovascular Computed Tomography (SCCT), the American College of Cardiology (ACC), the American College of Radiology (ACR), and the North America Society of Cardiovascular Imaging (NASCI)

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ABSTRACT

Coronary Artery Disease Reporting and Data System (CAD-RADS) was created to standardize reporting system for patients undergoing coronary CT angiography (CCTA) and to guide possible next steps in patient management. The goal of this updated 2022 CAD-RADS 2.0 is to improve the initial reporting system for CCTA by considering new technical developments in Cardiac CT, including data from recent clinical trials and new clinical guidelines. The updated CAD-RADS classification will follow an established framework of stenosis, plaque burden, and modifiers, which will include assessment of lesion-specific ischemia using CT fractional-flow-reserve (CT-FFR) or myocardial CT perfusion (CTP), when performed. Similar to the method used in the original CAD-RADS version, the determinant for stenosis severity classification will be the most severe coronary artery luminal stenosis on a per-patient basis, ranging from CAD-RADS 0 (zero) for absence of any plaque or stenosis to CAD-RADS 5 indicating the presence of at least one totally occluded coronary artery. Given the increasing data supporting the prognostic relevance of coronary plaque burden, this document will provide various methods to estimate and report total plaque burden. The addition of P1 to P4 descriptors are used to denote increasing categories of plaque

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burden. The main goal of CAD-RADS, which should always be interpreted together with the impression found in the report, remains to facilitate communication of test results with referring physicians along with suggestions for subsequent patient management. In addition, CAD-RADS will continue to provide a framework of standardization that may benefit education, research, peer-review, artificial intelligence development, clinical trial design, population health and quality assurance with the ultimate goal of improving patient care.

Abbreviations

CAD	coronary artery disease
CAD-RADS	coronary artery disease reporting and data system
CAC	coronary artery calcium
CCTA	coronary CT angiography
CT-FFR	computed tomography fractional flow reserve
CTP	computed tomography perfusion
HRP	high-risk plaque
ICA	invasive coronary angiography
PCI	percutaneous coronary intervention
SIS	segment involvement score

1. Introduction

Coronary CT Angiography (CCTA) has undergone significant technical advancements and clinical validation in the last decade, and several professional societies have issued guidelines, expert consensus documents, and Appropriateness Criteria for CCTA.[1–11] Training physicians and technologists in image acquisition and interpretation is essential for fostering quality.[12] Such training should also include an approach to standardized reporting in order to decrease variability among practitioners and ensure that test results are appropriately used in patient management decisions.

The purpose of this document is to update the first version of the CAD-RADS[13] standardized classification of coronary artery disease for patients undergoing CCTA that was originally published in 2016 in order to include additional features such as plaque burden and ischemia, and to incorporate evidence from recent clinical trials as well as new clinical practice guidelines. The updated 2022 CAD-RADS 2.0 classification will follow a framework of stenosis, plaque burden and modifiers, with the option to also include ischemia evaluation by CT fractional-flow-reserve (CT-FFR) or myocardial CT perfusion (CTP), if performed. As in the original version, the most severe coronary artery luminal stenosis defined on a per-patient basis will be the central component of assessment and will provide the numeric descriptor. In addition, methods to estimate, quantify and report overall plaque burden will be provided. Collectively, the goal of these additions is intended to enhance patient management decisions following CCTA.

The main goal of CAD-RADS remains to standardize reporting of CCTA results and to facilitate communication of test results to referring physicians along with suggestions for subsequent patient management. Importantly, CAD-RADS should not be viewed as a substitute for the impression section of the report provided by the reading physician. CAD-RADS provides a complementary assessment and should always be interpreted in conjunction with the more detailed and patient-specific information found in the report and the impression, particularly because the report may provide more specific information regarding the location and extent of coronary plaque and stenosis. Furthermore, the clinical management suggestions provided by CAD-RADS should not replace clinical judgment, particularly as there are many patient-specific factors that may influence clinical management.

2. Clinical value of CAD-RADS and coronary CT angiography

More than 50 publications have further validated specific aspects of CAD-RADS since its original publication in 2016[14] Fig. 1. The CAD-RADS classification has been shown to accurately predict major adverse cardiovascular events, defined as unstable angina, myocardial infarction, or death, in patients with stable chest pain with superior performance when compared with traditional risk factors, other risk stratification scores, the Coronary Artery Calcium Score (CAC) and the earlier SCCT coronary stenosis scoring system.[15–19] CAD-RADS has also been demonstrated to correlate with the degree of stenosis measured by invasive coronary angiography (ICA) with high diagnostic accuracy.[20,21] Recent publications have highlighted that adoption of CAD-RADS in clinical practice results in reduced downstream testing and cardiology referral rates in patients with non-obstructive coronary artery disease[22] and has a favorable impact on medical therapy and systolic blood pressure control.[23] Finally, recent studies have validated the performance of deep learning algorithms for the evaluation of CAD-RADS classification on CCTA.[24]

There has been widespread adoption of CAD-RADS in clinical practice with most sites in the United States and around the world using this classification for reporting CCTA on a routine basis. Overall, available research suggests that CAD-RADS offers a clinically useful and appropriate categorization of coronary artery disease with high diagnostic accuracy when compared with invasive angiography, with robust prognostic value and a beneficial impact on medical management.

Since the publication of the original CAD-RADS classification, several prospective trials have provided evidence supporting the clinical utility of CCTA and the relevance of CT findings among patients with suspected stable coronary artery disease. They include the PROMISE[25] and SCOT-HEART[26] trials, which demonstrated that CCTA is clinically useful as an alternative to functional testing (PROMISE) or in addition to standard of care (SCOT-HEART). Based on these trials and multiple registries, the prognostic value of the CAD-RADS classification has been confirmed, demonstrating that higher CAD-RADS scores were associated with increased risks of fatal and non-fatal MI.[15–17]

Moreover, several large randomized trials (CT-STAT, ACRIN-PA, ROMICAT II, CT-COMPARE) have compared CCTA to the current standard of care in patients with acute chest pain[27–30]. Complemented by real world implementation data,[31–33] they consistently demonstrated the safety of discharging patients from the emergency department based on a negative CCTA, resulting in guidelines supporting the use of CCTA in low to intermediate risk patients presenting with acute chest pain to the emergency department.[34]

CCTA is now considered a first-line test (Class I) for use in acute and chronic coronary syndromes by the European Society of Cardiology,[11] NICE guideline[10] and by the new American College of Cardiology and American Heart Association Chest Pain Guideline,[35] particularly in symptomatic patients with stable symptoms and intermediate or high pre-test probability of obstructive coronary artery disease, or among intermediate-risk acute chest pain patients. Moreover, there have been numerous advances in the detection and quantification, understanding of atherosclerotic plaque burden by CCTA, as well as a better understanding of the clinical implications of various CCTA findings.[36]

Despite the robust evidence base supporting the use of CCTA in patients with acute and stable chest pain, there is insufficient prospective

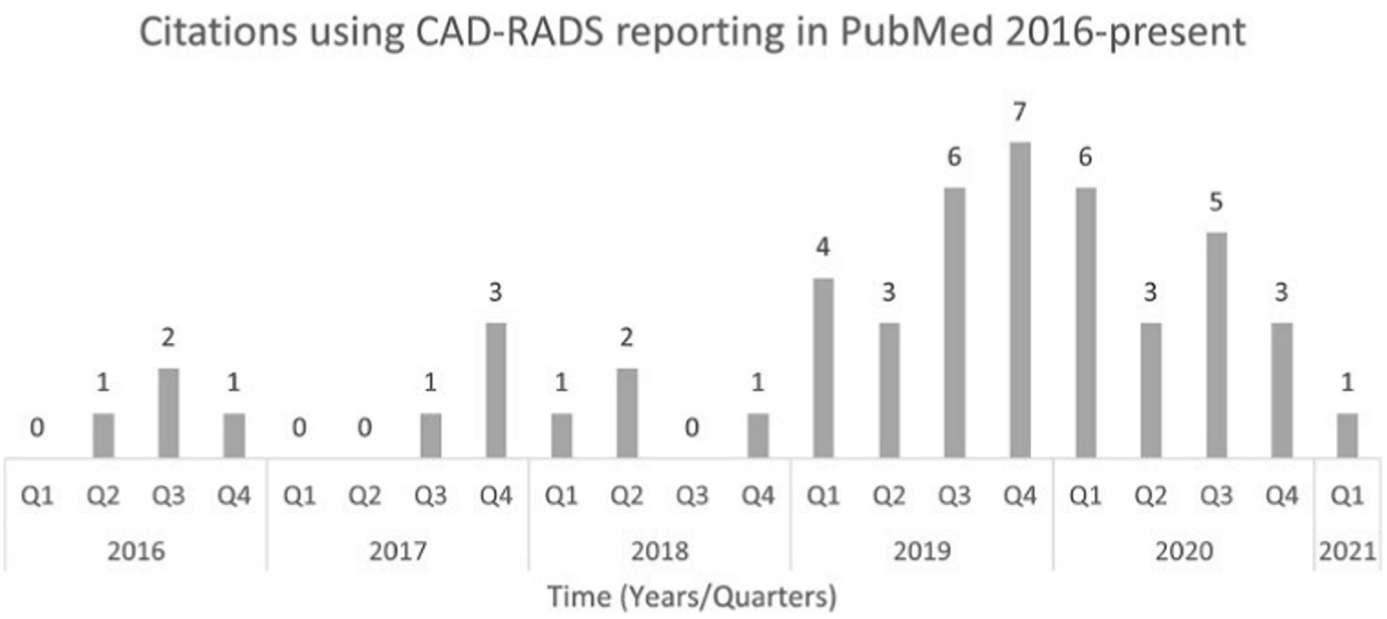


Fig. 1. Timeline plots of total quarterly PubMed citations resulting from the search "CAD-RADS" [Title/Abstract] OR "CADRADS" [Title/Abstract]. The date of the search was January 25, 2021. Permission received[63] Radiol Cardiothorac Imaging. 2021 Jun; 3 (3): e210016.

randomized clinical trial data to support the optimal clinical management strategy following CCTA. Accordingly, the CAD-RADS classification is an expert consensus document. As such, the recommendations provided in this document are based on the available research data from clinical trials as well as on broad expert consensus. This includes the suggested categories for reporting and the recommendations for further patient

Table 1
Grading scale for stenosis severity, plaque burden and ischemia.

Degree of luminal diameter stenosis	Terminology
0%	No visible stenosis
1–24%	Minimal stenosis
25–49%	Mild stenosis
50–69%	Moderate stenosis
70–99%	Severe stenosis
100%	Occluded
Grading Scale for plaque burden: Terminology	**Overall plaque burden**
P1	Mild amount of plaque
P2	Moderate amount of plaque
P3	Severe amount of plaque
P4	Extensive amount of plaque
Grading scale for Ischemia detection: Terminology	**Meaning**
Modifier I	Indicates that CT Ischemia test was performed either with CT-FFR or myocardial CTP
I+	Indicates that CT-FFR or CTP demonstrates lesion-specific ischemia or reversible perfusion defect
I-	Indicates that CT-FFR or CTP is negative for lesion specific ischemia or reversible ischemia[a]
I ±	Indicates that CT-FFR or CTP is borderline

[a] Patients with prior myocardial infarction and fixed perfusion defects without evidence of myocardial ischemia by CTP would be classified as I-. The presence of myocardial infarction should be documented in the impression of the report.

Table 2
Different methods to categorize the overall amount of coronary plaque.

	Overall amount of coronary plaque	CAC	SIS*	Visual*
P1	Mild	1–100	≤2	1-2 vessels with mild amount of plaque
P2	Moderate	101–300	3–4	1 -2 vessels with moderate amount; 3 vessels with mild amount of plaque
P3	Severe	301–999	5–7	3 vessels with moderate amount; 1 vessel with severe amount of plaque
P4	Extensive	>1000	≥8	2-3 vessels with severe amount of plaque

Note: categories may not always correspond across different scores; if discrepant use CAC = Coronary Artery Calcium or Total plaque burden quantification, if available.
SIS = Segment Involvement Score.
* Please note that CAD-RADS 0 denotes absence of stenosis or plaque, therefore P0 is not required as a classification.
* As there is currently no one single method that should be used to identify the overall amount of plaque, CAD-RADS recommends that imagers select the technique which is considered most appropriate at a given institution.
* see examples in Figs. 2 to 6.

Table 3
Examples of non-atherosclerotic causes of coronary abnormalities to be included in Modifier "E" = Exceptions. Please note that this is not a comprehensive list.

Coronary dissection
Anomalous origin of the coronary arteries
Coronary artery aneurysm or pseudoaneurysm
Vasculitis
Coronary artery fistula
Extrinsic coronary artery compression
Arterio-venous malformation
Other causes

Table 4
CAD-RADS Reporting and Data System for patients presenting with stable chest pain.

Category	Degree of maximal coronary stenosis	Interpretation	Further Cardiac Investigation	Management considerations
CAD-RADS 0	0% (No plaque or stenosis)	Absence of CAD[a]	None	- Reassurance. Consider non-atherosclerotic causes of symptoms
CAD-RADS 1	1–24% (Minimal stenosis or plaque with no stenosis[b])	Minimal non-obstructive CAD[b]	None	- Consider non-atherosclerotic causes of symptoms - P1: Consider risk factor modification and preventive pharmacotherapy - P2: Risk factor modification and preventive pharmacotherapy - P3 or P4: Aggressive risk factor modification and preventive pharmacotherapy
CAD-RADS 2	25–49% (Mild stenosis)	Mild non-obstructive CAD	None	- Consider non-atherosclerotic causes of symptoms - P1 or P2: Risk factor modification and preventive pharmacotherapy - P3 or P4: Aggressive risk factor modification and preventive pharmacotherapy
CAD-RADS 3	50–69% (Moderate stenosis)	Moderate stenosis	Consider functional assessment[c]	- P1, P2, P3 or P4: Aggressive risk factor modification and preventive pharmacotherapy - Other treatments (including anti-anginal therapy) should be considered per guideline directed care[d] - When modifier I+, consider ICA, especially if frequent symptoms persist after guideline-directed medical therapy
CAD-RADS 4	**A** - 70–99% stenosis or **B** - Left main ≥50% or 3- vessel obstructive (≥70%) disease	Severe stenosis	A: Consider ICA[e] or functional assessment B: ICA is recommended	P1, P2, P3 or P4: Aggressive risk factor modification and preventive pharmacotherapy. - Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care[c]
CAD-RADS 5	100% (total occlusion)	Total coronary occlusion or sub-total occlusion	Consider ICA, functional and/or viability assessment	P1, P2, P3 or P4: Aggressive risk factor modification and preventive pharmacotherapy. - Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care[c]
CAD-RADS N	Non-diagnostic study	Obstructive CAD cannot be excluded	Additional/alternative evaluation may be needed	

The CAD-RADS classification should be applied on a per-patient basis for the clinically most relevant (usually highest-grade) stenosis.
All vessels greater than 1.5mm in diameter should be graded for stenosis severity. CAD-RADS will not apply for smaller vessels (<1.5mm in diameter).

[a] CAD – coronary artery disease.

[b] CAD-RADS 1 - This category should also include the presence of plaque with positive remodeling and no evidence of stenosis.

[c] Functional Assessment includes CT-FFR, CTP, stress testing (ETT, stress echocardiogram, SPECT, PET, Cardiac MRI) or invasive FFR.

[d] Guideline-directed care per 2021 AHA/ACC Chest Pain Guideline,[35] 2012 ACC/AHA Guideline for the diagnosis and management of patients with stable ischemic heart disease[61] and 2019 ACC/AHA Prevention Guidelines.[62] Further evaluation of CAD-RADS 3 and 4A with functional imaging or invasive coronary angiography should be considered to identify a target lesion (if unknown) and if the patient has persistent symptoms despite adequate medical therapy.

[e] ICA – invasive coronary angiography may be favored if high-grade stenosis (>90%), high-risk plaque features or I + (presence of lesion-specific ischemia on CT FFR or perfusion defects by CTP) or concordant ischemia by other stress tests and a candidate for revascularization. It should be clarified that benefit of revascularization should be confined to patients with persistent symptoms despite optimal medical therapy.

Table 5
CAD-RADS Reporting and Data System for patients presenting with acute chest pain.

Category	Degree of maximal coronary stenosis	Interpretation	Cardiac Investigation	Management considerations
CAD-RADS 0	0%	ACS highly unlikely	- No further evaluation of ACS is required - If Tn (+) consider other sources of increased troponin (See Table 9)	- Reassurance.
CAD-RADS 1	1–24%[a]	ACS unlikely	- No further evaluation of ACS is required - If Tn (+) consider other sources of increased troponin (See Table 9)	- P1 or P2: Referral for outpatient follow-up for risk factor modification and preventive pharmacotherapy. - P3 or P4: Referral for outpatient follow-up for aggressive risk factor modification and preventive pharmacotherapy
CAD-RADS 2	25–49%	ACS less likely	- No further evaluation of ACS is required - If clinical suspicion of ACS is high, Tn (+) or HRP features, consider hospital admission with cardiology consultation.	- P1 or P2: Referral for outpatient follow-up for risk factor modification and preventive pharmacotherapy. - P3 or P4: Referral for outpatient follow-up for aggressive risk factor modification and preventive pharmacotherapy
CAD-RADS 3	50–69%	ACS possible	- Consider hospital admission with cardiology consultation. - Consider functional assessment[b]	- P1, P2, P3 or P4: Preventive management, including aggressive preventive pharmacotherapy. Other treatments, including anti-anginal therapies, should be considered per guideline directed care[c]. - When modifier I+, consider ICA.
CAD-RADS 4	**A** - 70–99% or **B** - Left main ≥50% or 3-VD	ACS likely	- Hospital admission with cardiology consultation. A Consider ICA[d] or functional assessment B ICA is recommended	- P1, P2, P3 or P4: Preventive management, including aggressive preventive pharmacotherapy. - Other treatments, including anti-anginal therapies and options of revascularization, should be considered per guideline directed care[c]
CAD-RADS 5	100% (Total occlusion)	ACS very likely	- Hospital admission with cardiology consultation. Expedited ICA and revascularization if suspected acute occlusion[e]	- P1, P2, P3 or P4: Preventive management, including aggressive preventive pharmacotherapy. - Other treatments (including anti-anginal therapies and options of revascularization) should be considered per guideline directed care[c]
CAD-RADS N	Non-diagnostic study	ACS cannot be excluded	Additional or alternative evaluation for ACS is needed	

The CAD-RADS classification should be applied on a per-patient basis for the clinically most relevant (usually highest-grade) stenosis.
All vessels greater than 1.5mm in diameter should be graded for stenosis severity. CAD-RADS will not apply for smaller vessels (<1.5mm in diameter).

[a] CAD-RADS 1 – This category should also include the presence of plaque with positive remodeling and no evidence of stenosis.

[b] Functional Assessment includes CT-FFR, CTP, stress testing (ETT, stress echocardiogram, SPECT, PET, Cardiac MRI) or invasive FFR.

[c] Guideline-directed care per 2021 AHA/ACC Chest Pain Guideline,[35] 2012 ACC/AHA Guideline for the diagnosis and management of patients with stable ischemic heart disease[61] and 2019 ACC/AHA Prevention Guidelines.[62]

[d] ICA – invasive coronary angiography. It should be clarified that benefit of revascularization is confined to patients with persistent symptoms despite optimal medical therapy.

[e] Unless the total coronary occlusion can be identified as chronic (through CT and clinical characteristics or patient history).

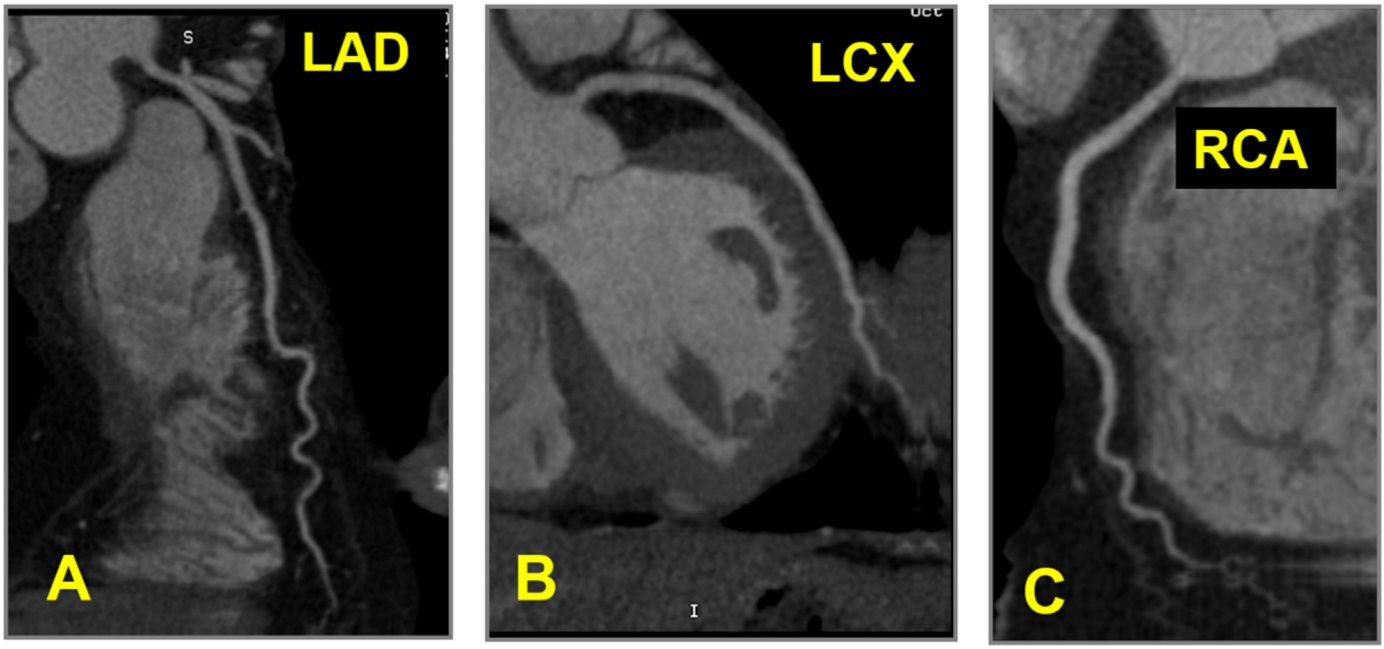


Fig. 2. CAD-RADS 0 – No coronary stenosis. Absence of calcified and non-calcified plaque in the coronary tree. The classification P is not required for CAD-RADS 0.

management, which need to be interpreted in the context of other available clinical information for each individual patient.

3. CAD-RADS reporting system

3.1. CAD-RADS categories

CAD-RADS categories are based on stenosis severity and plaque burden. For the grading of stenosis severity, a classification system originally developed by the Society of Cardiovascular Computed Tomography is used (see Table 1). Table 1 also describes the terminology used to estimate the overall amount of plaque burden (P1 to P4) and the classification of ischemia into positive (I+), negative (I-) or borderline (I+/−), if a CT-based ischemia test such as, FFR-CT or myocardial CTP has been performed. Table 2 describes selected methods to categorize the overall amount of coronary plaque by CCTA. Table 3 describes examples of non-atherosclerotic causes of coronary abnormalities to be included in Modifier "E" = Exceptions. Tables 4 and 5 list the categories of the CAD-RADS reporting system for stable chest pain (Table 4) and acute chest pain (Table 5) with suggestions for further cardiac investigation and management considerations. In both settings, they range from CAD-RADS 0 (absence of atherosclerosis) to CAD-RADS 5 (presence of at least one total vessel occlusion). Fig. 2 through 6 provide examples of different amounts of plaque burden and associated categories and terminology. Fig. 7 through 12 provide examples of CAD-RADS categories 4A, 4B, 5 and N.

Fig. 3. CAD-RADS 1/P1 - Minimal coronary stenosis (1–24%). Plaque Burden – P1: Mild amount of plaque burden.

3.1.1. CAD-RADS categories 3, 4 and 5 require further consideration

In the presence of CAD-RADS 3, which reflects moderate stenosis (50–69%), there is an option to consider the use of CT-FFR, CTP, or stress testing (ETT, stress echocardiogram, SPECT, PET or Cardiac MRI) to document or exclude the presence of ischemia. Further testing should be considered if this information will change patient management and, in the presence of stable or acute chest pain, if the patient has persistent symptoms despite adequate medical therapy. In addition to symptoms, it is important to consider other factors, such as stenosis lesion location and severity, and the presence of high-risk plaque features. Ultimately, the need for invasive coronary angiography as the next step in patient management requires careful integration of all clinical data together with all available imaging and stress test findings.

For **CAD-RADS 4**, recommendations may vary depending on the involvement of left main coronary artery and the presence of severe obstructive three-vessel disease (>70%). If a left main coronary artery stenosis at least greater than 50% is suspected or if the examination demonstrates three-vessel obstructive disease, then further evaluation with invasive angiography and possible revascularization is recommended. For this reason, **CAD RADS 4** is sub-divided into A and B**:**

CAD RADS 4A - This category indicates the case of a single vessel or two vessels demonstrating severe stenosis (70–99%). Further evaluation with ICA or functional imaging, including CT-FFR, CTP and stress testing (ETT, stress echocardiogram, SPECT, PET or Cardiac MRI) or invasive FFR is usually recommended depending on location, extent and severity

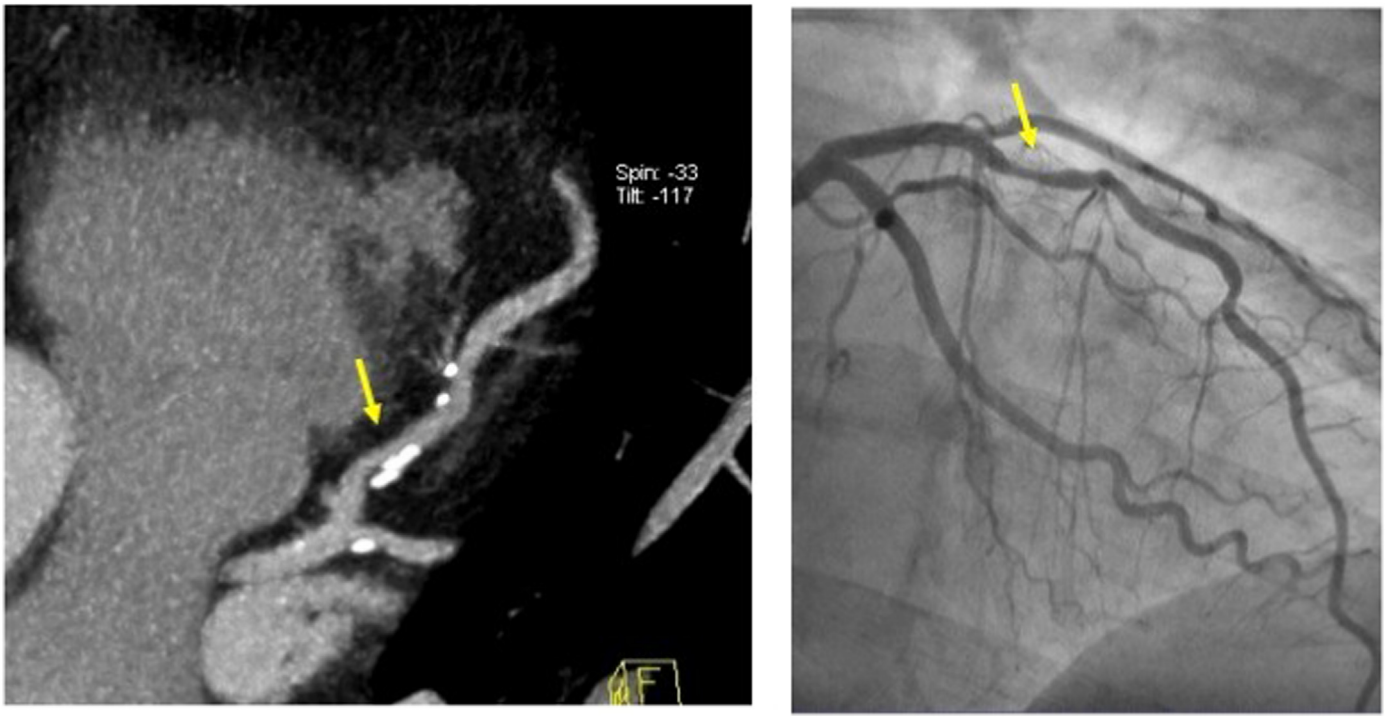


Fig. 4. CAD-RADS 2/P2 – Mild coronary stenosis (25–49%). Plaque Burden – P2: Moderate amount of plaque burden.

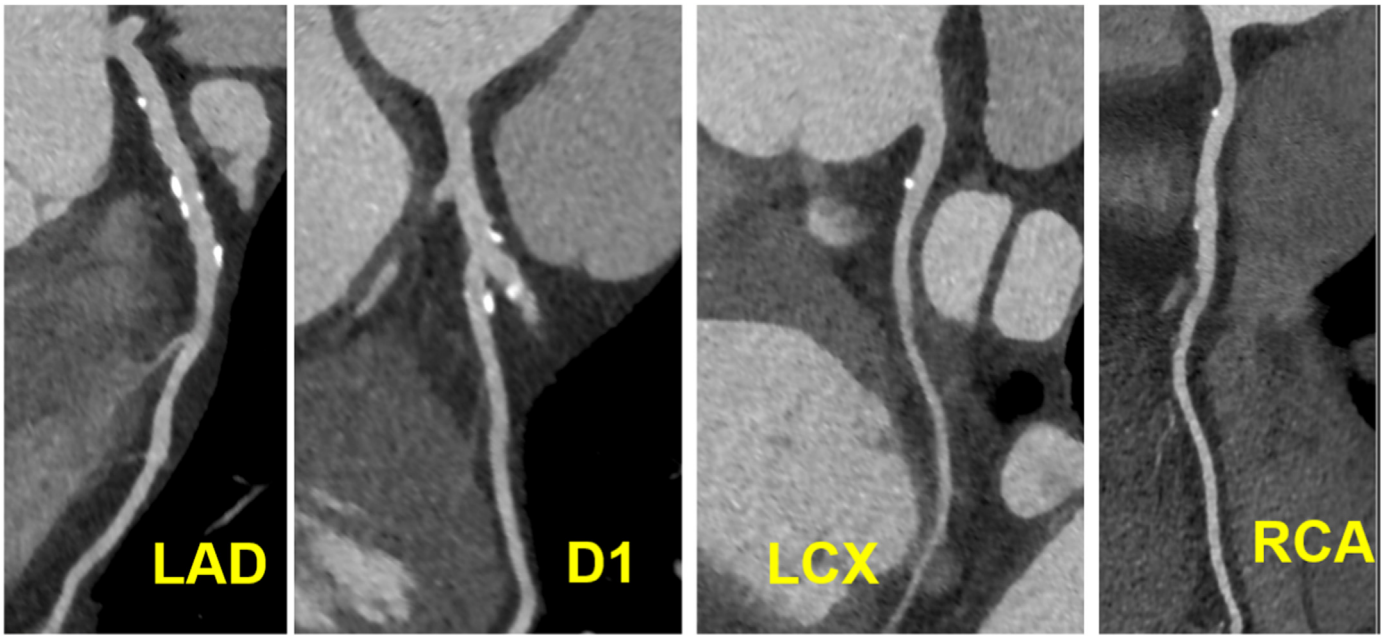


Fig. 5. CAD RADS 1/P3 - Plaque Burden – P3: Severe amount of plaque burden – SIS = 7, Extensive amount of diffuse plaque and minimal coronary stenosis.

of the lesion(s), and clinical characteristics, such as angina severity and the use of current guideline-directed medical therapies. It should be clarified that the benefit of revascularization is confined to patients with frequent symptoms despite optimal medical therapy. Other important considerations such as the presence of very-high-grade coronary stenosis (>90%) or high-risk plaque features as well as evidence of lesion-specific ischemia by FFR-CT or perfusion defects by myocardial CTP may favor the use of ICA as the next step in patient care, if revascularization is being considered. Persistent anginal symptoms despite medical therapy should also favor the use of ICA.

CAD RADS 4B - This indicates the presence of a left main stenosis of at least 50% or three-vessel obstructive disease (>70%). Further evaluation with ICA and possible revascularization is usually recommended, particularly for patients with frequent symptoms despite optimal medical therapy.

The clinical relevance of **CAD-RADS 5** (total coronary occlusion) varies widely depending on the clinical context. It may be acute or chronic, and, in the context of chronic occlusion, factors such as lesion length, calcification particularly at the proximal aspect, tortuosity and degree of collateralization may be of relevance for management decisions (Fig. 11).

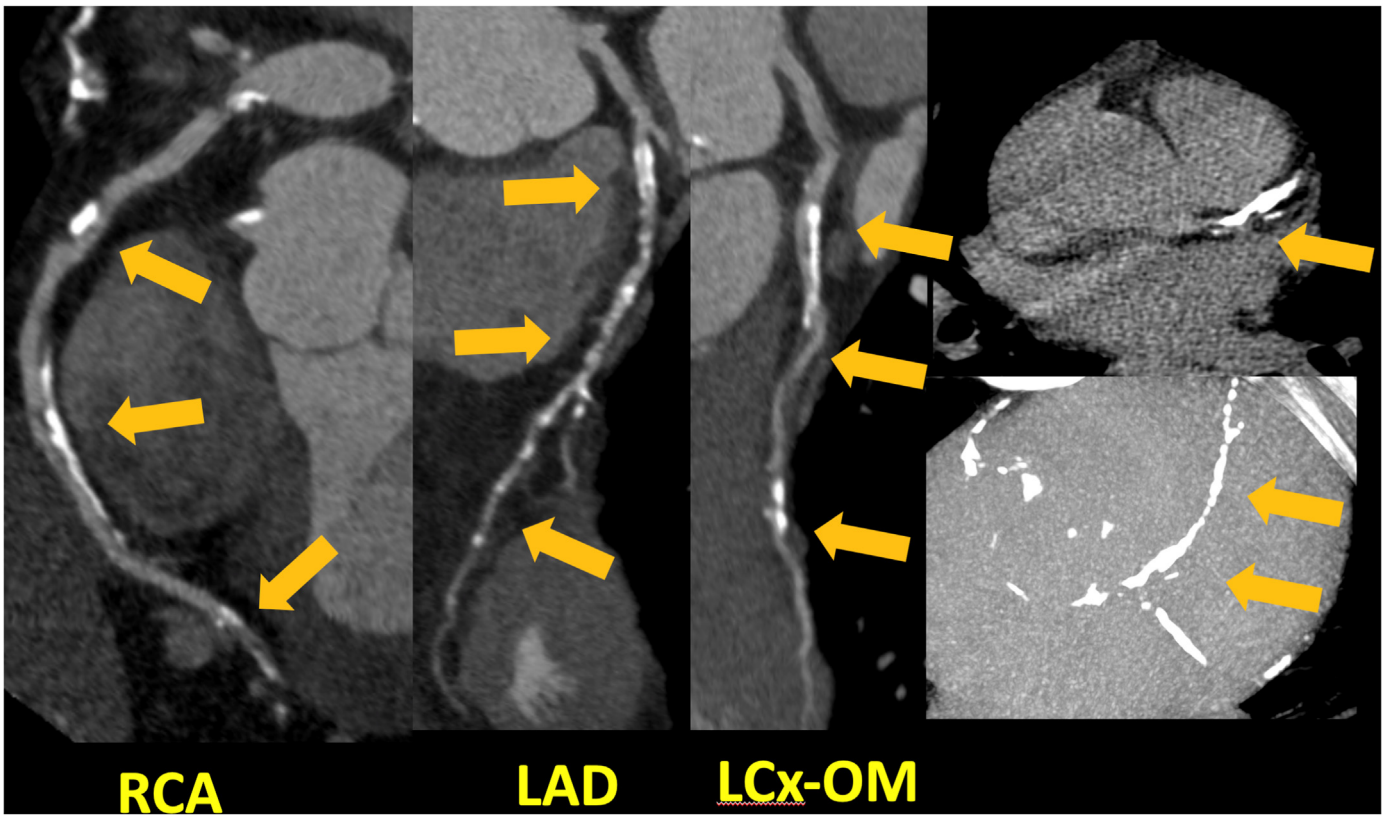


Fig. 6. CAD-RADS 4B/P4. Plaque Burden – P4: Three vessel severe coronary stenosis with extensive amount of plaque burden – CAC = 3607.

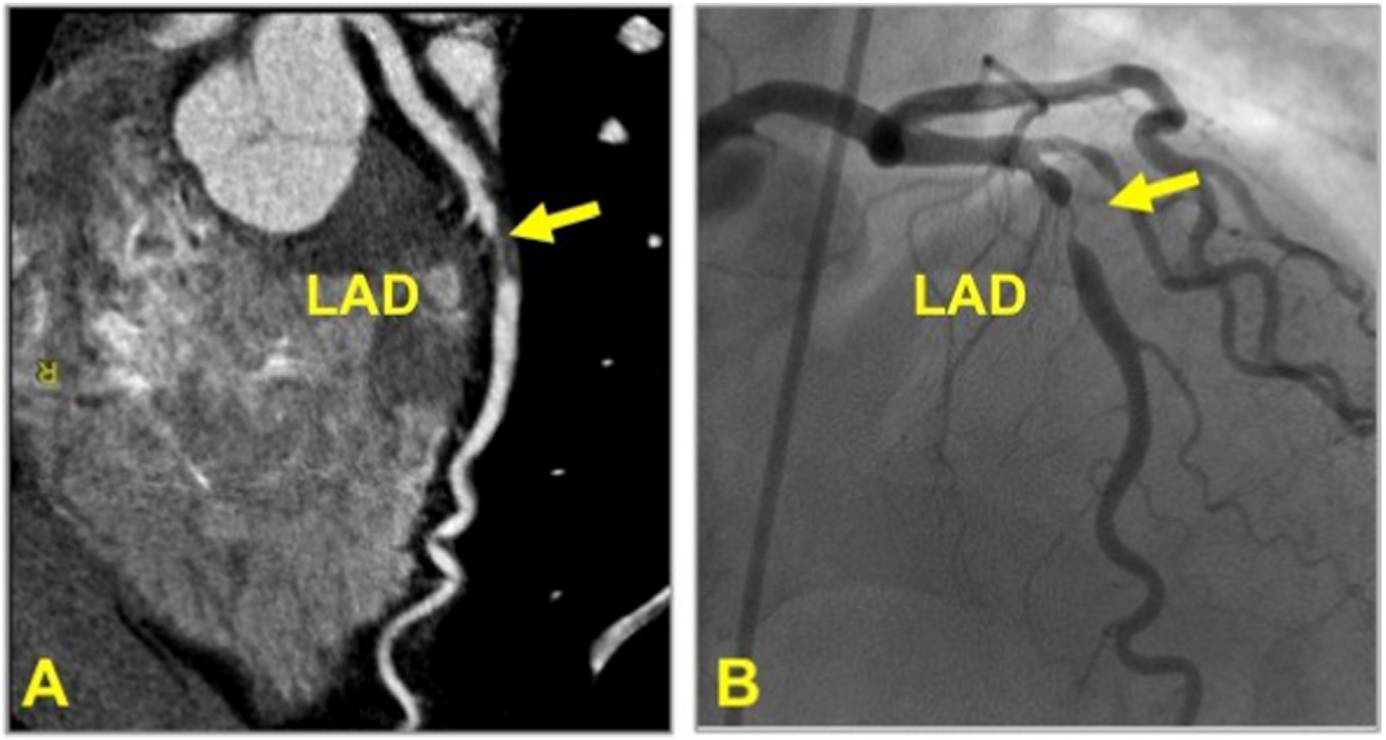


Fig. 7. CAD-RADS 4A/P1. Focal non-calcified plaque in the mid LAD (yellow arrow) with 70–99% severe coronary stenosis and mild amount of focal non-calcified plaque burden (P1) (left). Invasive coronary angiography confirming 70–99% stenosis in the mid LAD (yellow arrow, right). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

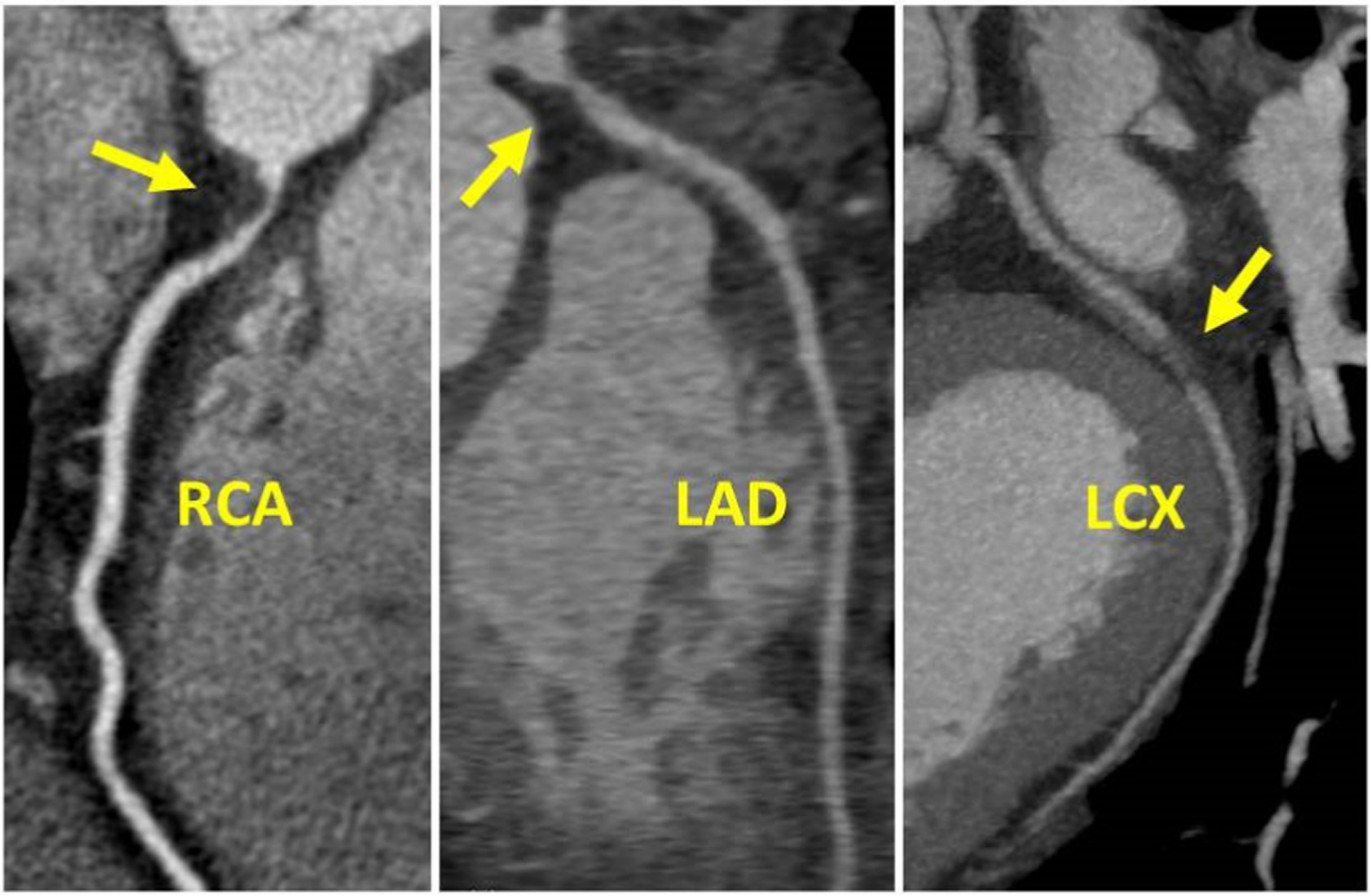


Fig. 8. CAD-RADS 4B/P2. Three-vessel obstructive disease (>70% stenosis), including in 70–99% stenosis of the proximal RCA (*left*), 70–99% stenosis of the proximal LAD (*middle*) and 70–99% stenosis of the mid LCX (*right*) and moderate amount of non-calcified plaque burden (P2).

Overall, a similar framework (Table 5) is used for patients with acute chest pain with other considerations including persistent clinical symptoms, troponin levels, EKG changes and high-risk plaque features leading to hospital admission and cardiology consultation for further work-up and management.

3.2. Plaque burden sub-classification

3.2.1. Overall amount of coronary plaque ("P")

There are substantial data demonstrating that the overall amount of coronary plaque by CCTA has strong association with incident coronary heart disease events[36–40] and such information may offer stronger prognostic value than merely the presence or absence of anatomical stenosis and clinical variables.[41] Indeed, the ability to detect the presence and amount of plaque by CCTA is a unique attribute of cardiac CT when compared with other non-invasive tests.

The updated version of CAD-RADS classification incorporates the designation "P" with categories ranging from P1 to P4 to categorize the overall amount of plaque as mild, moderate, severe or extensive on a per-patient basis (Table 2). Please note that CAD-RADS 0 denotes absence of stenosis or plaque, therefore P0 is not required as a classification. Importantly, there is currently no single method that is used to quantify the overall amount of plaque and thus the CAD-RADS classification enables imagers to select the technique which is most relevant for each CCTA study at a given institution. Assessment of plaque burden within an individual patient may vary substantially depending upon the method applied. Thus, it is recommended that imagers select the technique which is considered most appropriate for the individual patient and according to local practice norms. However, it is important to emphasize that when multiple different approaches can be performed to assess plaque burden, the most severe plaque assessment for the study should be used. It is also important to highlight that the P recommendations based on CAC or SIS is supported by prior evidence[36] and may be more reproducible. The methods for reporting total coronary plaque burden include the following:

(1) **CAC testing** - CAC provides a reproducible, and accurate method to quantify the amount of calcified plaque burden. The total CAC score is an established surrogate of overall coronary plaque burden. When performed as part of a CCTA exam, CAC testing (most commonly quantified according to the Agatston method) can be used to identify the overall amount of plaque (Table 2). However, calcium score should not be used in isolation and should be combined with at least a qualitative assessment of total plaque burden (calcified and non-calcified) to ensure that non-calcified plaque is also accounted. Therefore, the plaque burden and "P" category based on Calcium score will stay the same (if no non-calcified plaque is seen) or may increase after incorporating information on the total burden of non-calcified plaque. Moreover, institutional protocols may not always include CAC testing as a component of CCTA and importantly, the CAC score alone lacks the important quantification of non-calcified plaque burden.

(2) **Segment involvement score (SIS)** - the segment involvement score can easily be calculated from CCTA by assigning a score of 1 for each of the 16 coronary segments with any detectable plaque (highest possible score = 16).[36] This method provides an estimate

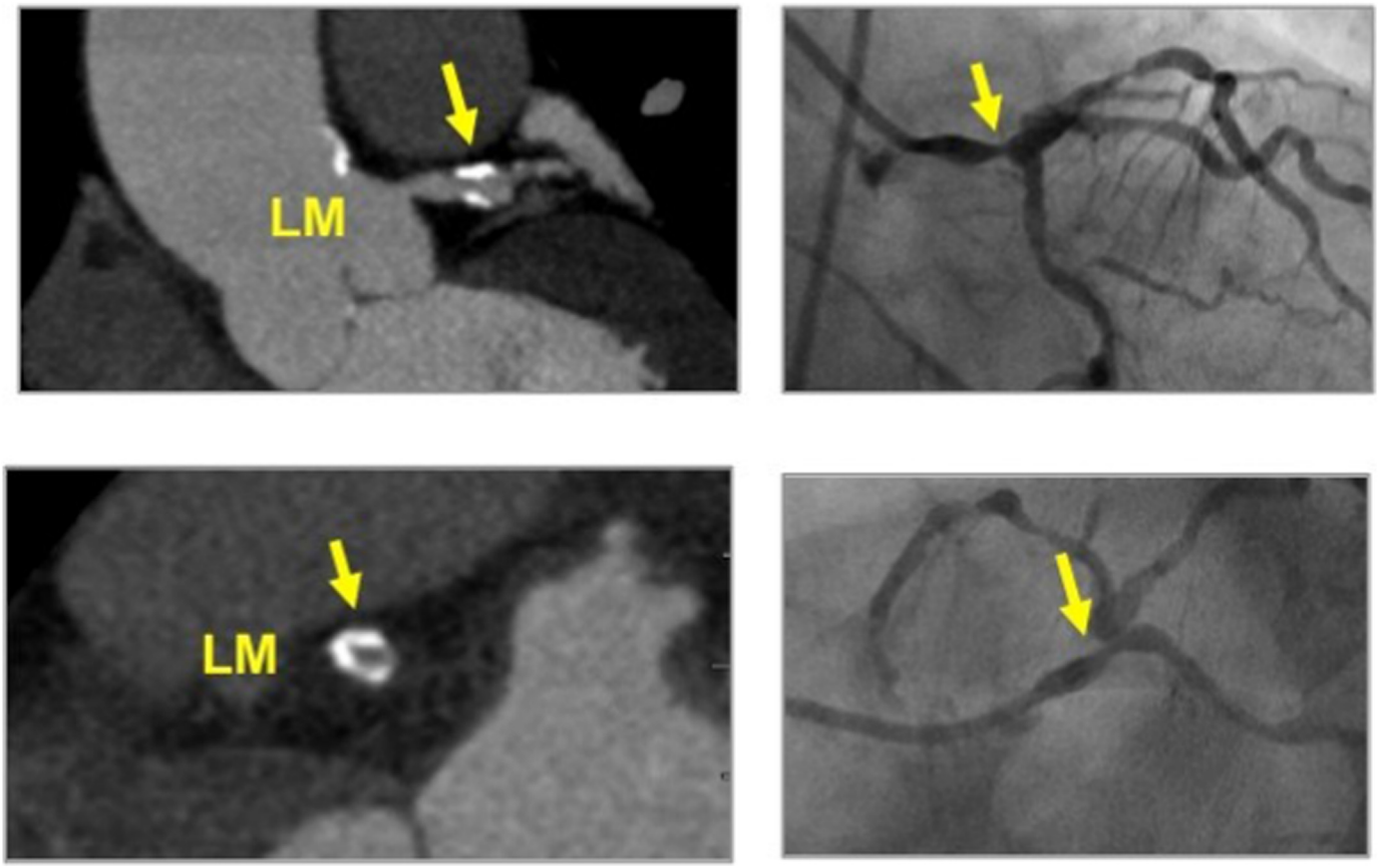


Fig. 9. CAD-RADS 4B/P3. Distal left main stenosis with circumferential calcified plaque resulting in >50% stenosis (arrow) and severe amount of plaque (P3 - Calcium Score = 640). *Upper left panel*: oblique longitudinal plane of the left main coronary artery. *Lower left panel* – cross-sectional slice of the distal left main coronary artery. *Figures on the right* - Invasive coronary angiography confirming focal severe stenosis in the distal left main coronary artery.

of the overall extent of coronary plaque, and there are several studies demonstrating that a larger SIS is associated with higher rates of cardiovascular death or MI.[38,41]

(3) **Visual estimate of overall plaque burden** - this method is based on a qualitative estimate of the amount of calcified and non-calcified plaque in each coronary vessel, and then providing an assessment of overall plaque burden (Table 2; Examples Figs. 2–6).

(4) **Quantitative Assessment of Total Coronary Plaque -** The writing group discussed various quantitative approaches that are available to quantify total coronary plaque volume on CCTA.[42] While there are numerous important emerging techniques for performing a quantitative and reproducible assessment of total plaque burden and plaque type beyond visual assessment alone, these techniques are not widely available and not routinely performed as part of clinical CCTA interpretation. In addition, most of the available techniques are time and labor intensive, which inhibit incorporation into routine clinical interpretation. These techniques require further validation against other techniques, including intravascular ultrasound, optical coherence tomography, and histology. In addition, clinical registries and multi-center trials will need to validate the reproducibility of different approaches, as well as establish sex and age reference ranges that can enhance risk assessment. The writing group anticipates that future iterations of CAD-RADS will incorporate novel techniques for plaque quantification as these become more developed and widely used.

The writing group recognizes that providing various different options to estimate overall plaque burden may lower the reproducibility of such an assessment. However, it is important to offer different options in recognition that different methods are used by different centers. Moreover, providing flexible options to estimate the overall amount of plaque is important to facilitate routine assessment of plaque burden as part of the clinical reading. Ultimately, gaining wider adoption by CCTA programs to report the overall amount of plaque may be more important than reliance upon a particular technique. Moreover, the CAD-RADS recommendations for patient management using plaque assessment are mostly based on expert opinion (i.e. the number of studies that have evaluated the efficacy of various therapies based on different thresholds of atherosclerosis is limited). As such, there are no absolute consensus thresholds based on these categories, but rather a framework whereby more aggressive therapies are suggested for individuals that have a higher plaque burden (See Tables 2, 4 and 5).

3.3. Modifiers

CAD-RADS categories can be complemented by modifiers to indicate that a study is not fully evaluable or non-diagnostic (N), or to indicate the presence of stents (S), grafts (G), and high-risk plaque (HRP). In this updated CAD-RADS version, the panel has added two new modifiers: ischemia (I) and exceptions (E). In addition, the term "vulnerable plaque (V)" has now been replaced with "high risk plaque (HRP)" to be consistent with evolving terminology.

3.3.1. Modifier N – non-diagnostic study

"**N**" can be used as a modifier or as a CAD-RADS category, depending on context. If the study is not fully diagnostic, due to motion artifacts, calcium blooming, metal artifacts or other types of artifacts, (i.e. not all segments >1.5 mm diameter can be interpreted with confidence) and a stenosis ≥50% is present in a diagnostic segment (CAD-RADS ≥ 3), the

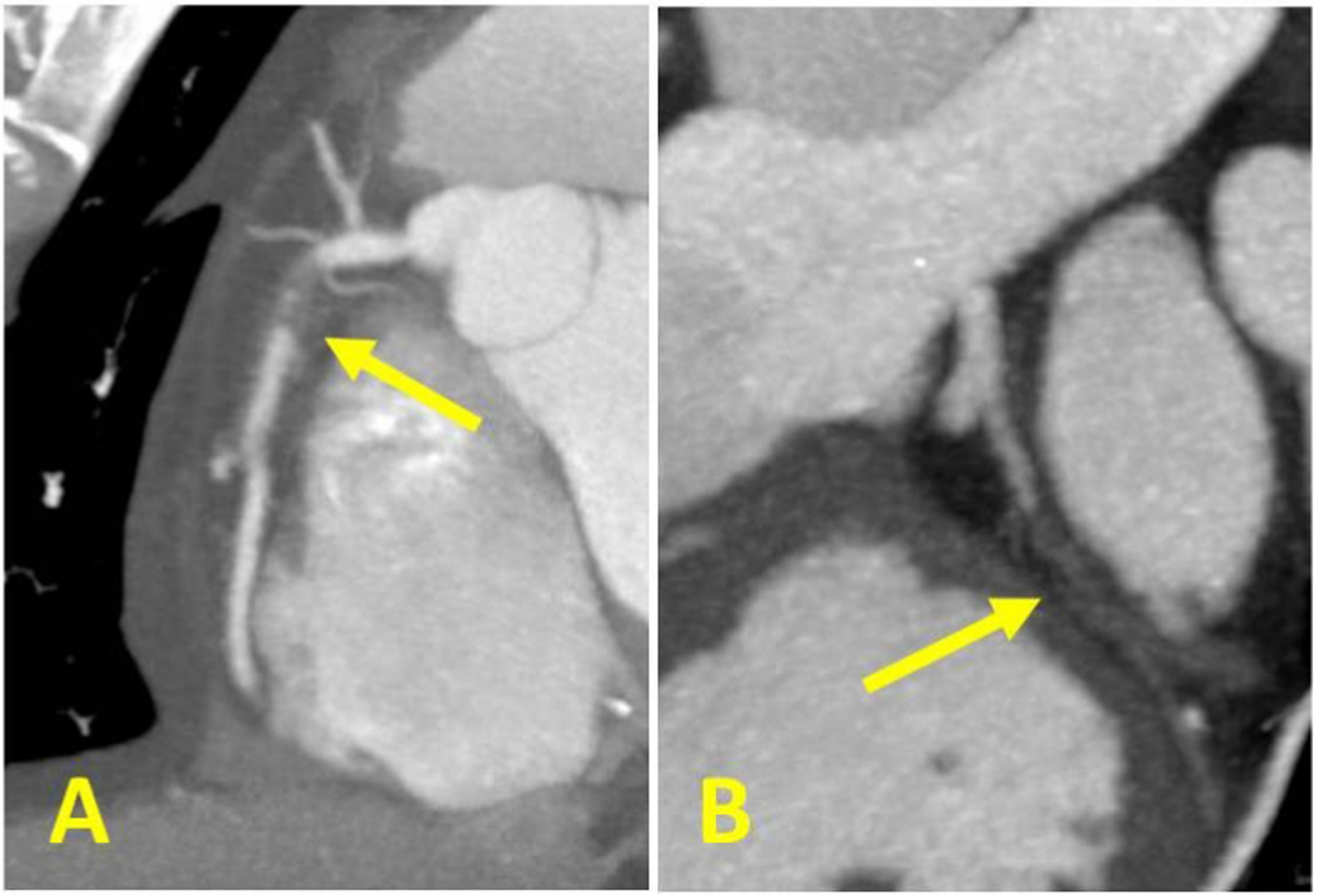


Fig. 10. CAD-RADS 5/P3. Two examples of 5mm thick MIPs CCTA cases coded as CAD-RADS 5. *Left*: Focal, non-calcified occlusion of the proximal RCA (*arrow*) and severe amount of plaque (P3). *Right*: Total occlusion of the proximal LCX (*arrow*) and extensive amount of plaque (P4). A small focus of "orphan" calcium along the distal LCX supports the diagnosis of chronic total occlusion.

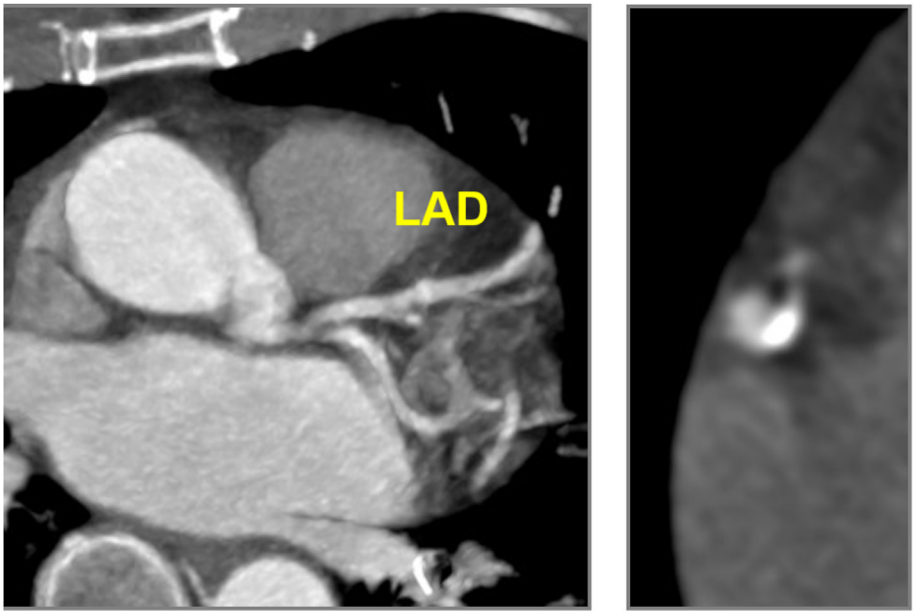


Fig. 11. CAD-RADS N/P2. Motion artifacts obscuring the left main, LAD and LCX arteries, which renders these segments non-diagnostic (left) and moderate amount of plaque (P2 - Calcium Score = 247). Motion artifacts in the mid RCA (right) with calcified plaque.

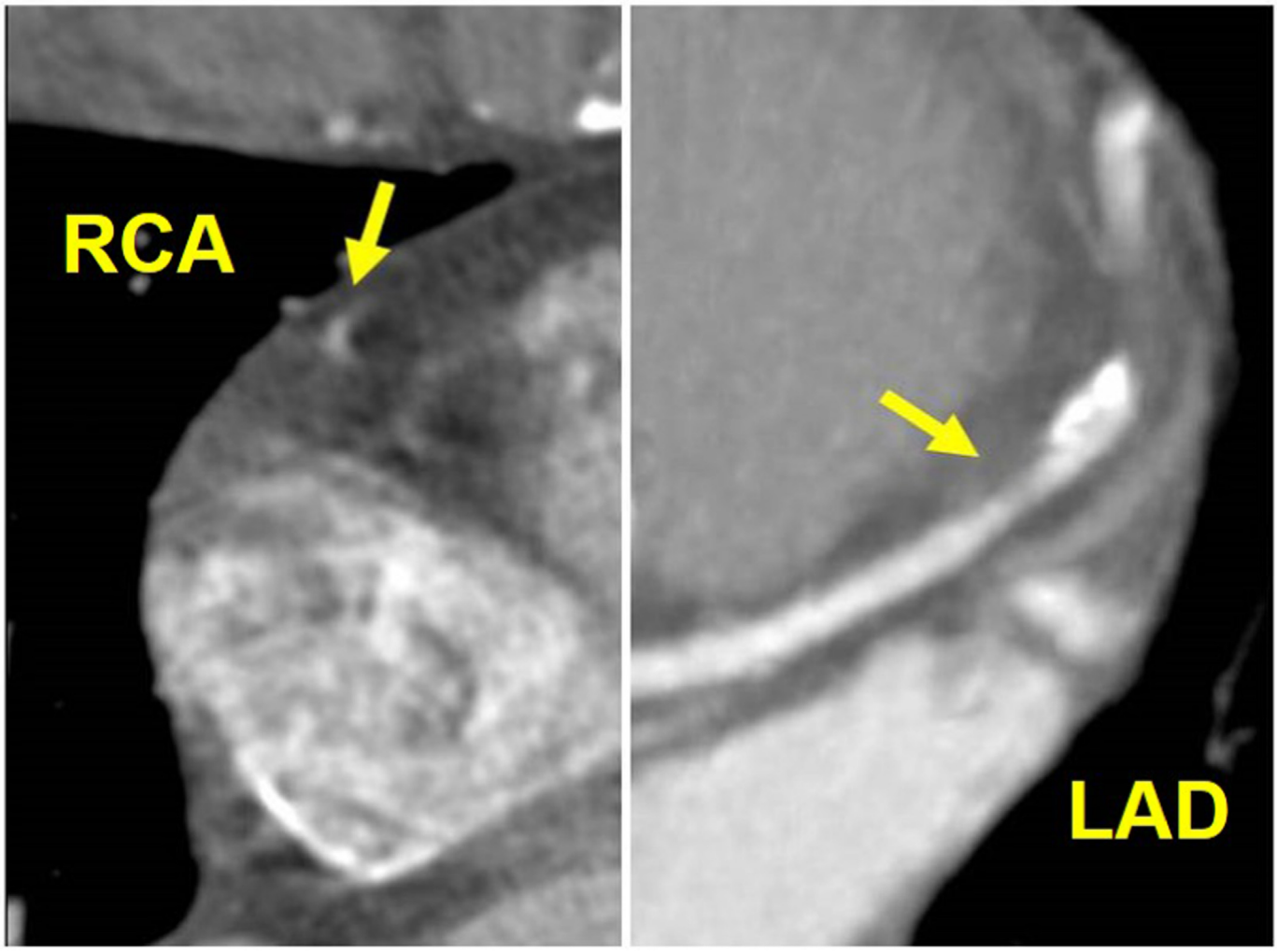


Fig. 12. CAD-RADS 3/P2/N. Motion artifact obscuring the mid RCA (*left, arrow*), which renders this segment non-diagnostic. There is also stenosis of the mid LAD with 50–69% luminal narrowing (*right, arrow*), qualifying this lesion as CAD RADS 3 and moderate amount of coronary plaque (P2). Although the mid RCA segment is non-diagnostic, the presence of suspected obstructive disease within the LAD should be coded as CAD RADS 3/P2/N. If the LAD lesion were mild (less than 50% diameter stenosis), and no other stenosis were identified, the patient would be coded as CAD RADS N.

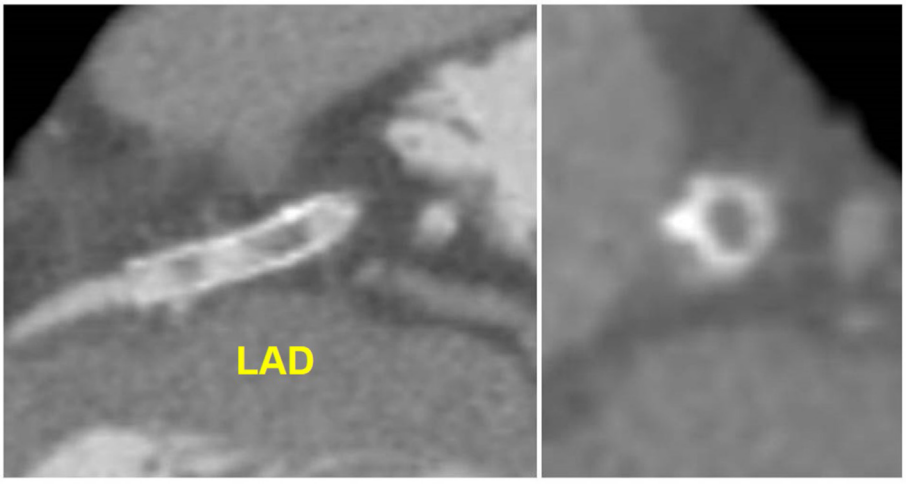


Fig. 13. CAD-RADS 4A/P3/S. In-stent stenosis of the proximal LAD with significant luminal narrowing (70–99% stenosis) and severe amount of coronary plaque (P3). Grading of in-stent stenosis should follow the grading of normal coronary arteries (0% stenosis, 1–24% stenosis, 25–49% stenosis, 50–69% stenosis, 70–99% stenosis, and >99% stenosis). In this case, severe in-stent restenosis designates a CAD-RADS 4A lesion, which would be followed by category P3 for extensive plaque burden and the stent modifier "S" for the presence of stent.

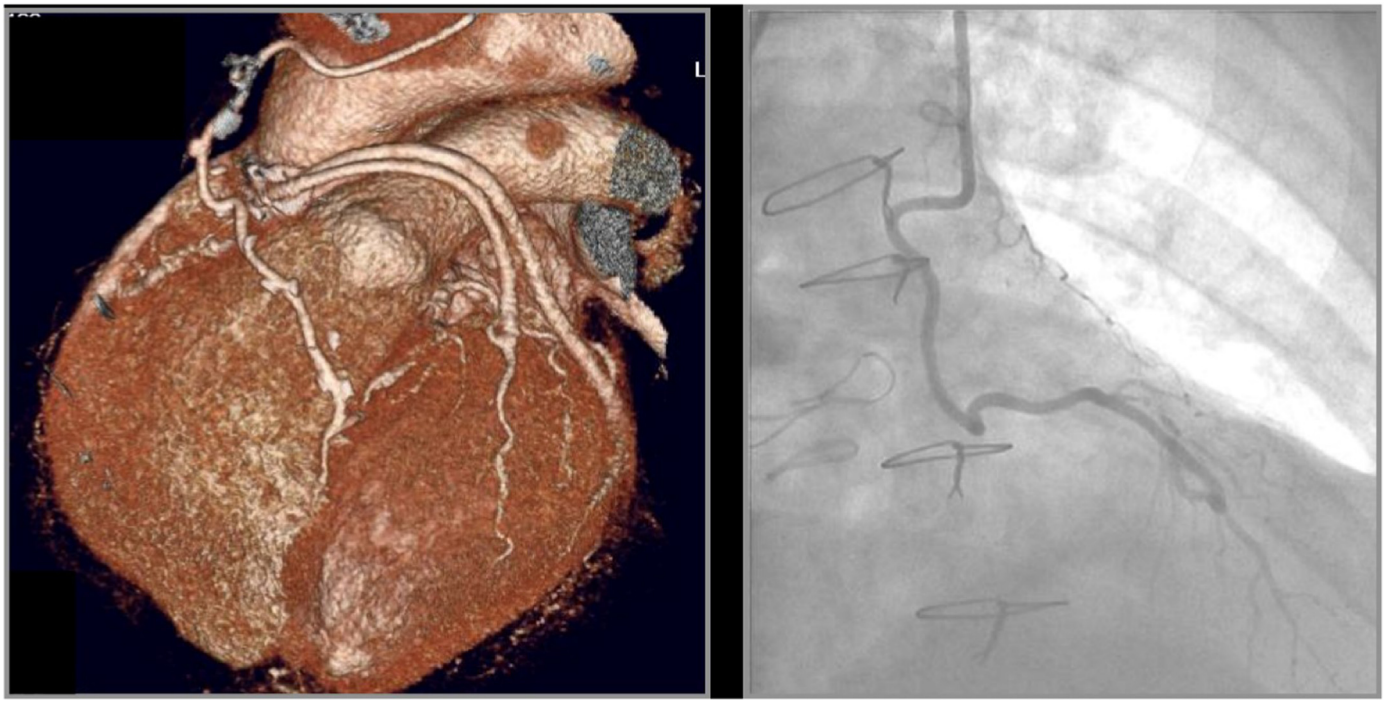


Fig. 14. MODIFIER G. Coronary CTA demonstrating a patent left internal mammary artery to the LAD and patent saphenous vein grafts to the ramus intermedius and second obtuse marginal branch. No stenoses or luminal narrowing throughout the grafts (0% stenosis, left). Invasive coronary angiography demonstrating patent LIMA graft to the LAD (right). When evaluating coronary CTA of patients with bypass grafts, the native coronary artery segments *proximal* to the graft anastomoses should not be evaluated for purposes of CAD RADS coding. Only the grafts and the native coronary artery segments *distal to* and *including* the anastomosis should be evaluated for CAD RADS coding.

most severe stenosis should be graded in addition to the modifier N. For example, a patient with moderate stenosis (50–69%) in one segment and one or more non-diagnostic segments and also moderate amount of plaque burden, should be graded as **CAD-RADS 3/P2/N** (Fig. 12) and not **CAD-RADS N,** since further evaluation is needed, possibly with functional imaging, and patient recommendations for anti-ischemic and preventive management apply. However, for a patient with at least one non-interpretable segment and no stenosis (zero), minimal (1–24%), or no more than mild stenosis (25–49%) in interpretable segments, **CAD-RADS N** should be used since CCTA cannot reliably exclude a significant stenosis and cannot be used to guide patient management and hence, further evaluation is still needed. Category "P" should be used with category or modifier "N", if total coronary plaque assessment can be performed reliably. Category "N" should precede Category "P" in replacement of the numerical stenosis assessment, if there is a non-interpretable coronary segment and no other coronary segment with greater than 50% stenosis. On the other hand, the numerical stenosis category and category "P" will precede Modifier "N" if there is a stenosis greater than 50% (CAD-RADS 3 or greater).

3.3.2. Modifier S = stent - presence of coronary stents

The modifier "**S**" indicates the presence of at least one coronary stent anywhere in the coronary system. For example, if a patient has a stent in the proximal left anterior descending coronary artery (LAD) with no significant in-stent restenosis or occlusion and demonstrates mild non-obstructive disease (25–49%) in the left circumflex (LCX) and right coronary arteries (RCA), the CCTA would be classified as: **CAD-RADS 2/S**. If a patient demonstrates significant in-stent restenosis of a stent in the proximal LAD, the study would be classified as: **CAD-RADS 4A/S** (Fig. 13). Similarly, a non-stenotic stent in the LAD and a new severe stenosis in the RCA would be classified as **CAD-RADS 4A/S**. Finally, if a stent is non-evaluable, the study would be classified as CAD-RADS N/S if there is no other stenosis greater than 50% in the coronary tree. Note: CAD-RADS was created to guide management recommendations, so it does not matter whether the severe stenosis is in stented or non-stented vessel. Rather, the key issue is whether the patient has a severe stenosis and may be considered for further work-up. Category P should also be added to indicate the amount of plaque burden.

3.3.3. Modifier G = grafts - presence of coronary bypass grafts

The modifier "**G**" indicates the presence of at least one coronary-artery bypass graft (Fig. 14). A stenosis bypassed by a fully patent graft is not considered for the CAD-RADS classification. For example, if a patient has a graft to LAD, with absence of significant stenosis in the graft, distal anastomosis and run-off vessel, and demonstrates non-obstructive lesions (25–49%) in the LCX and RCA, in addition to the "expected" proximal LAD severe stenosis, and moderate plaque burden, the case would be classified as: CAD-RADS 2/P2/G. In the example of a patient with total occlusion of a saphenous vein graft (SVG) to the RCA, and a patent LIMA to LAD and SVG to LCX, and severe plaque burden, the case would be classified as: CAD-RADS 5/P3/G. The interpretation is that a total occlusion is present and further management or investigation may be considered. Total plaque burden should be assessed in both native coronary arteries and by-pass grafts. A combined assessment should be considered for deciding on Category "P".

3.3.4. High-risk plaque (HRP) features (previously "vulnerable plaque" [V])

Data from recent CCTA studies have described high-risk plaque characteristics that are associated with a higher risk of future ACS as well as lesion specific ischemia. Features originally described as indicating HRP include positive remodeling, low-attenuation plaque, spotty calcification, and the napkin-ring sign.[43–46] These plaque characteristics are associated with intravascular ultrasound and histological features of more advanced atherosclerotic plaque and thin cap fibroatheroma, which has the potential to develop to plaque rupture/thrombosis. However, the prevalence of these features on CCTA is high (~30% of CCTA, with an even higher frequency in the presence of

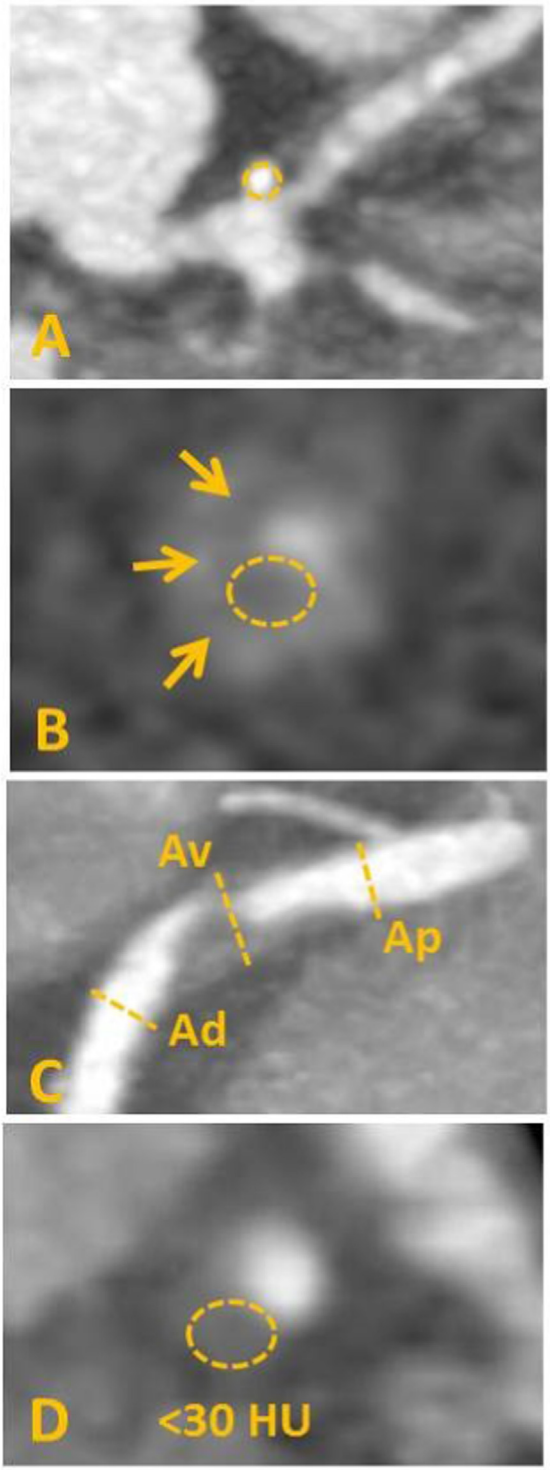


Fig. 15. High-risk plaque (HRP) features on coronary CTA a) Spotty calcium, defined as punctate calcium within a plaque b) "napkin ring sign", defined in a non-calcified plaque cross-sectional image by the presence of two features: a central area of low attenuation plaque that is apparently in contact with the lumen; and a ring-like peripheral rim of higher CT attenuation surrounding this central area (*arrows*); c) Positive remodeling, defined as the ratio of outer vessel diameter at the site of plaque divided by the average outer diameter of the proximal and distal vessel greater than 1.1, or Av/[(Ap + Ad)/2] >1.1; and d) Low attenuation plaque, defined as non-calcified plaque with internal attenuation less than 30 HU. Please note that a combination of two or more high-risk features is necessary to designate the plaque as high-risk for CAD-RADS.

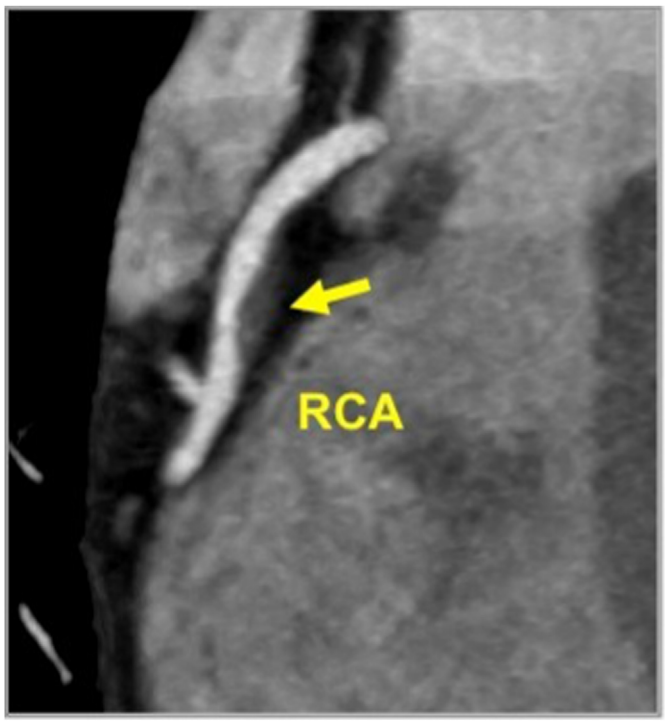


Fig. 16. CAD-RADS 2/P2/HRP. Focal non-calcified plaque in the mid RCA with 25–49% diameter stenosis and overall moderate amount of total coronary plaque. The plaque demonstrates two high risk features, low attenuation (<30 HU) and positive remodeling, thus coding with the modifier "HRP."

stenosis), and thus the positive predictive value for identifying future events is relatively modest, especially when evaluated on top of plaque burden.[39]

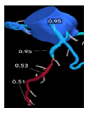
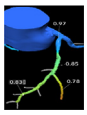
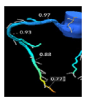
If a coronary plaque clearly demonstrates two or more high-risk features by CCTA, the modifier "HRP" (high risk plaque) should be added (Figs. 15 and 16). High-risk features include: spotty calcifications, low attenuation plaque (less than 30 Hounsfield Units), positive remodeling, and the "napkin ring sign" (see Fig. 15).

As an example, **HRP** should be used for a patient demonstrating plaque with two or more high-risk features (spotty calcifications, positive remodeling, low attenuation plaque or the napkin ring sign) (Fig. 16). The specific features should be described in the report text.

When deciding on how the presence of HRP should impact patient management it is important to recognize that these features have been associated with (a) acute chest pain – a higher risk of ACS, independent of stenosis severity[44]; (b) stable chest pain – a higher risk of incident adverse cardiovascular events[39,47]; (c) a higher likelihood of lesion specific ischemia, as defined by invasive FFR. Therefore, among patients with acute chest pain who have HRP, hospital admission or observation may be considered even in the absence of severe stenosis. If the patient is discharged from an acute chest pain presentation, short-term clinical follow-up may be useful. Among patients with stable chest pain, the presence of HRP may be most relevant in the presence of non-obstructive CAD or when there is uncertainty regarding whether lesion specific ischemia is present. Importantly, regardless of the clinical setting (i.e. acute or stable chest pain), the identification of HRP (i.e. 2 or more features) – similar to the presence of more extensive plaque, should signify the need for more aggressive preventive therapies (i.e. statins and possibly aspirin), including for nonobstructive lesions (CAD-RADS 1 and CAD-RADS 2).

Studies coded with CAD-RADS 3 and HRP (the presence of high risk plaque with 50–69% diameter stenosis, excluding left main lesions) should prompt consideration of more aggressive management than studies coded only with CAD-RADS 3, particularly in patients presenting

Table 6
Interpretation of CT-FFR. If there is presence of abnormal CT-FFR as defined as a lesion-specific value ≤ 0.75 in a vessel large enough for PCI the designation of "I+" (I=Ischemia) should be included. "I-" in the setting of a lesion-specific CT-FFR >0.80. For values between 0.76 and 0.80 the modifier "I+/−" is used and decisions around ICA referral depend on lesion location, symptom severity and delta CT-FFR.

CCTA (Stenosis)	CT-FFR	Interpretation and Considerations
CT-FFR may be used in coronary stenosis ranging from 50 to 90% to better define if a stenosis is hemodynamically significant (particularly CAD-RADS 3 and 4A) CAD-RADS 3 - Moderate stenosis CAD-RADS 4A - Severe stenosis CAD-RADS 2 could be considered if proximal lesion and stenosis ≥40%, including in the presence of high-risk plaque features	Abnormal (I+) (≤0.75) 	CAD-RADS 3 or 4/**I +** Anatomical stenosis in one vessel with concordant lesion-specific abnormal CT-FFR ≤0.75. Consider ICA for individuals likely to benefit from revascularization
	Normal (I-) (>0.80) 	CAD-RADS 3 or 4/**I-** Anatomical stenosis with lesion-specific CT-FFR >0.80. Defer invasive angiography and optimize medical therapy. Anatomical stenosis with lesion-specific CT-FFR >0.80. At least one vessel has a distal value ≤ 0.80, but this value does not appear to be associated with a specific stenosis. Defer invasive angiography and optimize medical therapy.
	Borderline (I+/−) (0.76–0.80) 	CAD-RADS 3 or 4/**I ±**Anatomical stenosis in one vessel with borderline, grey-zone CT-FFR 0.76–0.80. Consider invasive angiography based on symptoms, lesion location, and *trans*-lesional pressure loss (>.12 significant measured 1–2 cm proximal to a stenosis – CT-FFR 1–2 cm distal to the stenosis) and for individuals likely to benefit from revascularization

to the emergency department with acute chest pain. This includes consideration of further testing with CT-FFR, CTP, other stress imaging, or invasive coronary angiography depending on the clinical symptoms, EKG findings and biomarkers. However, management decisions should ultimately be made on an individual basis taking into consideration all supporting clinical and laboratory data.

3.3.5. *Modifier I = ischemia: CT-FFR or CTP*

Historically, CCTA exclusively provided anatomical information comprising luminal stenosis severity and atherosclerotic burden. Given the growing evidence regarding the critical importance of physiology to guide decisions around coronary revascularization and the development of techniques enabling functional assessment of CCTA the writing group deemed it important to update the CAD-RADS reporting guidelines to reflect this practice shift. The **Modifier "I"** indicates that an ischemia test has been performed (either CT-FFR or stress CTP).

3.3.5.1. Computed tomography - fractional-flow reserve (CT-FFR). CT-FFR was first introduced over a decade ago and allows for the computation of pressure across the coronary tree through the integration of machine learning for anatomical data extraction and computational fluid dynamics. The technique has been shown to be accurate and demonstrates excellent agreement with invasive FFR.[48] There is also growing clinical utility data across multiple healthcare systems documenting the safety of deferral from catheterization in the setting of a negative CT-FFR (>0.80), the improved catheterization lab efficiency (ICA) and increased risk associated with an CT-FFR ≤0.80.[49] There is also growing evidence of the continuous rather than discrete nature of physiology with increasing risk with lower CT-FFR values. Given the non-binary nature of CT-FFR, current clinical guidance emphasizes that the CT-FFR value 1–2 cm distal to an area of coronary stenosis should be considered to guide decisions around referral to invasive angiographic and revascularization.[50] The lowest overall value along the entire vessel may be informative but typically reflects total plaque burden and the ratio of coronary volume to mass, and hence reflects vascular health, as a result it can be used to inform medical management but should not be used to guide catheterization laboratory referral.[51]

Table 7
Interpretation of Stress Myocardial CT Perfusion. If there is presence of myocardial ischemia (reversible perfusion defect) or peri-infarct ischemia (perfusion defect during stress larger than rest perfusion defect), then the Modifier I+ (I=Ischemia) will be added to CAD-RADS. If no ischemia is detected or if there is presence of a prior fixed myocardial infarct, then the Modifier I- will be added to CAD-RADS. Modifier I ±indicates that the study is borderline for the presence of ischemia.

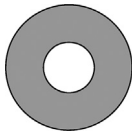
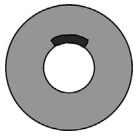
CCTA (Stenosis)	Stress CTP	Rest CTP	Interpretation
Stress CTP may be used in coronary stenosis ranging from 50 to 90% to better define if a stenosis is hemodynamically significant (particularly CAD-RADS 3 and 4A) CAD-RADS 3 - Moderate stenosis CAD-RADS 4A - Severe stenosis *CAD-RADS 2 could be considered if proximal lesion and stenosis >40%, including in the presence of high-risk plaque features	Perfusion defect (+) 	Negative (−) 	Myocardial ischemia in a defined coronary territory CAD-RADS 3 or 4/**I+**
	Perfusion defect (+) 	Perfusion defect (+) 	Myocardial infarct or no evidence of ischemia in a defined coronary territory CAD-RADS 3 or 4/**I-**
	Perfusion defect (+) 	Perfusion defect (+) 	Peri-infarct ischemia in a defined coronary territory CAD-RADS 3 or 4/**I+**

Table 8
Summary of the main changes for 2022 CAD-RADS update when compared to the first version published in 2016.

	2016 CAD-RADS	2022 CAD-RADS
Stenosis grading	CAD-RADS 0, 1, 2, 3, 4A, 4B and 5	No change
Plaque burden grading	No systematic classification	New CAD-RADS category grading scale for Plaque Burden ranging from P1 to P4
Modifiers	Four modifiers were introduced to complement the CAD-RADS classification First: modifier N (non-diagnostic) Second: modifier S (stent) Third: modifier G (graft) Fourth: modifier V (vulnerability)	Addition of two new modifiers: modifier I (ischemia) and modifier E (exceptions) and replacement of modifier V (vulnerable) with HRP (high-risk plaque) First: modifier N (non-diagnostic) **Second: modifier HRP** (replaces V) **Third: modifier I+ (ischemia), I- and I ±** Fourth: modifier S (stent) Fifth: modifier G (graft) **Sixth: modifier E (exceptions)**

Table 9
Potential sources of high-sensitivity troponin elevation[a].

Cardiac	Myocardial infarction Myocardial injury Myocarditis/myocardial inflammation Infiltrative heart disease (amyloid, sarcoidosis) Cardiomyopathy (e.g. stress cardiomyopathy) Recent ablation/defibrillation
Vascular	Pulmonary embolism/pulmonary hypertension Aortic dissection
Other	Central nervous system pathology (e.g. stroke, seizure) Kidney disease Chest wall trauma Rhabdomyolysis/myositis Chemotherapy Metastatic disease Inherited conditions (e.g. muscular dystrophy) Carbon monoxide Infectious

[a] Adapted based on Causes on Troponin Elevation and Associated Mortality in Younger Patients.[60]

To that end, current evidence suggests possible ICA referral for a symptomatic patient in the setting of an appropriate clinical context for coronary revascularization and the designation of "**I+**" (positive ischemia) for a lesion-specific value ≤ 0.75 in a vessel large enough for percutaneous coronary intervention (PCI). Similarly, deferral of ICA would be approximate in the setting of a "I-" (negative ischemia) lesion-specific CT-FFR >0.80 (Table 6). For values between 0.76 and 0.80 the modifier "**I+/−**" (borderline or indeterminate value) is used and decisions around ICA referral will further depend on lesion location, symptom severity and delta CT-FFR (*trans*-lesional gradient >0.12 considered significant) as measured as the pressure loss from 1 to 2 cm proximal to 1–2 cm distal to a stenosis.[52] For lesions with an abnormal CT-FFR without a concordant anatomic lesion, the modifier "**I-**" should be described in case the reader is confident that this is false-positive result by CT-FFR or "**I+/−**" if it is indeterminate and there is questionable interpretation of both findings. In multivessel disease the physiologically significant lesion may not be the most anatomically severe. This needs to be contextualized and clarified in the body of the report and impression. In case the CT-FFR study is non-diagnostic, modifier N can also be applied to CT-FFR or CTP. Table 6 summarizes interpretation of CT-FFR.

3.3.5.2. Myocardial CT perfusion. Advancements in CT technology, in particular the development of wide-area detectors with greater z-axis coverage and dual-source CT, have improved functional assessment of the myocardium using stress CTP. Myocardial CTP has been validated in patients with acute and chronic chest pain against modalities such as cardiac MRI, SPECT-MPI, invasive coronary angiography, invasive FFR and cardiac biomarkers.[53–55] Furthermore, a combined approach of myocardial CTP with coronary CTA has been shown to have better diagnostic accuracy than CCTA alone in patients at intermediate-to-high risk for coronary artery disease (CAD).[56–58] Therefore, the Society of Cardiovascular Computed Tomography has provided resources to facilitate clinical implementation of CTP.[59] The addition of stress myocardial CTP to CCTA allows detection of hemodynamically significant stenosis in a single setting with the identification of reversible myocardial ischemia correlating with the same territory in which a moderate or severe stenosis is suspected. Stress myocardial CTP also allows the exclusion of myocardial ischemia in moderate coronary stenosis (50–69%) or a suspected severe coronary stenosis (>70%) with dense calcified or mixed plaques, avoiding additional downstream testing. It also allows the identification of fixed perfusion defects related to prior myocardial

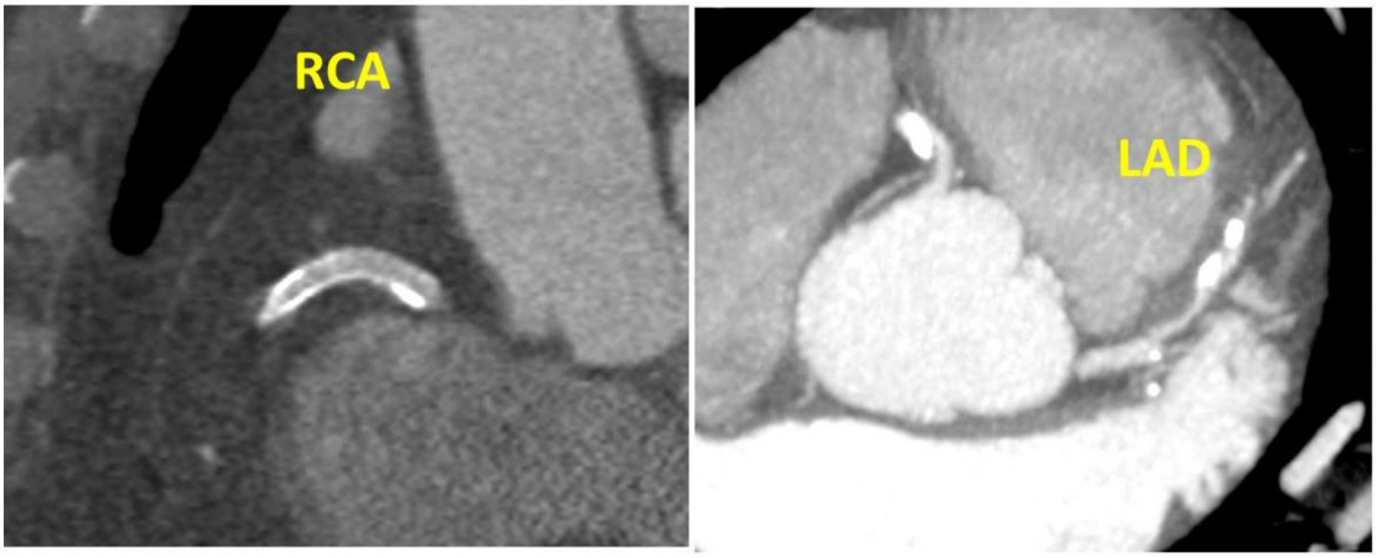


Fig. 17. CAD-RADS 3/P3/HRP/S. Example demonstrating a patent stent (S) in the proximal RCA (0% stenosis) with high-risk plaque (HRP) in the proximal LAD with thick MIP images resulting in 50–69% stenosis and overall severe amount of total coronary plaque burden (P3). In isolation, the proximal LAD lesion would be coded CAD RADS 3/P3/HRP. However, since CAD RADS is coded on a per-patient basis, and a RCA stent is present, this patient would be coded as CAD RADS 3/P3/S/HRP.

EXAM: CORONARY CT ANGIOGRAPHY WITH CALCIUM SCORE

CLINICAL HISTORY: []

COMPARISON: []

TECHNIQUE: Using a [*scanner type*], a preliminary scout study was obtained, followed by coronary artery calcium protocol. Following administration of intravenous contrast, [*0.5*] mm collimated images were obtained through the coronary arteries. Data were transferred off-line for 3D reconstructions
ACQUISITION: [*Prospective*; *Retrospective*>] ECG triggering was used. Heart rate at the time of acquisition was approximately [] bpm.

MEDICATIONS: [*100mg of oral metoprolol was administered prior to scanning*]. [0.*4mg sublingual nitroglycerine was administered immediately prior to scanning*].

TECHNICAL QUALITY: [*excellent, with no artifacts*; *good, with minor artifact but good diagnostic quality; acceptable, with moderate artifacts; poor/suboptimal, with severe artifacts*]

FINDINGS:
<<If CAC performed>> The total calcium score is zero indicating absence of calcified plaque in the coronary tree.

The coronary arteries arise in normal position. There is ____ (right/ left/ co) coronary artery dominance.

Left main: The left main coronary artery is a _____ (short/ medium/ large) size vessel and (bifurcates in LAD and LCX / or trifurcates in LAD, LCX and RI). It demonstrates no evidence of plaque or stenosis.

LAD: The left anterior descending artery has no evidence of plaque or stenosis. It gives off ____ patent diagonal branches.

LCX: The left circumflex artery has no evidence of plaque or stenosis. It gives off ____ patent obtuse marginal branches.

RCA: The right coronary artery has no evidence of plaque or stenosis. It gives off a patent posterior descending artery and a patent posterior left ventricular branch.

Non-coronary cardiac findings:

Cardiac valves: The aortic valve is trileaflet. There is no thickening or calcifications in the aortic and mitral valves.

Pericardium: The pericardial contour is preserved with no effusion, thickening or calcifications.

Extra-cardiac findings: There are no significant extra-cardiac findings in the available limited views of the lungs, mediastinum and upper abdomen.

IMPRESSION:
1- *Stenosis:* No evidence of coronary stenosis or plaque by Coronary CT Angiography.

Examples If stenosis:

Mild (25-49%) stenosis of the proximal LAD.
Moderate (50-69%) stenosis of the mid RCA.
Severe (70-99%) stenosis of the distal RCA.

2- *Plaque:* Overall, there is <<mild / moderate / severe / extensive>> amount of coronary plaque. ** only when plaque present ** OR Total calcium score of Zero indicating absence of calcified coronary plaque.

3- *Modifiers:* (None)

RECOMMENDATION: << Insert recommendations based on 2022 CAD RADS as summarized in Tables 10 and 11 >>

Other: []

Fig. 18. Sample standardized reporting template for Coronary CTA incorporating CAD-RADS coding.

infarction. Table 7 describes the interpretation of stress CTP and how it is incorporated with the different CAD-RADS categories. In the presence of myocardial ischemia (reversible perfusion defect) or peri-infarct ischemia (perfusion defect during stress larger than rest perfusion defect), the **Modifier "I+"** should be added to CAD-RADS. If no ischemia is detected or if there is presence of a prior fixed myocardial infarct, the **Modifier "I-"** will be added to CAD-RADS. The presence of myocardial infarct should be documented in the impression of the report and the Modifier "I" should be reserved exclusively to ischemia. The **Modifier "I+/−"** indicates that the study is borderline or inconclusive for the presence of ischemia. Similarly to the mismatch between CT-FFR and CCTA results, an ischemic segment without a concordant anatomic lesion, should be classified as modifier "**I-**" in case the reader is confident that this is a false-positive result by CTP or "**I+/−**" if it is indeterminate and there is questionable and discrepant interpretation of both findings.

Table 10
2022 CAD-RADS 2.0 Suggested Text for Recommendations Section of CCTA Reporting in Patients with Stable Chest Pain (See Table 4 for further detail). Below intended to aid reporting based on specific CAD RADS categorization. Note: including information from footnotes in patient report is optional.

Stenosis	Plaque	Suggested Recommendation for Report
CAD RADS 0	N/A	• Reassurance. Consider non-atherosclerotic causes of symptoms.
CAD RADS 1 or CAD RADS 2	P1	• Consider non-atherosclerotic causes of symptoms. • Consider risk factor modification and preventive pharmacotherapy.
	P2	• Consider non-atherosclerotic causes of symptoms. • Risk factor modification and preventive pharmacotherapy.
	P3 or P4	• Consider non-atherosclerotic causes of symptoms. • Aggressive risk factor modification and preventive pharmacotherapy.
CAD RADS 3	P1/P2/P3/P4	• Consider CT-FFR, CTP or stress testing • Aggressive risk factor modification and preventive pharmacotherapy. • Other treatments (including anti-anginal therapy) should be considered per guideline directed care
	If I+	• Consider ICA, especially if frequent symptoms persist after guideline-directed medical therapy
CAD RADS 4	P1/P2/P3/P4	• Consider ICA[a] or functional[b] assessment • Aggressive risk factor modification and preventive pharmacotherapy. • Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care
CAD RADS 5	P1/P2/P3/P4	• Consider ICA[a], functional[b], and/or viability assessment • Aggressive risk factor modification and preventive pharmacotherapy. • Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care

[a] ICA – invasive coronary angiography may be favored if high-grade stenosis (>90%), high-risk plaque features or I + (presence of lesion-specific ischemia on CT FFR or perfusion defects by CTP) or concordant ischemia by other stress tests and a candidate for revascularization. It should be clarified that benefit of revascularization should be confined to patients with persistent symptoms despite optimal medical therapy.

[b] Functional Assessment includes CT-FFR, CTP, stress testing (ETT, stress echocardiogram, SPECT, PET, Cardiac MRI) or invasive FFR.

Table 11
2022 CAD-RADS 2.0 Suggested Text for Recommendations Section of CCTA Reporting in Patients with Acute Chest Pain (See Table 5 for further detail). Below intended to aid reporting based on specific CAD RADS categorization. Note: including information from footnotes in patient report is optional.

Stenosis	Plaque	Suggested Recommendation for Report
CAD RADS 0	N/A	• Reassurance. No further evaluation of ACS is required. • If Tn (+) consider other sources of increased troponin
CAD RADS 1	P1 or P2	• No further evaluation of ACS is required. • If Tn (+) consider other sources of increased troponin • Referral for outpatient follow-up for risk factor modification and preventive pharmacotherapy.
CAD RADS 1	P3 or P4	• No further evaluation of ACS is required. • If Tn (+) consider other sources of increased troponin • Referral for outpatient follow-up for aggressive risk factor modification and preventive pharmacotherapy.
CAD RADS 2	P1 or P2	• If clinical suspicion of ACS is high, Tn (+) or high risk plaque (HRP) features, consider hospital admission with cardiology consultation. • If Tn (+) consider other sources of increased troponin • Referral for outpatient follow-up for risk factor modification and preventive pharmacotherapy,
CAD RADS 2	P3 or P4	• If clinical suspicion of ACS is high, Tn (+) or high risk plaque (HRP) features, consider hospital admission with cardiology consultation. • If Tn (+) consider other sources of increased troponin. • Referral for outpatient follow-up for aggressive risk factor modification and preventive pharmacotherapy.
CAD RADS 3	P1/P2/P3 /P4	• Consider hospital admission with cardiology consultation. • Consider CT-FFR, CTP or stress testing • Preventive management, including aggressive preventive pharmacotherapy. Other treatments (including anti-anginal therapy) should be considered per guideline directed care.
	If I+	• Consider ICA
CAD RADS 4A	P1/P2/P3 /P4	• Hospital admission with cardiology consultation. • Consider ICA[a] or functional assessment[b] • Preventive management, including aggressive preventive pharmacotherapy. Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care
CAD RADS 4B	P1/P2/P3 /P4	• Hospital admission with cardiology consultation. • ICA is recommended. • Preventive management, including aggressive preventive pharmacotherapy. Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care
CAD RADS 5	P1/P2/P3 /P4	• Hospital admission with cardiology consultation. • Expedited ICA and revascularization if suspected acute occlusion. • Preventive management, including aggressive preventive pharmacotherapy. Other treatments (including anti-anginal therapy and options of revascularization) should be considered per guideline directed care.

[a] ICA – invasive coronary angiography may be favored if high-grade stenosis (>90%), high-risk plaque features or I + (presence of lesion-specific ischemia on CT FFR or perfusion defects by CTP) or concordant ischemia by other stress tests and a candidate for revascularization. It should be clarified that benefit of revascularization should be confined to patients with persistent symptoms despite optimal medical therapy.

[b] Functional Assessment includes CT-FFR, CTP, stress testing (ETT, stress echocardiogram, SPECT, PET, Cardiac MRI) or invasive FFR.

Either CT-FFR or CTP can be performed at the time of the CCTA interpretation or later. If performed later, the recommendation is to update the CAD-RADS score by adding the Modifier "I". Table 7 summarizes interpretation of myocardial CTP.

3.3.6. *Modifier E = exceptions*

In clinical practice, sites that have adopted the CAD-RADS classification report scores approximately 95% of the time for CCTA.[14] In general, CAD-RADS scores are not used in cases of non-atherosclerotic causes of coronary abnormalities, such as coronary dissections, anomalous coronary arteries, coronary artery aneurysms or pseudo-aneurysms, vasculitis, coronary artery fistulas, extrinsic coronary artery compression and other causes (Table 3). These exceptions are far less frequent than atherosclerosis as a cause of coronary stenosis or obstruction but remain important differential diagnostic considerations and are increasingly being recognized. Therefore, in the updated version of CAD-RADS, a **modifier "E"** is used to account for any non-atherosclerotic narrowing of the coronary arteries and should be added at the end of the score as a modifier. For example, if an anomalous coronary artery with inter-arterial course results to a moderate stenosis, then CAD-RADS 3/E should be coded. The **modifier "E"** will have the following purposes: 1- it will allow for non-atherosclerotic causes of coronary obstruction to be identifiable in the CAD-RADS reporting system; 2- it will provide a framework for tracking of such etiologies; 3- and it will indicate to the referring clinician that the CAD-RADS classification, which is strictly related to atherosclerotic coronary artery disease, may not fully capture the full range of coronary abnormalities.

VII. The framework for the new CAD-RADS coding should follow three categories: stenosis, plaque and then modifiers. Therefore, the Category "P" for plaque should follow the CAD-RADS score for stenosis. Then modifiers should be added, if present. If more than one category and/or modifier is present, the symbol "/" (slash) should follow each modifier in the following order:

i. First: modifier **N (non-diagnostic)**
ii. **Second: modifier HRP (high-risk plaque)**
iii. **Third: modifier I (ischemia)**
iv. Fourth: modifier **S (stent)**
v. Fifth: modifier **G (graft)**
vi. **Sixth: modifier E (exceptions)**

Examples:

i. Non-interpretable coronary stent with moderate amount of plaque burden without evidence of other obstructive coronary disease: **Categories N and P should be used and Modifier S = CAD-RADS N/P2/S. Please note that Category "N" will replace the numerical stenosis grading and will precede Category "P"**
ii. Presence of a stent and at least one moderate stenosis demonstrating severe amount of plaque burden and high-risk plaque features: **Modifiers S and HRP = CAD-RADS 3/P3/HRP/S** (Fig. 17)
ii. Presence of stent, grafts, severe amount of plaque burden and non-evaluable segments due to metal artifacts: **Categories N and P and Modifiers S and G = CAD-RADS N/P3/S/G**
iv. Presence of a patent LIMA graft to the LAD and expected occlusion of the proximal LAD and extensive amount of plaque burden in the native coronary arteries. Mild non-obstructive stenosis in the RCA and LCX. **Modifier G = CAD-RADS 2/P4/G**
v. For a patient with severe stenosis (70–99%) in one segment with severe amount of plaque burden and a non-diagnostic area in another segment, the study should be graded as **CAD-RADS 4A/P3/N**
vi. Presence of moderate stenosis (50–69%) with severe amount of plaque burden and FFR-CT performed with a value < 0.75. **CAD-RADS 3/P3/I+**
vii. Presence of severe stenosis in the distal RCA (70–99%) with moderate amount of plaque burden and stress CTP demonstrating no evidence of reversible ischemia. **CAD-RADS 4A/P2/I-**
vii. Anomalous left main coronary artery from the right sinus of Valsalva with inter-arterial course leading to severe compression and stenosis, absence of coronary plaque and positive stress CTP. **CAD-RADS 4A/I+/E** - Please note that because there is no evidence of plaque, the category "P" is not used

3.4. *Presence of other cardiac or extra-cardiac findings*

Patients undergoing CCTA may demonstrate other significant, potentially significant or non-significant cardiac or extra-cardiac findings. CAD-RADS is intended to focus solely on the classification of coronary artery stenosis and further management. However, other cardiac and extra-cardiac findings of relevance should be reported in the body and/or impression of the CCTA report. Specific follow-up and recommendations should be included depending on the pathology.

Table 8 summarizes the main changes for 2022 CAD-RADS update when compared to the first version published in 2016. Table 9 describes the potential sources of troponin elevation and Fig. 18 provides a sample standardized reporting template for CCTA incorporating CAD-RADS coding. Table 10 summarizes suggested text for recommendations section of CCTA reporting in patients with stable chest pain and Table 11 summarizes suggested text for recommendations section of CCTA reporting in patients with acute chest pain.

MODIFIERS: The framework for the new CAD-RADS coding should follow: stenosis, plaque and then modifiers. Therefore, The Category "P" for plaque should follow the CAD-RADS score for stenosis. Then the modifier should be added. If more than one modifier or category is present, the symbol "/" (slash) should follow each category or modifier in the following order:

i. First: modifier **N (non-diagnostic)**
ii. **Second: modifier HRP (high-risk plaque)**
iii. **Third: modifier I (ischemia)**
iv. Fourth: modifier **S (stent)**
v. Fifth: modifier **G (graft)**
vi. **Sixth: modifier E (exceptions)**

Modifier E = Exceptions to CAD-RADS/non-atherosclerotic abnormalities. Modifier E should be used in addition to CAD-RADS 0–5. Non-atherosclerotic narrowing of the coronary arteries may require disease-specific management considerations and/or subspecialty referral.

MODIFIERS: The framework for the new CAD-RADS coding should follow: stenosis, plaque and then modifiers. Therefore, The Category "P" for plaque should follow the CAD-RADS score for stenosis. Then the modifier should be added. If more than one modifier or category is present, the symbol "/" (slash) should follow each category or modifier in the following order:

i. First: modifier **N (non-diagnostic)**
ii. **Second: modifier HRP (high-risk plaque)**
ii. **Third: modifier I (ischemia)**
iv. Fourth: modifier **S (stent)**
v. Fifth: modifier **G (graft)**
vi. **Sixth: modifier E (exceptions)**

Modifier E = Exceptions to CAD-RADS/non-atherosclerotic abnormalities. Modifier E should be used in addition to CAD-RADS 0–5. Non-

atherosclerotic narrowing of the coronary arteries may require disease-specific management considerations and/or subspecialty referral.

4. Discussion

CAD-RADS has been developed based on scientific data, consensus guidance from cardiac imaging experts and a multi-disciplinary effort involving societies comprised of radiologists and cardiologists (SCCT, ACR, ACC and NASCI). It has been extensively validated over the past 5 years and has shown to provide a clinically useful categorization of coronary artery disease with high diagnostic accuracy when compared with invasive angiography. CAD-RADS has also shown to provide prognostic value and to impact medical management.

CAD-RADS is intended to be a "living document" that will undergo continuing development to provide up-to-date, evidence-based recommendations that allow imagers to communicate with providers and to convey concise findings using unambiguous and standardized terminology. Beyond its utilization in clinical reporting, CAD-RADS will allow reliable and reproducible data collection, storage and retrieval for future research trials and audits.

CAD-RADS has the potential to provide the basis as a framework for standardized collection of coronary CTA reports across multiple sites for quality improvement, benchmarking, registries and multi-center trials. Further, it can provide the framework for collecting outcome data in each of several sub-categories of CAD-RADS, such as:

1 Follow-up of patients based on CCTA results;
2 Rate of downstream testing;
3 Correlation with ICA;
4 Rate of coronary revascularization including percutaneous coronary intervention and coronary artery bypass graft surgery;
5 Major adverse cardiac events, including cardiovascular death and myocardial infarct.

Therefore, it is recommended that CCTA reporting use the CAD-RADS classification in addition and in conjunction with the impression of the report. The writing group recognizes that the CAD-RADS classification alone will not always provide all the information which is necessary to convey to referring providers for the purposes of patient management. Furthermore, the recommendations provided by this document may not apply to every clinical scenario. Therefore, imagers should provide additional comments, advice, and convey any degree of uncertainty whenever applicable.

Peer-reviewed journals may also find the CAD-RADS terminology useful for standardized classification of CCTA results, which in turn will further promote the use of CAD-RADS nationally and internationally.

Finally, standardization of reports and management recommendations will not only improve the clarity of communication of imaging results among all members of the clinical care team, but also will enhance communication between imagers, providers, researchers, and computer-based systems. This may facilitate the development of decision support technologies and serve as the basis for developing artificial intelligence and natural language processing algorithms.

5. Conclusion

The 2022 updated CAD-RADS version enhances the initial standardized reporting system for CCTA by including data from recent large trials, new clinical guidelines, and by adding features of plaque burden and lesion physiology determined from cardiac CT. Hence, the updated CAD-RADS classification follows a framework of stenosis, plaque burden and modifiers which now also include ischemia evaluation by CT-FFR or myocardial CT perfusion, when applicable. With these new iterations, CAD-RADS will continue to provide an important framework of standardization that is expected to benefit education, research, peer-review, artificial intelligence development, quality assurance, with the ultimate goal of improving patient care.

Declaration of competing interest

*In accordance with SCCT policy, writing group members and reviewers are required to disclose relationships with industry; see Appendices 1 and 2 for detailed information.

Appendix

Appendix 1

Author relationships with industry—CAD-RADS 2.0 — 2022 coronary artery disease – Reporting and data system.

Writing Group Member	Employent	Consultant/Honoraria	Speakers Bureau	Stock and stock options	Grants and research support	Royalties
Ron Blankstein (co-chair)	Brigham and Women's Hospital, Harvard Medical School	Caristo, Novartis, Silence Therapeutics	None	None	Amgen	None
Ricardo Cury (co-chair)	Miami Cardiac and Vascular Institute and Baptist Health of South Florida	Cleerly, Covera Health, GE Healthcare	None	Cleerly	None	None
Suhny Abbara	UTSW Medical Center	None	None	None	None	None
Stephan Achenbach	Friedrich-Alexander-Universität Erlangen-Nürnberg	None	None	None	None	None
Daniel Berman (ACC)	Cedars-Sinai Heart Institute, Cedars-Sinai Medical Center	GE Healthcare	None	None	None	None
Marcio Bittencourt	University of Sao Paulo	Bayer	NovoNordisk	None	None	None
Matthew Budoff	Lundquist Institute at Harbor UCLA	None	None	None	None	None
Kavitha Chinnaiyan (ACC)	Beaumont Hospitals	Heartflow	None	None	None	None
Andrew Choi	The George Washington University School of Medicine	None	None	Cleerly	None	None
Brian B. Ghoshhajra	Massachusetts General Hospital	Philips Healthcare	None	None	Siemens Healthineers	None
Jill Jacobs (NASCI)	NYU Langone Medical Center	None	None	None	None	None
Lynne Koweek (ACR)	Duke University Medical Center	None	None	None	None	None
Jonathon Leipsic	University of British Columbia	Circle CVI, Heartflow, MVRX	Philips	Circle CVI	Abbott, Boston Scientific, Edwards, GE Healthcare, Medtronic	None
John Lesser	Minneapolis Heart Institute	None	None	None	None	None

(continued on next column)

Appendix 1 (*continued*)

Writing Group Member	Employent	Consultant/Honoraria	Speakers Bureau	Stock and stock options	Grants and research support	Royalties
Chris Maroules	Naval Medical Center	None	None	None	None	None
Geoffrey Rubin	Duke University	Boehringer Ingelheim, Fovia, Heartflow, Nanox	None	Heartflow, Nanox	None	None
Frank Rybicki (ACR)	University of Cincinnati Medical Center	None	None	Imagia	None	None
Leslee Shaw	Icahn School of Medicine at Mount Sinai	None	None	None	None	None
Todd Villines	University of Virginia Health System	None	None	None	None	None
Charles White (NASCI)	University of Maryland	Arterys, Riverain Medical	None	None	None	None
Michelle Williams	University of Edinburgh	None	Canon Medical	None	None	None
Eric Williamson	Mayo Clinic	None	None	None	None	None

Appendix 2

Reviewer relationships with industry—CAD-RADS - 2022 coronary artery disease – Reporting and data system.

Reviewer	Representation	Employent	Consultant / Honoraria	Speakers Bureau	Stock and stock options	Grants and research support	Royalties
Karen Ordovas		University of Washington	None	None	None	None	None
Joseph Schoepf		Medical University of South Carolina	Heartflow	None	Elucid Bioimaging	Bayer, Bracco, Elucid Bioimaging, Guerbet, Heartflow, Keya Medical, Siemens	None
Prabhakar Rajiah	Offical Reviewer — American College of Radiology	Mayo Clinic	None	None	None	None	None
Pál Maurovich-Horvat		Semmelweis University	None	None	Neumann Medical	None	None
Michael Salerno	Offical Reviewer — American College of Cardiology	Stanford University	G3 Genetics, Imagion Biosystems, Valo Health	None	None	GE Healthcare, Heartflow, Siemens Healthineer	None
Harold Litt	Offical Reviewer — North American Society for Cardiovascular Imaging	Perelman School of Medicine of the University of Pennsylvania	None	None	None	Philips Healthcare, Siemens Healthineers	None

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